SOIL, WATER AND AIR

TRAINING COURSE 7000.1

VOLUME II

PHOENIX TRAINING CENTER
USDI BUREAU OF LAND MANAGEMENT
1986

FIELD TRIP

Course 7000.1
Instructors: McGlothlin
Humphreys
Van Haveren

FIELD TRIP

OBJECTIVES:

(1) Identify and evaluate the restoration components of the San Simon watershed project.

(2) Apply knowledge of watershed condition analysis and activity planning to on-the-ground control of runoff, erosion, and sediment.

(3) Respond to the overall issue of watershed structure maintenance.

TOPIC OUTLINE

I. Itinerary - Field Tour of the San Simon Valley

Stop No.	Location - Project Type - Tour Sheet Number
0	Safford District Office, District Manager's greetings, San Simon tour handouts
1	Barrier Dam - detention structure (drop-chute spillway), riparian improvement - 1
2	Halfway Dam - detention structure (drop-chute spillway) - 2
3	Goat Well Dam - detention structure (drop-chute spillway) - 3
4	Timber Draw Dam Site - proposed detention structure - 5
5	Hot Well - artesian well, ORV use area, (lunch stop) - 6
6	Ryan Dikes - headcut control and diversion structures, revegetation - 7
7	San Simon Crossing - diversion dike, prescribed burn - 9
8	Fan Dam - detention structure (drop-chute spillway) - 12
9	Posey Well - artesian well, wildlife, and riparian habitat development - 10

10	Contest Well - mechanical vegetation treatment, vegetation conversion - 11
11	Hospital Flat - untreated, relict site - 14
12	Whitlock Dam - failed detention structure (drop-pipe spillway) - 15
13	Slickrock Dams - livestock, wildlife, water developments - 16
14	Safford District Office

II. Field Watershed Exercise (Saturday morning, April 26, 1986)

BIOGRAPHICAL SKETCH

DANIEL J. McGLOTHLIN

Present Position

Hydrologist - Program Leader for
Soil, Water and Air Resources Management
Bureau of Land Management
Arizona State Office (AZ-932).
Phoenix, Arizona
Telephone FTS 261-5512, Comm (602) 241-5512

Education

B.S. - Watershed Management, University of Arizona, 1976

Professional Experience

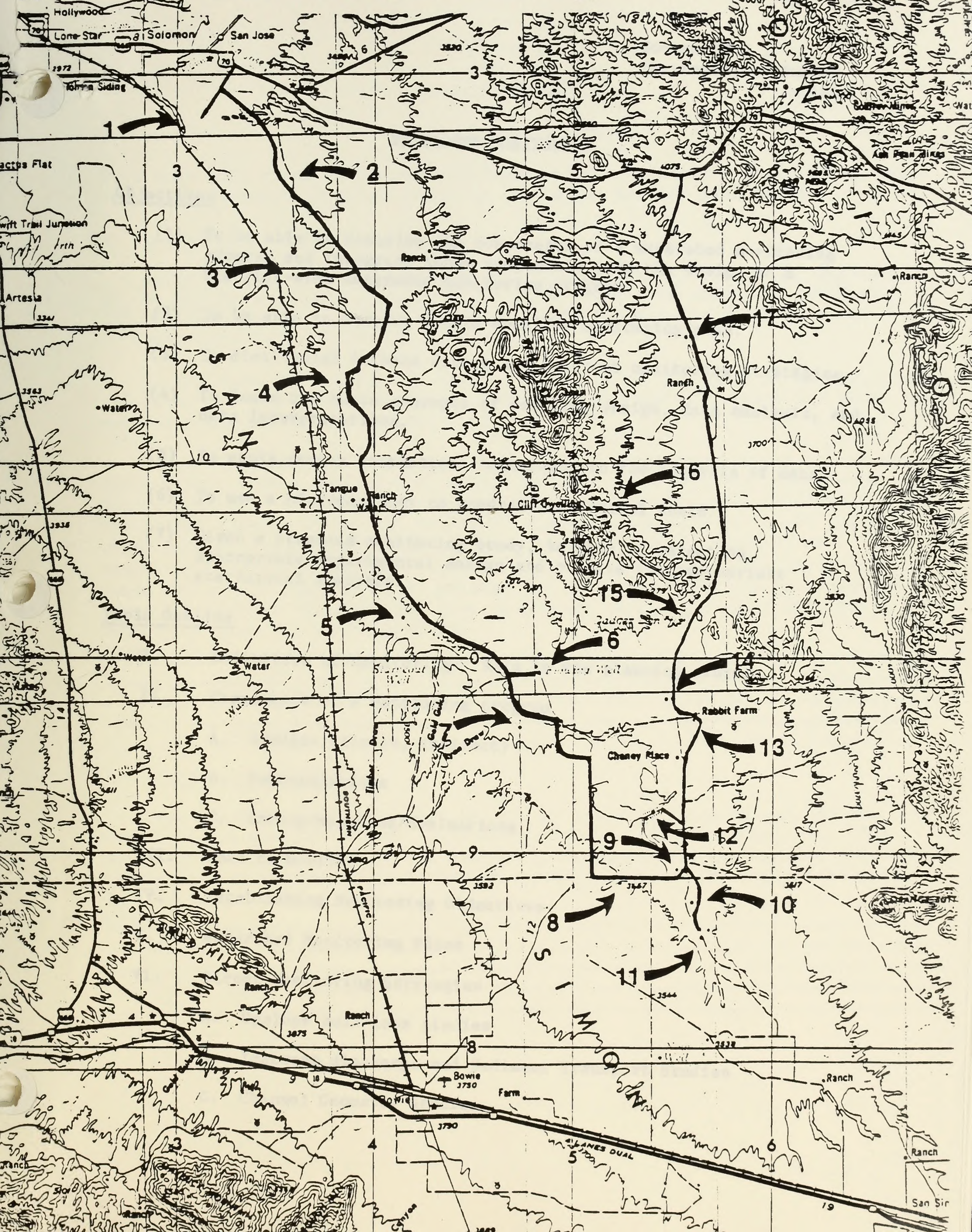
1985 - present, Hydrologist, Arizona State Office, Phoenix, Arizona
1981 - 1985, Hydrologist, Phoenix District Office, Phoenix, Arizona
1979 - 1981, Digital Cartographic Specialist, Defense Mapping Agency, Washington, D.C.
1977 - 1979, Hydrologist, American Ag International, Tucson, Arizona

Professional Societies

Member, Arizona Hydrological Society
Member, American Water Resources Association

4/8/86

San Simon Valley Tour



Course 7000.1
Instructors: Hudson
Jackson

WATERSHED MONITORING

Objectives

(1) To be able to describe the components of a watershed monitoring program and integrate those components into the design of a District-wide watershed monitoring program.

(2) To be able to develop a site-specific monitoring plan.

(3) To distinguish between direct and indirect monitoring strategies.

(4) To learn the basic concepts of sampling design, data analysis, and data interpretations.

(5) To apply common statistical techniques to the analysis of data.

(6) To use a microcomputer to conduct statistical tests.

(7) Given a proposed monitoring study, be able to select an appropriate experimental design and outline the appropriate statistical analysis.

Topic Outline

I. Definition of Monitoring: Role in the planning process

II. Components of a monitoring program

A. Studies (direct, indirect)

B. Extrapolations

C. Interpretations/Evaluations

III. When to Monitor

IV. Establishing Monitoring Objectives

V. Watershed Monitoring Plans

VI. Direct Monitoring Strategies

A. Upslope soil-loss studies

B. Instream discharge and Sediment Transport Studies

C. Channel Geometry Studies

TOUR OF THE SAN SIMON VALLEY

Safford District

Bureau of Land Management

This tour will focus on the effectiveness of erosion control structures, range reseeding projects, wildlife projects, and other related activities.

1. Barrier Detention Structure

Built in 1980 by BLM for erosion control and rehabilitation and regrading of the San Simon channel, the cost was $1,300,000. The structure contains 224,000 cubic yards of compacted earthfill and 2,684 cubic yards of reinforced concrete requiring 313,000 lbs. of steel.

In the first two years, the channel silted in to the level of the spillway (17 ft.). To date, the channel has completely regraded for about 0.5 miles and partially regraded for a further 1 mile.

Since 1982 about 300 cottonwoods and willows have been planted within the flood plain, with a 30% survival rate. In 1983 about 30 acres were disked and seeded with good success. The area near the dam (30-40 acres) is presently being root plowed, disked and seeded to replace invading seep willow and salt cedar with more desirable species. Future plans call for planting an additional 300-500 cottonwoods and willows. The goal is to eventually have about 75% of the flood plain in grasses and forbs and about 25% in riparian trees and shrubs. The regraded area ~~is~~ already becoming popular with the hunters of game birds and javelinas.

Notes: ______

2. Halfway Detention Dam

This dam was originally built in 1938 by the Soil Conservation Service. It washed out in the 1983 flood. Reconstruction has just been completed. The design of the drop structure was changed to be similar to but smaller than that of the Barrier Structure. A number of wildlife projects are being evaluated for this area.

Notes: ______

3. Goat Well Structure

This detention dam was built in 1940 by the Soil Conservation Service to control headcutting in Slick Rock Wash above the San Simon channel. This site is typical of the highly erodible soil conditions found throughout a large portion of the San Simon drainage. This structure has effectively stopped the headcutting in Slick Rock Wash, as noted by the sediment-filled channel above the structure, and the 30-foot deep, vertical-walled channel below the structure. Note that perennial grasses are more abundant behind the structure and in nearby washes than on the drier surrounding sites.

Notes:

4. New Well Seeding

This area was experimentally root plowed and seeded in 1966 to replace desert saltbush with grasses. The seeding eventually failed due to poor soil conditions, several years of drought, and a lack of plant species adapted to the 8" per year rainfall zone.

Notes:

5. Timber Draw Site

This is the site of an erosion control dam to be built by BLM when money is available. Estimated cost is 2 million dollars. This is the last major structure proposed for the San Simon River.

The structure will consist of 400,000 cubic yards of compacted earthfill and 2,100 cubic yards of reinforced concrete. It will be about 1 mile in length. The average height of the dam is about 30 ft. The drop structure will be similar to that at the Barrier Structure, with a width of 110 ft. and will drop water a height of 31.5 ft.

Wildlife projects for the Timber Draw Site will be similar to those installed and planned for the Barrier Structure.

Notes:

6. Hot Well Exchange Area and ORV Use Area

Hot Well was drilled in 1928 as an exploratory oil well. The depth was 1,555 ft. Though no oil was found, artesian water was and it continues to flow at a rate of 300 gallons per minute. The water is warm, low in soluble salts, but high in sodium.

This land is presently owned by the State of Arizona. It, along with many other scattered State sections, is part of an ongoing exchange with the State that is scheduled for completion by the end of this fiscal year.

The sand dunes in this area are very popular during the winter with ORV enthusiasts, with many coming from the Tucson, Sierra Vista, and Douglas areas as well as Graham County. The rancher grazing livestock in this area has recently come in with a proposal to fence off part of his allotment and make it exclusively an ORV use area. Upon completion of the land exchange, BLM will do an evaluation of this proposal.

This area has great potential for the development of wildlife habitat due to the abundance of water. Management may include development of one or more ponds and the planting of riparian trees.

Notes:

7. Ryan Dikes and Seeding

These dikes were constructed in the mid-1960s to prevent headcutting on the side channels of the San Simon River and to spread water on terraces for revegetation. The dikes have drawdown tubes at intervals to let water back in to the San Simon River.

A 200-acre seeding was done in 1969. Though not totally successful, some species of seeded grasses can be found.

Notes:

8 Zeolite Mines

The zeolite mines in this area cover less than 50 acres at present. They may, however, eventually cover as much as 2,500 acres. There was a problem concerning the zeolite claims as to whether they were locatable or leasable minerals. The courts have ruled them to be locatable. There are many environmental concerns with this type of mining, such as impacts on paleontological resources. In the mined area camel tracks and a mammoth tusk have been found. At present there is a pending mineral patent application on some of these claims.

Notes:

9. San Simon Crossing and Prescribed Burn

The dike to the south of the road is designed to spread water on the flood-plain. This area is part of the completely regraded channel behind the Fan Structure. It has not been seeded. The revegation has occurred through natural processes. About 1,500 acres were burned in 1982 to control invading mesquite and salt cedar. The burn achieved a good top kill. Mesquite and salt cedar rootsprouting has occurred and will be controlled with future burns.

Notes:

10. Posey Well Wildlife Development

This four-acre pond was constructed in 1981 to provide habitat for migratory waterfowl, shorebirds, and a variety of resident wildlife. Water for the project originates from an artesian well drilled in 1973 during exploration for oil and gas. Aquatic vegetation was planted along the inside edge of the dike to help prevent erosion of the dike and to provide escape and nesting cover for waterfowl. Cottonwood and willow trees were planted around the pond by volunteers to provide a windbreak, improve aesthetics, and provide nesting and roosting habitat for a variety of birds. Several small ponds have been built in preparation for the introduction of the Federally endangered Gila topminnow and the proposed endangered desert pupfish. Future management for this area may include the drilling of an additional well and the construction of one or more ponds. About 60 acres around Posey Well have been fenced to exclude cattle and vehicles. Posey Well has recently become known to birdwatchers and the hunters of game birds and waterfowl.

Notes:

11. Contest Well Seeding

This 600-acre site was rootplowed to a depth of 18 inches to eradicate a dense stand of mesquite and salt cedar. In 1966 it was aerially seeded to Giant Blue Panic and Bermuda grasses. This seeding is located on the sediment that has filled in behind the Fan Structure. The seeding has controlled the reinvasion of salt cedar. Johnson grass has also invaded the site. This seeding receives periodic flooding and is highly productive as a result. Before the seeding vegetation production was minimal. After the seeding the vegetation production was extremely high. Livestock forage production has increased markedly. Wildlife benefits have increased with game and non-game birds and other wildlife feeding on the abundant seed supply and using the dense cover. Raptors frequent this area in search of rodents and other prey items. In 1983 volunteers built four gabions to stabilize areas with small head cuts. They also planted 40 cottonwoods and willows.

Notes:

12. San Simon Fan Structure

The Fan Structure was built in 1953. Its installation has resulted in regrading of the San Simon channel for about 10 miles upstream. The area that has filled in behind the structure is 20 ft. deep at the dam and is now supporting a dense growth of vegetation in contrast with the low production of the higher, drier sites. Behind the Fan, floodplain vegetation averages about 300 acres per mile. Elsewhere the channel average is only about 17 acres per mile. The regraded area is now capable of supporting 150 cattle per section as opposed to two or three head per section on adjacent land. The controlled flow of water from the drop structure has also reduced the amount of erosion immediately downstream. The drawdown pipe releases water onto a once barren flat that is now supporting dense vegetation. The water from the drawdown pipe is prevented from cutting back into the channel by dikes.

Cottonwood and willow trees (about 250) have been planted just south of the San Simon crossing. Additional plantings are planned for the entire area that has regraded behind the Fan Structure.

Notes:

13. Rabbit Farm

The Rabbit Farm is part of a 680-acre parcel acquired through an exchange in 1980. In 1981 approximately 80 acres around the one-acre pond were fenced to exclude livestock and vehicles, to protect and encourage vegetation growth and reproduction. This area's riparian vegetation is used by a wide variety of wildlife. Since acquisition, water from two artesian wells has nearly ceased flowing. A windmill was installed to boost the flow rate but has not provided enough water to maintain the pond. Future plans include drilling deeper wells and construction of a small pond to the west of the existing pond.

Notes:

14. Hospital Flat

Hospital Flat is an uneroded area on Whitlock Wash. Erosion was prevented by check dams and water spreading structures built by the Civilian Conservation Corps in the 1930s. This area gives an idea of what the area above Whitlock Dam looked like before erosion set in. Of historical note, this area was used in the late 1800s to rest livestock from Ft. Bowie.

Notes:

15. Whitlock Dam

This structure was built in 1968 on Whitlock Wash. The dike is 1,250 ft. long, 30 ft. high, and drains an areas of 12.5 square miles. This dam, in an area of extremely fragile soils, shows evidence of severe erosion above and below the dam that led to three washouts. These failures occurred in 1971, 1972, and 1982, and were reconstructed in 1972, 1979, and 1983. The last reconstruction was completed by the grazing allottee.

The pond behind the dam benefits a wide variety of wildlife. future plans may include fencing all or part of the floodplain to exclude livestock, planting of riparian trees, and planting of food and cover species.

Notes:____

16. Slickrock Dams

A system of masonry dams built in 1985 by a permittee to capture runoff from bare rock canyon areas in the Whitlock Mountains. BLM supplied concrete for constructing 14 small dams. Traps were built to capture sediment and the main reservoirs were lined to minimize seepage losses. With above average rainfall in the first year of operation, the dams were able to capture enough runoff to remain full for the entire year.

Notes:____

15. <u>Whitlock Dam</u>

This structure was built in 1968 on Whitlock Wash. The dike is 1,750 ft. long, 20 ft. high, and drains an area of 12.5 square miles. This dam, in an area of extremely fragile soils, shows evidence of severe erosion above and below the dam that led to three washouts. These failures occurred in 1971, 1972, and 1982, and were reconstructed in 1972, 1979, and 1983. The last reconstruction was completed by the grazing allottee.

The area behind the dam benefits a wide variety of wildlife. Future plans may include fencing all or part of the floodplain to exclude livestock, planting of riparian trees, and planting of food and cover species.

Notes:

16. <u>Hillcrest Dams</u>

A string of masonry dams built in 1967 by a permittee to capture runoff from bare rock canyon areas in the Whitlock Mountains. BLM supplied materials for construction. In small dams. These were built to capture sediment and the main reservoirs were lined to slow or prevent leakage. With above average rainfall in the first year of operation, the dams were able to capture enough runoff to remain full for the entire year.

Notes:

NEW PERSPECTIVES IN WATERSHED MANAGEMENT
ESTABLISHING A MAINTENANCE STRATEGY FOR WATER CONTROL STRUCTURES 1/

by Daniel J. McGlothlin 2/

The following points of my discussion focus on the need to establish management direction concerning the maintenance of water or erosion control structures.

1. Watershed management objectives contained in land-use plans usually fail to consider the long-term maintenance needs of watershed stabilization structures.

   - Maintenance of these large and elaborate systems of diversion, detention or retention structures will increasingly consume large portions of the soil, water and air program's base funding as the projects reach the end of their design life.
   - Maintenance of these older projects have or are rapidly approaching the end of their design life (usually a 50-year life span).
   - Maintenance of these projects has historically gone unquestioned; the need is presumed there, regardless of original objectives/benefits.

2. Maintenance costs continue to go up, while available funds for maintenance are decreasing each year.

   - Contract costs for earthwork, as an example, have increased by about a factor of 10 since 1950. (Figure 1)
   - Maintenance or repair costs, where severe structural problems occur, exceed the original construction costs, in most cases.
   - Many projects are "maintained" only when failure of the structure is imminent or has actually occurred, thus driving the repair bill higher.
   - Tracking maintenance or repair is difficult with the current records system.

3. Management objectives for soil and water actions should be clearly defined at both RMP and activity planning levels. Maintenance of water control structures should be included in these objectives. (Figure 2)

   - Recent Draft Supplemental Program Guidance for Environmental Factors for use in resource management planning purposes establishing a maintenance strategy for existing erosion or water control structures and treatments.

1/Presented at BLM National Rangeland Program Workshop, January 28-31, 1986

2/Hydrologist, Division of Lands and Renewable Resources, Arizona State Office

- The Willow Creek Interdisciplinary Watershed Activity Plan, developed by Lewistown District Office, is the first recent activity to propose a long-term maintenance strategy.

- The San Simon Coordinated Resource Management Plan, developed by Safford District Office, focuses on key resources management objectives within a watershed project area.

- Original objectives for water control structures may no longer be valid and should be evaluated, as these two plans do, in light of present resource conditions and the reality of our budget constraints. (Figure 3)

4. Present day conditions in our program dictate the need for adopting management objectives for watershed stabilization projects. Managers and soil and water specialists need to be thinking about:

   - Maintaining an old project versus building a new project and the equivalent benefits derived from each action.

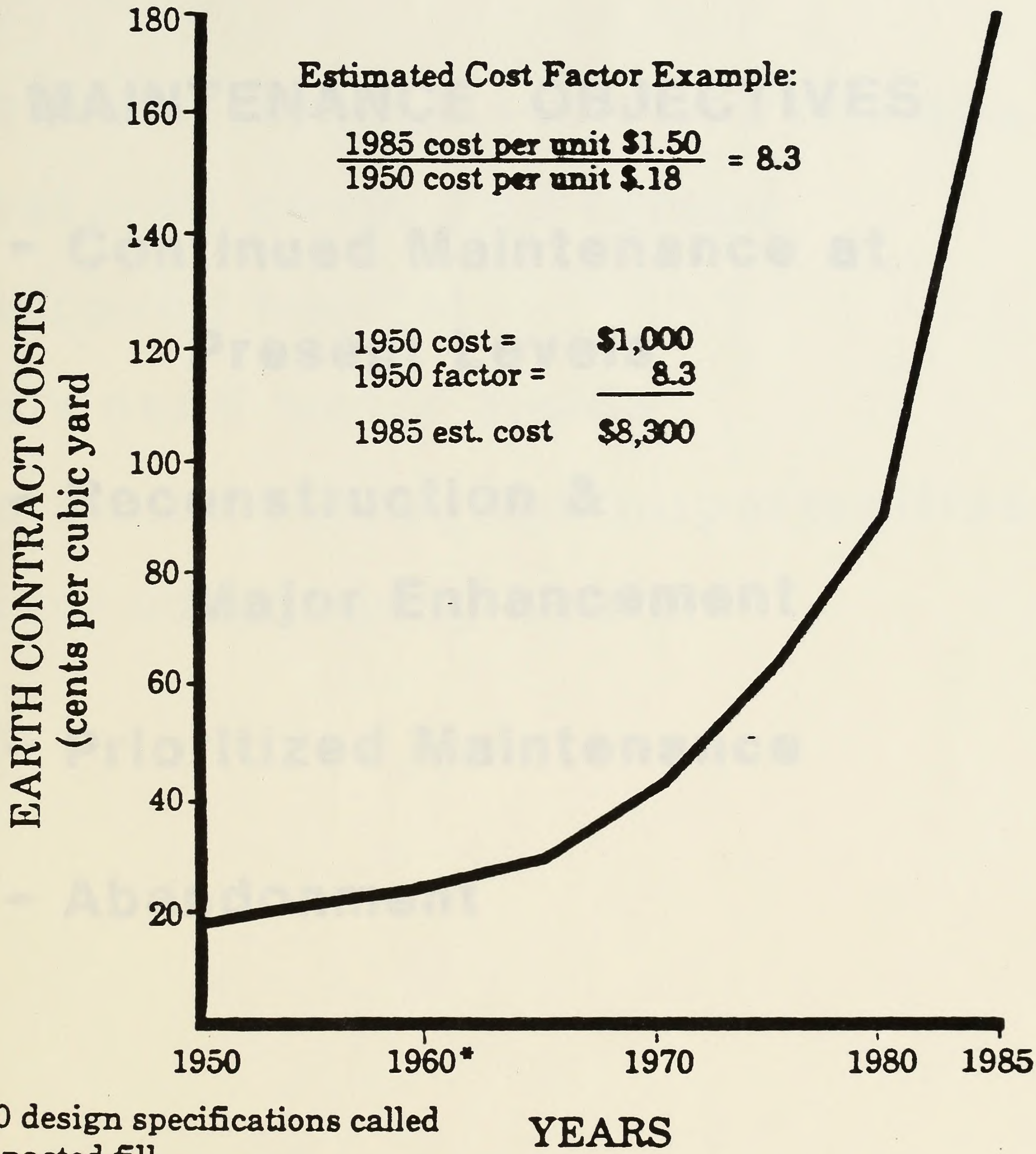
   - Establishing site specific watershed objectives if original project objectives are no longer valid or should be modified.

   - Quantifying off-site/on-site benefits and distinguishing between the two.

   - Developing long-term maintenance strategies that address attainable, economically feasible resource management objectives.

   - Determining those benefitting activities for cost-sharing the maintenance.

ESCALATING COST FIGURES



* By 1960 design specifications called for compacted fill.

Source: Official contract files bid price/payments, 1950-1984

Figure 1

MAINTENANCE OBJECTIVES

- Continued Maintenance at Present Levels
- Reconstruction & Major Enhancement
- Prioritized Maintenance
- Abandonment

Figure 2

PLANNED OBJECTIVES - THEN (50's & 60's)

- Reduced flood & sediment damage
- Restored cover and forage
- Improved habitat
- Increased water yields
- Increased recreation opportunities
- Reduced pumping costs

Figure 3

WATERSHED ACTIVITY PLANNING EXERCISE

Objectives:

1. To be able to determine the cause(s) of a typical watershed problem
2. To be able to formulate alternative prescriptions for treating the problem
3. To be able to use a microcomputer to model storm runoff and reservoir routing for design purposes
4. To be able to outline a watershed activity plan

Topic Outline:

1. Elements of a Watershed Activity Plan
2. Watershed Problem Analysis
   a. Identification of the resource problems/management issues
   b. Watershed "sleuthing" (identification of sources/causes)
3. Activity Plan Formulation
   a. Set specific objectives for what you want to accomplish.
   b. Formulate alternative actions (prescriptions) for solving the problem.
   c. Analyse each alternative for technical feasibility, risk exposure, and economics.
4. Use of SCS CN Model to Simulate Rainfall Runoff for Design and Problem Analysis
5. Use of a Reservoir-Routing Algorithm for Structure Design
6. Use of CHANL and MCHANL for Channel Geometry Computations

BIOGRAPHICAL SKETCH

BRUCE P. VAN HAVEREN
FTS 776-0150
(303) 236-0150

Present Position

Hydrologist - Division of Resource Systems
Service Center
Bureau of Land Management
Bldg. 50 (D-470), Denver Federal Center
P.O. Box 25047
Denver, Colorado 80225-0047

Professional Experience

1985 (October-November) -	Visiting Scientist, People's Republic of China
1982 to Present -	Hydrologist, Service Center, BLM, Lakewood, Colorado
1981 (August-September) -	Visiting Scientist, Argonne National Laboratory, Argonne, Illinois
1981-82 -	Project Leader, EMRIA Project, BLM, Service Center, Lakewood, Colorado
1978-81 -	Hydrologist, Service Center, BLM, Lakewood, Colorado
1977-78 -	State Hydrologist - BLM Denver, Colorado
1976-77 -	Hydrologist, Bonneville Power Administration Vancouver, Washington
1974-75 -	Hydrologist, Cameron Engineers, Inc., Denver, Colorado
1973-74 -	Hydrologist, U.S. Forest Service, Sandpoint, Idaho and Fortine, Montana
1968-70 -	Research Technician - Intermountain Forest and Range Experiment Station, Logan, Utah

Education

B.S. - Forestry (Watershed Management) - Utah State University
M.S. - Watershed Hydrology - Colorado State University
Additional graduate work - Public Administration - University of Colorado, Denver

WATERSHED PROBLEM ANALYSIS AND ACTIVITY PLANNING
FIELD EXERCISE FOR BUREAU COURSE 7000-1
SAFFORD DISTRICT, APRIL 26, 1986

LOCATION: Tributary to San Simon River, San Simon Resource Area
Approximately 15 miles SE of Safford, Arizona

PROBLEM: A permittee-installed diversion dike located below the Halfway Detention Dam has breached. Flood flows occasionally damage the road. Serious headcutting is progressing upstream from the tributary's confluence with the San Simon River.

MATERIALS: Each group will be given color air photos, 7 1/2' quads and pertinent information about the watershed. An SCS soil survey report will be available for reference. Channel cross-section data for the natural channel just above the road will be given to each group at the beginning of the exercise.

PROCEDURE: Enough time will be given (approximately 1 1/2 hours) to walk the area, assess the problems and their causes, and collect information for the hydrologic analysis to be done on Monday.

FIELD DATA NEEDED: Plan on collecting enough information to select curve numbers for the watershed. Sufficient measurements of the drop structure will be needed to work through the following broad-crested weir equation:

$$Q = C * L * H^{3/2}$$

(Do not forget to determine an allowable freeboard).

Cross-section data have already been obtained from the main channel between the road and the dam. The location has been flagged. We will briefly explain the measurement procedure. You will have the opportunity of running these data through the CHANL computer program.

OBJECTIVE: Analyse the problem, formulate alternative solutions, and prepare a recommendation in the form of an outline of an activity plan.

MICROCOMPUTER EXERCISE FOR WATERSHED PROBLEM ANALYSIS AND ACTIVITY PLANNING
STORM HYDROGRAPH GENERATION AND RESERVOIR ROUTING

1. Prepare the PC.

   - Make sure the CAPS LOCK key is on.

   - Use the "A" drive.

   - Load SIDEKICK at the A prompt ... enter /sk/.

   - Enter /go/.

   - Opt for hydrology programs.

   - Choose the SCS CN program.

2. Choose three design storms for rainfall-runoff modeling from the precipitation information given:

STORM DURATION/FREQUENCY/DISTRIBUTION TYPE	PRECIP. DEPTH
a. 6-hr, 10-yr, SCS Type B	________
b. 6-hr, 50-yr, " " "	________
c. 6-hr, 100-yr, " " "	________

3. Run the SCS CN program using the following watershed characteristics:

   AREA = 3.815 sq. mi.
   AVERAGE WATERSHED SLOPE = 3%
   LENGTH OF LONGEST CHANNEL = 25,600 ft

4. Compute the weighted-average curve number for the watershed.

5. Check to see that the input data are all correct.

6. Opt for the "long" output.

7. Note the runoff depth and peak discharge from the summary table and enter below:

STORM	RUNOFF DEPTH	PEAK Q
6-hr, 10-yr	________	______
6-hr, 50-yr	________	______
6-hr, 100-yr	________	______

8. Save the output file as "RUN10."

9. Run through the program two more times, using the other storm data.

10. Use "RUN50" and "RUN100," respectively, for the other output files.

11. Exit the program--you should be back at the HYDROLOGY PROGRAM MENU.

12. Choose the STORAGE ROUTING option.

13. Enter a name of one of the storm hydrographs you saved from the CN program (RUN10, RUN50, or RUN100).

14. This program routes an inflow hydrograph through a storage reservoir having a single spillway of the broad-crested weir type. The program assumes the reservoir is full at the start of the runoff event. The program will query you for the following information:

    -Surface area of the reservoir (at spillway elevation)
    (use 50 acres for the Halfway Detention Dam)

    -Length of spillway ____ ft (from field measurement)

    -Spillway weir coefficient (use 3.1 for the Halfway drop structure)

15. Run through the program once for each of the three inflow hydrographs and enter the summary information below:

RUNOFF EVENT	PEAK INFLOW	PEAK OUTFLOW	PEAK DEPTH
6-hr, 10-yr	______	_______	______
6-hr, 50-yr	______	_______	______
6-hr, 100-yr	______	_______	______

16. Run the program "CHANL" on the Honeywell DPS-8 computer, using the channel geometry data provided. Develop a discharge rating curve for the channel below the Halfway Detention Dam.

17. Use the above information together with your field observations to develop some alternatives for treating the watershed problem(s).

PRECIPITATION RETURN PERIOD DATA FOR DUNCAN, ARIZONA

Maximum Precipitation (Inches) for Indicated Duration (M=min, H=hours)

Return Period (yrs.)	30M	1H	6H	12H	24H
2	0.7	0.9	1.2	1.3	1.4
10	1.2	1.5	1.9	2.1	2.4
25	1.3	1.7	2.4	2.6	2.8
50	1.5	1.9	2.6	2.8	3.0
100	1.7	2.2	2.8	3.1	3.4

7313 - COVER

CORRESPONDING RUN-OFF CURVE NUMBERS FOR THREE ANTECEDENT MOISTURE CONDITIONS AMC-I, II, AND III ($I_a = 0.2S$)

AMC Group			AMC Group			AMC Group		
I	II	III	I	II	III	I	II	III
100	100	100	57	75	88	31	50	70
97	99	100	55	74	88	30	49	69
94	98	99	54	73	87	29	48	68
91	97	99	53	72	86	28	47	67
89	96	99	52	71	86	27	46	66
87	95	98	51	70	85	26	45	65
85	94	98	50	69	84	25	44	64
83	93	98	48	68	84	25	43	63
81	92	97	47	67	83	24	42	62
80	91	97	46	66	82	23	41	61
78	90	96	45	65	82	22	40	60
76	89	96	44	64	81	21	39	59
75	88	95	43	63	80	21	38	58
73	87	95	42	62	79	20	37	57
72	86	94	41	61	78	19	36	56
70	85	94	40	60	78	18	35	55
68	84	93	39	59	77	18	34	54
67	83	93	38	58	76	17	33	53
66	82	92	37	57	75	16	32	52
64	81	92	36	56	75	16	31	51
63	80	91	35	55	74	15	30	50
62	79	91	34	54	73	12	25	43
60	78	90	33	53	72	9	20	37
59	77	89	32	52	71	4	10	22
58	76	89	31	51	70	0	0	0

RUN-OFF CURVE NUMBERS FOR RANGE AREAS
(Antecedent Moisture Condition II and I_a = 0.2S)

Cover	Cover Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Grassland		Poor	66	79	86	89
		Fair	51	69	79	84
		Good	37	61	74	80
	Contoured	Poor	47	67	78	83
	"	Fair	38	61	74	80
	"	Good	28	55	70	77
Herbaceous		Poor	68	80	87	90
		Fair	55	71	81	85
		Good	42	63	74	81
Desert shrub		Poor	68	80	87	90
		Fair	52	70	80	85
		Good	39	62	75	80
Sagebrush		Poor	47	67	78	83
		Fair		48	65	74
		Good		30	53	64
Pinyon-juniper		Poor	60	75	83	87
		Fair	34	58	73	78
		Good		41	61	70
Chaparral (Arizona)		Poor	68	80	87	93
		Fair	32	57	71	83
		Good		41	58	74
Oak-aspen		Poor	43	64	76	82
		Fair		47	64	73
		Good		30	53	64
Ponderosa pine		Poor	45	66	77	83
		Fair	29	56	70	77
		Good		46	64	72
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77

.4 Interpretation of Data. Cover inventory data is used for determining hydrologic condition classes which in turn are used for estimating run-off curve numbers (CN) for various soil-cover complexes (see .43).

.41 Hydrologic Condition. The hydrologic condition of a cover influences the rainfall run-off relationship (run-off potential) for a watershed. Hydrologic condition is affected by the physical properties of cover. For this reason, percentage of ground cover and litter-humus data are used to determine hydrologic condition of range and forest area cover classes. Hydrologic condition for cultivated areas is not included in this section of the Manual (see .21), while other areas are represented by a single condition class since run-off potential is assumed maximum at all times (see .24).

A. Classification by Percentage of Ground Cover. Hydrologic condition for range cover classes is divided into three classes by percentage of ground cover as follows:

- Poor condition, less than 30 percent cover

- Fair condition, 30 to 70 percent cover

- Good condition, over 70 percent cover

Determine hydrologic condition classes by using weighted average percentage of ground cover as recorded on Form 7310-10 in column (12) (see .32A2h).

B. Classification by Litter-Humus Data. Hydrologic condition for forest area cover classes is divided into three categories based on a numerical rating as follows: (See Illustration 3, Column 14)

- Poor Condition, 1.0 - 2.4

- Fair Condition, 2.5 - 4.4

- Good Condition, 4.5+

Determine the hydrologic condition rating by using the nomograph and specific instructions for Column 14 on Illustration 3, page 2.

7313 - COVER

C. Other Hydrologic Condition Indicators. Other parameters should be considered when making hydrologic condition classifications. For range area cover classes, such factors as dry weight herbage production, bulk density of surface soil, ratio of large to small pores in surface soil, etc., should be investigated. For forest area cover classes, factors such as weight of dead organic matter, noncapillary pores, and forest canopy cover should be examined. Where such data is available, it should be analyzed for possible use as hydrologic condition indicators or for correlation with ground cover percentage or litter-humus data.

D. Estimating Future Hydrologic Condition. General watershed planning and hydraulic structure design require estimates of change in hydrologic condition which may be expected from application of management and treatment practices. Future conditions may be estimated for various time periods by predicting changes that are expected to occur. Such changes may result from:

- Deterioration (natural or accelerated) which reduces percentage of ground cover or lowers litter-humus condition as indicated by current change,

- Improvement (natural) which increases percentage of ground cover or improves litter-humus condition as indicated by current change, or

- Improvement (artificial) which increases ground cover as result of vegetation conversion or other land treatments.

1. For Range Areas. Future conditions of these cover classes are estimated by predicting the changes in cover class and/or percentage of ground cover over a given time period. Such predicted changes should be based on documented studies and/or plans for the watershed area.

2. For Forest Areas. A forest's future hydrologic condition is determined from the improvement potential of its watershed. Improvement potentials depend on the anticipated rate of change from compact-to-loose humus condition and the rate of humus accumulations as affected by:

- Physiographic factors of the sites, and

- Planned management and treatments.

(A detailed procedure for determining forest improvement potential may be found in references (1) and (3), Appendix 2.)

C. Other Hydrologic Condition Indicators. Other parameters should be considered when making hydrologic condition classifications. For range area cover classes, such factors as dry weight herbage production, bulk density of surface soil, ratio of large to small pores in surface soil, etc., should be investigated. For forest area cover classes, factors such as weight of dead organic matter, noncapillary pores, and forest canopy cover should be examined. Where such data is available, it should be analyzed for possible use as hydrologic condition indicators or for correlation with ground cover percentage or litter-humus data.

D. Estimating Future Hydrologic Condition. General watershed planning and hydraulic structure design require estimates of change in hydrologic condition which may be expected from application of management and treatment practices. Future conditions may be estimated for various time periods by predicting changes that are expected to occur. Such changes may result from:

- Deterioration (natural or accelerated) which reduces percentage of ground cover or lowers litter-humus condition as indicated by current change,
- Improvement (natural) which increases percentage of ground cover or improves litter-humus condition as indicated by current change, or
- Improvement (artificial) which increases ground cover as result of vegetation conversion or other land treatments.

1. For Range Areas. Future conditions of these cover classes are estimated by predicting the changes in cover class and/or percentage of ground cover over a given time period. Such predicted changes should be based on documented studies and/or plans for the watershed area.

2. For Forest Areas. A forest's future hydrologic condition is determined from the improvement potential of the watershed. Improvement potentials depend on the anticipated rate of change from present-litter-humus condition and the rate of humus accumulation as affected by:

- Physiographic factors of the sites, and
- Planned management and treatments.

(A detailed procedure for determining forest improvement potential may be found in references (2) and (3), Appendix 2.)

MONITORING AND
STATISTICS

VII. Indirect Monitoring/Interpretation Strategies

VIII. Statistical Considerations in Monitoring

A. General Considerations

1. Controls

2. Replication

3. Randomization

B. Specific Designs

1. Randomizded Block

2. Split Plot

3. Nested

4. Repeated Measures

IX. Data Analysis

A. T-Tests

1. Assumptions

2. Paired vs., Unpaired

3. One-tail vs., Two-tail

4. Exercises on microcomputer

B. Regressions

1. Assumptions

2. Multiple vs., simple

3. Significance tests

4. Exercises on microcomputers

C. Analysis of Variance

1. Assumptions

2. One-way and Two-way

3. Partitioning degrees of freedom and Sums of Squares

4. Exercises on microcomputers

BIOGRAPHICAL SKETCH

SHIRLEY HUDSON
FTS 776-0152
(303) 236-0152

Present Position

Statistician - Division of Resources
Service Center
Bureau of Land Management
Bldg. 50 (D-470), Denver Federal Center
P.O. Box 25047
Denver, Colorado 80225-0047

Professional Experience

1981 to Present - Statistician: Assist Bureau professionals with the design and/or analysis of studies, data, etc., including the design of monitoring programs. Provide training and/or assistance in the use of statistical techniques and procedures and in the use of BLM's statistical packages, both on the Honeywell DPS-8 and on PCs.

1977 to 1981 - Statistician for MSHA. Developed regression and discriminant analysis models to determine mines likely to experience fatal injuries.

1975 to 1977 - Statistician for National Jewish Hospital. Designed and analyzed clinical trial studies to test the effectiveness of new drugs in the treatment of asthma.

Education

B.S. - Mathematics - Oregon State University - 1969
M.S. - Biostatistics - University of Washington - 1971
Special - Advanced ASPEN Training - BLM
- COBOL and FORTRAN Programming courses

Other Interests

Bicycling, running, hiking and traveling. I want to tour Yugoslavia by bicycle this fall.

3/31/86

BIOGRAPHICAL SKETCH

Name:	William L. Jackson
Current Job Title:	Hydrologist Division of Resource Systems, D-470 Denver Service Center P.O. Box 25047 Denver, CO 80225-0047 FTS 776-0148; Commercial (303) 236-0148
Previous Experience	1972-1974 Maryland Department of Natural Resources Division Office of Planning and Evaluation Natural Resource Planner 1975-1976 Maryland Dept. of Natural Resources Power Plant Siting Program Administrator for Site Acquisition
Education:	B.S. - Mechanical Engineering, Univ. of Michigan, 1970 M.S. - Natural Resources Planning & Management University of Michigan, 1971 Ph.D. - Forest Hydrology, Oregon State University, 1981
Activities:	Phi Kappa Phi; Tau Beta Pi; Pi Tau Sigma American Water Resources Association American Geophysical Union American Institute of Hydrology
Interests:	Upland Erosion Stream Channel Processes and Sediment Transport Salinity Control Surface Water Hydrology Slope Stability Stream Restoration
Publications:	15 Professional Papers 3 BLM Technical Notes Misscellaneous Reports

RANGELAND WATERSHED MONITORING [1/]

Issues, management objectives, and management actions are identified and implemented in the RMP/Activity Planning Process. Of particular concern to both Resource Managers and the public is how well management actions are achieving management objectives. Monitoring is the orderly collection, analysis, and interpretation of resource data to evaluate progress in meeting management objectives. Thus, monitoring is the key feedback link in the RMP process. Except in cases where monitoring is required to insure compliance with laws or regulations, monitoring should be keyed to major issues and/or management objectives identified in the planning process.

It is worth emphasizing that monitoring is not only data collection and analysis. It also involves data interpretations, evaluations, and extrapolations. This is because management often needs to be evaluated on a broad, District-wide basis, based in large part upon professional judgement which, in turn, is supported by a few key studies and/or analytical tools (e.g., models). The components of a comprehensive monitoring program for rangeland soil loss are depicted in Figure 1. Note how a soil-loss monitoring program has to be carefully coordinated with the rangeland monitoring program.

1/ By William L. Jackson, Bureau of Land Management, Service Center, Denver, CO 80225

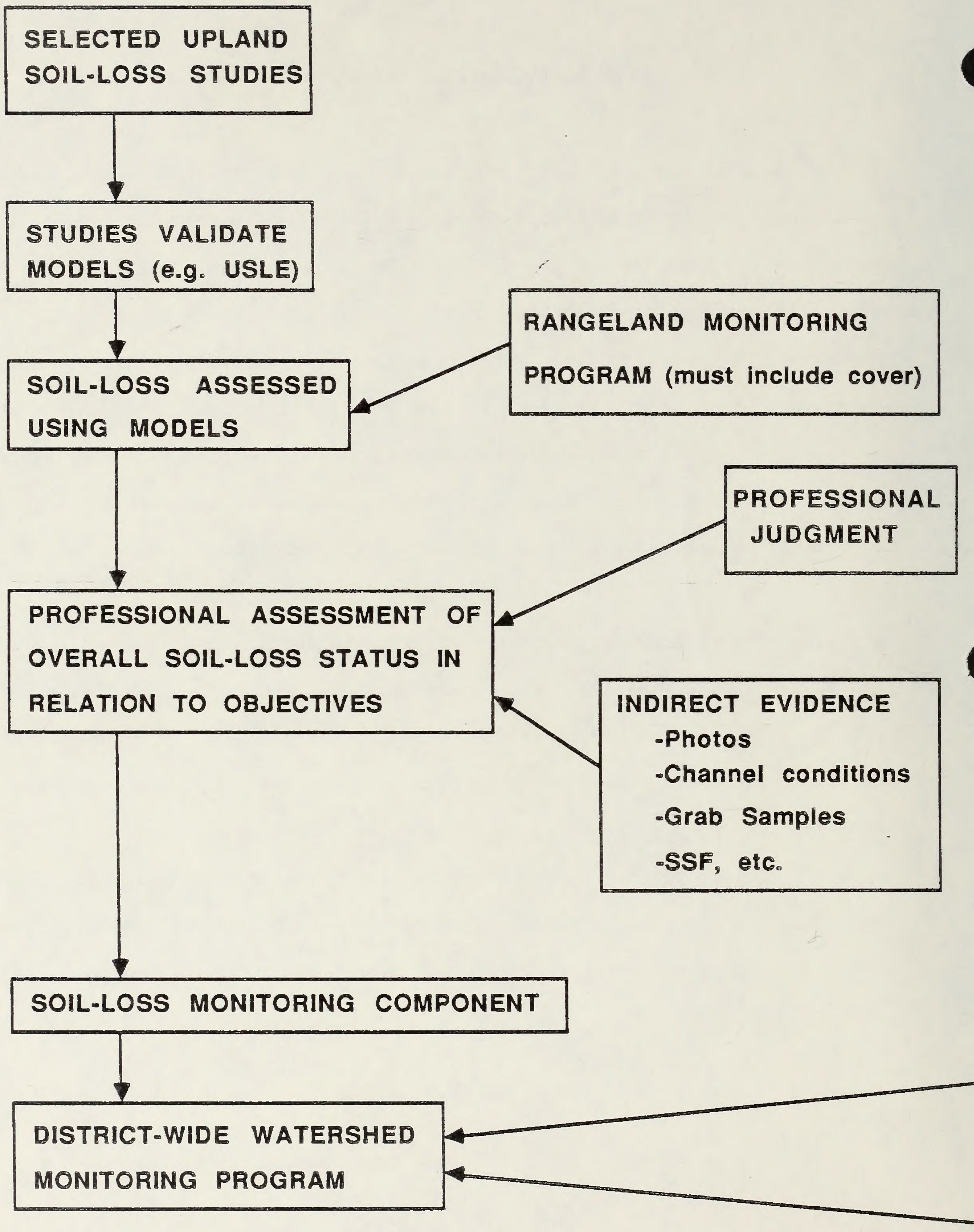


Figure 1: Components of a District-wide Soil-loss Monitoring Program

There are at least five basic concepts to be considered in the development of a District-wide watershed monitoring program:

1. The monitoring effort should be driven by the two or three most important soil-water issues identified in the RMP/AMP process (more on this later).

2. For each issue, one or two key, or representative resources/processes/management actions should be targeted for careful, systematic monitoring.

3. To the extent possible, data collected by a "representative" monitoring scheme should be used to calibrate or validate more generalized assumptions, techniques or procedures (including analytical or conceptual models) to allow extrapolation to and analysis of grazing management activities in relation to soil-water resources throughout the District.

4. Simplicity in sampling design, data collection, analysis, and interpretation is key to successful implementation of long-term monitoring programs.

5. Every effort needs to be made to coordinate monitoring with related resource disciplines, including selection of sampling parameters and sampling designs, sharing data, etc.

A "representative resource" monitoring approach would allow efforts to be concentrated on a small number of high-quality monitoring studies in support of the overall monitoring program. This would maximize the quality of information collected and one's ability, as a professional, to extrapolate the results to other areas experiencing similar management programs.

A hypothetical example of how this might work in a hypothetical District follows:

Using an RMP (or MFP) the specialist would support his opinion that the three most important rangeland soil-water issues are riparian zone restoration, upland soil loss (or upland watershed condition), and salt and phosphorus delivery to the Colorado River. Next, using a stratification approach the specialist would select two riparian zone restoration sites, two upland sites where management for runoff and soil loss is a high priority, and two important sites where salt and phosphorus from public lands discharge into the river. The stratification approach would, of course, have to be developed, but might be based upon a watershed analysis procedure, economic considerations (management costs, resource values), the need for more information for responsible management, or the need to coordinate with existing information sources or other related resource monitoring programs.

At this point three monitoring "issues" and six sites for intensive monitoring studies have been identified. Now it is possible to develop specific study objectives, study designs, sampling methods, data analyses, and interpretation methods, reporting procedures, and a general plan for extrapolating general results to other areas (see TN 369).

Regarding the riparian zone rehabilitation issue, it may be necessary to coordinate with wildlife, fisheries, and range interests to clearly define the soil-water component of the monitoring program (e.g., channel geometry changes). For the upland runoff-erosion issue, it is important to coordinate with range monitoring plans to insure proper sampling designs (e.g., replication and controls) are used and parameters are sampled which can be interpreted in terms of watershed condition (e.g., total cover). Runoff plots and gully condition surveys could be initiated in conjunction with range monitoring plans at the two selected sites to help validate assumptions or models used in watershed interpretations of range monitoring data.

For the water quality issue, it will be important to coordinate closely with existing monitoring programs (USGS and State) to make optimum use of existing data and facilities. The sampling design in this case may have to be geared towards analysis of trends - possibly employing a covariable such as discharge or suspended sediment concentration (assuming "controls" are not available). In all cases, sampling designs and data analysis plans should be developed in close consultation with a statistician <u>before</u> the monitoring program commences.

The results of the targeted/stratified monitoring studies would then have to be extrapolated District-wide. Thus subjective evidence (occular data, appearance, grab samples, infrequent inspections, general indicators, etc.), and professional judgement are still required. However, they are now supported by good data, professional tools, and careful study designs.

It may be that a targeted "representative resource" monitoring program will not always meet management's needs. The disadvantage is that you don't monitor everything. The advantage is that what you do monitor, you monitor well. Given careful stratification and extrapolation schemes, you maximize the utility of the data collected.

WATER QUALITY MONITORING PROGRAMS

DEVELOPED BY
STANLEY L. PONCE

WSDG TECHNICAL PAPER
WSDG-TP-00002
DECEMBER 1980

WATERSHED SYSTEMS DEVELOPMENT GROUP
USDA FOREST SERVICE
3825 EAST MULBERRY STREET
FORT COLLINS, COLORADO 80524

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

LIST OF FIGURES

LIST OF FIGURES

(continued)

LIST OF TABLES

LIST OF EXAMPLES

PREFACE

Recent legislation, such as Public Law 92-500 (the Federal Water Pollution Control Act Amendments of 1972), RPA and NFMA, and public opinion have forced water quality considerations to surface in many land and resource decision processes. This has generated a need to provide decision-makers with information about existing water quality and the impacts of land management practices on water quality. In general, this information is obtained through water quality monitoring.

Water quality monitoring, which is defined in the Forest Service Manual as "the systematic evaluation of achievement of water quality management goals, objectives, or targets," is usually the responsibility of the forest hydrologist. The purpose of this Technical Paper is to help forest hydrologists develop technically sound water quality monitoring programs. The material presented here is the result of an extensive literature review and personal experience.

It is intended that this paper be used as a technical guide, not a "cook book." Every water quality monitoring program will be different. As a result, each program will require that the hydrologist understand the hydrologic system at hand as well as the interaction between land-use activities and water quality. In my opinion, there is no substitute for careful planning by the professional forest hydrologist when developing a water quality monitoring plan of operation for a National Forest.

This paper was designed to be used in conjunction with Watershed Systems Development Group (WSDG) Technical Paper 00001, "Statistical Methods Commonly Used in Water Quality Data Analysis"; and WSDG Application Documents 00001, "Statistical Analysis Using the Statistical Analysis System (SAS) at the EPA National Computer Center"; and 00002, "Statistical

Analysis Using the Statistical Package for the Social Sciences (SPSS) at the USDA Fort Collins Computer Center."

I would like to acknowledge all the following people who reviewed this paper and provided many valuable suggestions for its improvement: Mr. John Potyondy, USDA Forest Service; Dr. David W. Schindler, Fisheries and Environment Canada; Dr. Robert C. Averett, USGS-WRD; Dr. Robert Beschta, Oregon State University; Mr. Karl Gebhardt, BLM; Dr. Ken Brooks, University of Minnesota; Mr. David Ryn, USDA Forest Service; Dr. Walt Hivner, Colorado State University; Dr. David DeWalle, Pennsylvania State University; Dr. Clarence Skau, University of Nevada; Mr. Ronald Russell, USDA Forest Service; Mr. Owen Williams, USDA Forest Service; Mr. Rhey Solomon, USDA Forest Service; Mr. Larry Schmidt, USDA Forest Service; Mr. Andrew Leven, USDA Forest Service; Mr. Dallus Hughes, USDA Forest Service; Mr. Keith McLaughlin, USDA Forest Service; Mr. Harry Parrott, USDA Forest Service, Mr. Ted Beauvais, USDA Forest Service; Ms. Ann Puffer, USDA Forest Service; and Mr. Warren Harper, USDA Forest Service.

WATER QUALITY MONITORING PROGRAMS

1.0 Introduction

Designing a water quality monitoring program that will provide useful information is an intellectual activity. It requires a great deal of thought and careful planning. Thinking about the measurements you are going to make and why you are going to make them leads to problem solving.

Just as a blood sample gives a physician insight into the functions of the human body, a water sample can tell a hydrologist a great deal about the complex system of a watershed. The quality of the water resource is directly related to natural factors, such as climate, geology, soils and terrestrial and aquatic vegetation; and man's land-use activities, such as timber harvesting, road building, grazing, recreation and mining. Consequently, to obtain useful information from water quality monitoring, the sampling network for collection of data must be properly located in both time and space and the constituents which are relevant to the management objectives must be sampled. In addition, if the monitoring is to be cost effective, the hydrologist needs to evaluate, at the outset of the program, what can be accomplished with the resources that are available.

The purpose of this paper is to (1) summarize the various types of water quality monitoring commonly carried out on National Forest System lands and (2) provide a series of guidelines to aid you with problem definition, establishing study objectives, locating past work, data analysis, locating sampling stations, selecting water quality constituents, determining sampling frequency, and collecting and handling samples.

One final comment before we begin our discussion on developing water quality monitoring programs. It is strongly recommended that you document your program in the form of a water quality monitoring plan of operation (see FSM 2542). A written monitoring plan serves several purposes. First, it forces you to clearly define your problem and study objectives as well as develop a logical approach to collecting data which will provide information. Second, it provides your supervisor and other interested parties with a statement of the problem you plan to address, how you will do it, the type of data that will be obtained, how the data will be analyzed, the expected knowledge to be gained, the financial commitment required, and when reports are to be done. Finally, if you leave the Forest before the project is completed, it provides the next hydrologist with the proper framework to continue the study. In general, the structure of a water quality monitoring plan varies from Region to Region. However, the major components of most plans are the topics discussed in this paper.

2.0 Types of Monitoring

In general, the types of water quality monitoring performed on National Forest System lands can be divided into four categories: cause-and-effect, compliance, baseline, and inventory. A brief summary of each follows.

Cause-and-effect (project) monitoring is performed to quantify the impacts of specific land management activities on water quality. The information obtained from this type of study is often used to evaluate the effectiveness of "Best Management Practices," calibrate existing models which were developed at different locations or under different conditions, and develop and verify models designed specifically for the Forest.

Cause-and-effect monitoring is generally implemented on a project level. The surveys are designed to deal with questions about what happened and why. The monitoring is generally short-term, lasting three years or less. Whenever possible, paired sampling is employed with samples being collected before, during and after the treatment.

Compliance monitoring on National Forest System lands is performed primarily to protect public health. It includes the monitoring of drinking water and water used for primary contact recreation. The water quality is generally compared with existing State water quality standards and when these standards are not met, corrective action should be taken as soon as possible.

Baseline monitoring is performed to provide land managers with reliable information on water quality trends. The data are generally used to determine if water quality maintenance and improvement criteria required by law and/or policy are being met and for long-term trend assessment. If the data indicate that water quality degradation is occurring as a result of activities on the National Forest, corrective action may be evaluated and appropriate action initiated. Water quality stations associated with this type of monitoring program are usually located at strategic points within the Forest and sampled on a routine basis for many years.

Inventory monitoring is carried out to provide land managers with reliable information of existing water quality conditions. The data are generally used to provide information for the land management planning process and to establish water quality goals. Usually the inventory data are obtained from existing stations established for cause-and-effect, compliance and baseline monitoring. However, if additional stations are required, they are often located at strategic points within the Forest and sampled intensively for a short period of time.

One of the keys to an effective water quality program is to integrate the various types of monitoring so that they are complementary. Some of each type of monitoring will generally be carried out on all Forests. Enough of each type should be accomplished to characterize the quality of the water resource, to assess the impacts of management activities on water quality and to determine if water quality standards, goals and objectives are being met.

Priorities for monitoring should be established because it is not feasible to monitor the water quality of all management activities or all water bodies within the Forest. Variation of priorities between Forests will exist depending on the existing data base, management issues and concerns, and water quality management objectives.

3.0 Defining Problem Areas and Setting Study Objectives

The first step in developing an effective water quality monitoring plan is to define problem areas. Each problem definition must evolve from the needs identified by the line officer for information which will aid in making management decisions (Boynton, 1972). It is very important that the needs of the line officer be clearly identified since water quality monitoring can only be justified if it is done to address specific needs of management for information. Furthermore, commitment by line officers to monitoring programs is achieved through their involvement in problem identification and setting specific study objectives.

The role of the hydrologist in the problem definition phase is to take the lead in suggesting specific problem areas which are technically feasible and satisfy the managers needs. The hydrologist has the technical expertise and the familiarity with land use and water quality relationships to make this linkage. Involvement of other functional specialists with an interest in water quality, such as fishery biologists, is often appropriate at this stage to coordinate common data needs. Interdisciplinary involvement can avoid duplication of effort and address a multitude of management needs at one time (Potyondy, 1980).

Problem definitions should be as specific as possible. A problem definition, such as "What is the effect of land use on the quality of water draining the Routt National Forest?" is too broad to be of much use. In this case, the problem definition could be greatly improved if (1) the land management activity of interest was identified (timber harvesting, mining, recreation, etc.); (2) the water resource was specified (stream, lake and/or ground water); and (3) the type of water quality was stated (physical, chemical, biological and/or radiological). An improved problem definition might read "What is the effect of clearcutting on the sediment regime of Trout Creek?" The problem definition is now very clear and direct. Often times problem definitions will not be this specific. More often they are as follows:

1. A reliable method to predict the effect of clearcutting on the sediment yield for the various stream types found in the Forest is needed.

2. A simple, reliable approach to classify lakes by water quality within the Forest is needed.

These problem statements, broad as they may appear, are consistent with the water quality information needed in the land management planning process and still provide the hydrologist with sufficient guidance to formulate study objectives.

Once the problem areas have been defined, the next step is to establish study objectives. This process should also be a mixed effort between the hydrologist and the line officer. The hydrologist's role, because of his technical knowledge of the watershed system and land use/water quality interactions, is to suggest specific monitoring objectives while the line officer's role is to act as a sounding board, continually asking why and making sure the objectives speak only to his needs and that the plan fits within the available resources (Boynton, 1972). When the objectives are agreed upon by the hydrologist and line officer, they should be documented in written form.

Objectives should be specific statements of measurable results to be achieved within a stated time period. In addition, they should be specific enough so that the hydrologist can convert them into statistical hypotheses which can be tested with the data obtained from the water quality monitoring program (more about this in Section 5.0). Some illustrations of problem definitions and related study objectives are given in Example 1.

Defining the problem and setting the study objectives phase of the study may seem like a lot of work which will require a substantial amount of your time. It is and it does. However, it is time very well spent. The point is, if you have spent time defining your objectives and making sure that they are compatible with management's needs, there is a very good chance that your study will be successful and provide meaningful information to the land manager.

Example 1
Establishing study objectives from problem definitions.

Case A.

Problem Definition:

Does the water at Public Beach A pose a health hazard to primary contact recreationists?

Study Objective:

To determine if the water at Public Beach A meets the State standards for swimming during the summer of 1980.

In this case, the strategy is to monitor the water quality at Swimming Beach A over the summer and compare it with the State standards for primary contact recreation.

Case B.

Problem Definition:

Is acid precipitation adversely affecting the productivity of Agnes Lake?

Study Objectives:

1. To determine the pH of the precipitation on a seasonal basis at Agnes Lake over the next five years.

2. To determine the seasonal trend of pH, alkalinity and conductivity in Agnes Lake over the next five years.

3. To determine the biological significance of any change in pH, alkalinity and conductivity in Agnes Lake that occurs over the next five years.

In this case, the strategy is to quantify the seasonal input of acid (hydrogen ions) to the lake from precipitation, to develop the trend of the lake's response over the next five years, and determine if this response is biologically significant.

4.0 <u>Reviewing Past Work</u>

After the objectives have been established, the next step is to determine what has already been done. Several common sources of data of interest to the wildland hydrologist are listed below:

1. Forest, District, and Regional Office resource reports.

2. U.S. Forest Service research, U.S. Geological Survey, U.S. Environmental Protection Agency, Bureau of Land Management, Water and Power Resources Administration, Corps of Engineers, National Oceanic and Atmospheric Administration, and Soil Conservation Service.

3. State Geological Survey, State Department of Health, State Department of Engineering, and State Water Pollution Control Agency.

4. State universities, especially the departments specializing in watershed management, hydrology, geology, chemistry, aquatic biology, limnology, and microbiology.

5. River basin commissions.

6. STORET.

In addition to the sources mentioned above, several of the Regions now have agreements with Forest Service research libraries or other libraries which provide computerized literature searches. The major indexes presently available or soon to be available are summarized in Table 1.

Most of the time, you can expect that little if any data will be available from your watershed of interest, or if they are, they often will be the wrong kinds of data. You can sometimes circumvent this problem by reviewing information available from tributary streams or adjacent drainages: However, <u>you must be cautious</u> when transferring data from one place to another.

Whenever data are available from your watershed of interest, they probably will have been collected for another purpose and will not solve your specific problem. Nevertheless, such data can provide you with

Table 1. Indexes for computerized search of water resources literature (modified from Busby, 1980).

INDEX	SUBJECT AREA
AGRICOLA	Covers worldwide journal and monographic literature in agriculture and related subject fields, including forestry, natural resources, chemistry and water resources. Prepared by the U.S. National Agriculture Library.
AQUALINE	Provides access to information on every aspect of water, waste water, and the aquatic environment. Worldwide sources cited are 400 periodicals, research reports, legislation, conference proceedings and preprints, books, monographs, pamphlets, dissertations, translations, standards and specifications, and miscellaneous publications from water-related institutions worldwide. Prepared by the Water Research Centre.
BIOSIS PREVIEWS	Includes contents of Biological Abstracts and Bio-Research Index, covering the entire life sciences. Citations are taken from approximately 8,000 serial publications, as well as books. Prepared by Biological Sciences Information Service.
CDI	Comprehensive Dissertation Index, containing all dissertations accepted for academic doctoral degrees granted by United States education institutions and some non-U.S. universities. Prepared by University Microfilms International.
COMPENDIX	Covers civil, environmental and geological engineering; mining, metals, petroleum and fuel engineering; mechanical, automotive, nuclear and aerospace engineering; chemical, agricultural and food engineering; and industrial engineering, management, mathematics, physics and instruments. Prepared by Engineering Index, Inc.
GeoRef	Geological Reference file, covering geosciences literature from 3,000 journals, plus conferences and major symposia and monographs in such areas as environmental geology, geochemistry, and fluvial geomorphology. Prepared by the American Geological Institute.
NTIS	This is a broad and cross-disciplinary file containing citations and abstracts of government-sponsored research and development reports and other government analysis prepared by Federal agencies on their contractors and grantees. Prepared by National Technical Information Service of the U.S. Department of Commerce.

INDEX	SUBJECT AREA
POLLUTION	Covers non-U.S., as well as domestic reports, journals, contracts, patents and symposia in the areas of pollution control and research. Prepared by Pollution Abstracts, Data Courier, Inc.
WATERLIT	Covers the water resources and water-related literature of the world. WATERLIT topics include, but are not limited to, water supply, reservoirs of all types, water utilization, water standards, limnology, health aspects of water, water law and water ecology. It is produced by the South African Water Information Centre.
WRD	Water Resources Abstracts is a computerized version of Selected Water Resources Abstracts, a semimonthly journal published by the Office of Water Research and Technology. It covers literature of water related aspects of the life, physical and social sciences as well as related engineering and legal aspects of the characteristics, conservation, control, use, or management of water.

information about the interactions between land use, hydrology and water quality and be very useful in the design of your sampling program.

5.0 Thinking About Data Analysis

This is the stage of your study design when you should begin thinking about how the data will be analyzed. You should start by converting your objective statements into null (H_0) and alternative (H_a) hypotheses. For example, consider the objective presented in Case A, Example 1. The study objective is a very specific water quality concern which can be readily converted into a set of null and alternative hypotheses. The hypotheses to be tested could be stated as follows:

H_0: The water at Public Beach A <u>does not</u> exceed the State water quality standards for swimming during any portion of the summer of 1980.

H_a: The water at Public Beach A exceeds the State water quality standards for swimming at some time during the summer of 1980.

At this point, we are ready to select a statistical model which will allow an efficient test of the null hypothesis against the alternative hypothesis. The statistical methods that you select, along with the knowledge you have gained about the system through reviewing past work, will influence where you sample, such as above or below a treatment or at the mouths of paired watersheds offering impact and controlled data comparisons; and when and how often you sample, such as once a season without replication or diurnally with replication. If you do not feel comfortable designing your statistical analysis, you should review in detail WSDG Technical Paper 00001 ("Statistical Methods Commonly Used in Water Quality Data Analysis", Ponce, 1980) and/or seek the aid of a statistician.

There are a few principles that you should keep in mind when you begin thinking about your data analyses. These have been summarized from Green (1979).

1. Carry out some preliminary sampling to provide a basis for evaluation of sampling design and statistical analysis options. Those who skip this step because they do not have enough time or money usually ending up loosing both time and money.

2. To test whether a condition (treatment) has an effect, collect samples both where the condition (treatment) is present and where it is absent but all else is the same. Remember, an effect can only be demonstrated by comparison with a control.

3. If possible, take replicate samples within each combination of time, space, and any other controlled variable. Differences among can only be demonstrated by comparison to differences within. For example, if you are comparing NO_3 yield from a clearcut area with a forested area, only if you take replicate samples can you separate sampling error from differences due to the treatment.

4. If the system to be sampled has a large-scale environmental pattern, break up the system into relatively homogeneous subsystems and allocate samples to each by some predetermined weighting criteria. For example, if you are measuring TDS in the northern Rockies, you could reduce the overall variance substantially if you broke your sampling periods into three strata; baseflow, snowmelt, and stormflow; and weigh each by discharge.

It is very important that you consider the statistical analysis at this stage of the study design. As Averett (1979) states "problems almost always arise when statistical methods become an afterthought of study design and are used as a salvage operation. This 'afterthought' application of statistical methodology leads to the deadliest data analysis trap of all--the mathematical manipulation of non-related, non-correlated data, into a probability function."

One final comment before we proceed; it is important that you keep the role of statistical methods in proper perspective. Their primary use is to reduce data and to help us make "yes" or "no" statements about the relation of samples collected from different populations. While there is much merit in designing water quality sampling studies around a statistical framework, it must be emphasized that the statistical testing of data is not interpretation of data (Averett, 1979). It is the responsibility of the hydrologist to interpret the results of the statistical analysis and provide the line officer with information which can be used in the decision making process.

6.0 Where, What and When

At this stage of your study design, you are ready to select your sampling stations (where), choose the water quality constituents to be sampled at each station (what), and determine the sampling frequency of each constituent at each sampling station (when). This phase of the study design requires a sound understanding of the hydrologic system and how the water quality relates to the beneficial uses of the water resource. If the study objectives have been clearly stated and you have spent time thinking about the interaction between land use, hydrology, and water quality in your system, the determination of where, what, and when should be fairly straightforward.

Throughout this section you should keep two points in mind. First, where, what, and when you sample should be directly related to the needs and objectives of the study. Remember, the line officer holds you responsible for the water quality data collected and it is your job to see to it that unnecessary data are not obtained. Second, station location, parameter selection, and sampling frequency are all very important. You cannot short cut one without affecting the others (Averett, 1976).

6.1 Guidelines for Locating Sampling Stations

There are two factors which strongly influence the location of sampling stations: (1) the type of monitoring and (2) the type of water body. Guidelines for locating sampling stations are discussed for each of these factors separately.

6.1.1 Station Location as Influenced by the Type of Monitoring

As you recall, water quality monitoring on National Forest System lands can generally be classified as (1) cause-and-effect, (2) compliance, (3) baseline, and (4) inventory. Locating the sampling stations for cause-and-effect monitoring is generally the easiest to carry out. The strategy in this case is to isolate the treatment effects by (1) sampling above and below the treatment and/or (2) sampling before and after the treatment. Consider the example presented in Figure 1. There we have a treatment which covers only a portion of a small stream. Stations A and B have been placed immediately above and below the treatment, respectively, to isolate it. Station A represents the control. Station B, in theory, is assumed to be similar to Station A in all respects except that it includes the effect of the treatment. Whenever the "above and below" approach is used, you must be certain the above station is a satisfactory control.

The type of sampling design shown in Figure 1 readily lends itself to two types of statistical testing: (1) comparison of the means of Stations A and B and (2) comparison of the regression of Stations A and B. If the variance of the water quality parameter of interest is not strongly influenced by fluctuations in the stream flow, a simple comparison of the means can be made to test for treatment effect. The hypotheses to be tested are as follows:

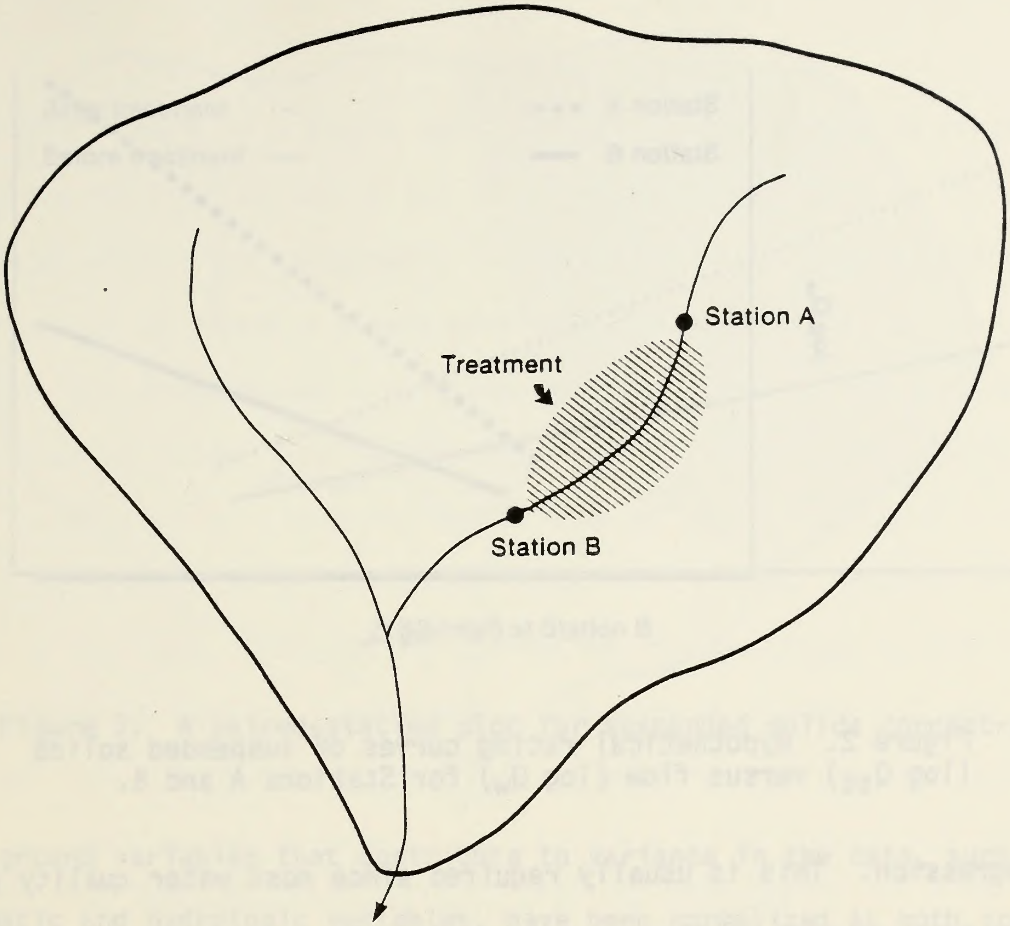


Figure 1. Example of station location for cause and effect monitoring study where the treatment can be readily isolated.

$$H_o: \mu_A = \mu_B$$
$$H_a: \mu_A \neq \mu_B$$

where μ_A and μ_B denote the mean at Stations A and B, respectively. The statistical method generally employed to make this comparison is the paired t-test. However, if the variance is strongly influenced by discharge, it is very likely that the treatment effects will be masked. If you develop a regression of the water quality constituent versus discharge (commonly referred to as a rating curve) you can remove or explain much of the variance due to flow and make a stronger test of the treatment effect.

A suspended solids rating curve is illustrated in Figure 2. Note, a log X transformation has been applied to the data to obtain a linear

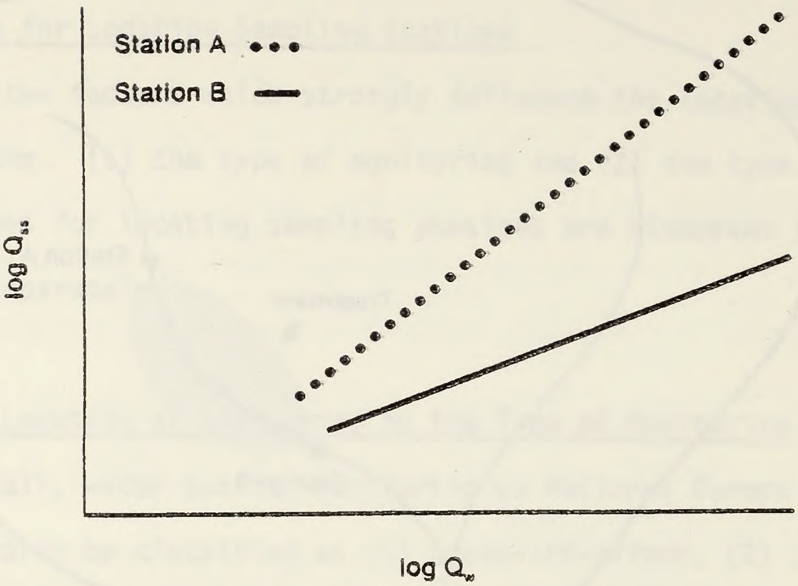


Figure 2. Hypothetical rating curves of suspended solids (log Q_{ss}) versus flow (log Q_w) for Stations A and B.

regression. This is usually required since most water quality constituents are best related to flow by a power function, which can be linearized with a log X transformation. To test for the treatment effect, we would compare the slopes of the regression lines and their intercepts. The hypotheses to be tested are as follows:

H_0: slope A = slope B H_0: intercept A = intercept B
H_a: slope A ≠ slope B H_a: intercept A ≠ intercept B

Covariance analysis would be the statistical method employed to make these comparisons.

If the above and below stations were established prior to the treatment and a paired sample data base developed both before and after the treatment, the opportunity exists to develop a paired-station plot. Such a plot for suspended solids concentrations at Stations A and B, both before and after treatment, is illustrated in Figure 3. In general, these regressions have strong correlation coefficients because many of the

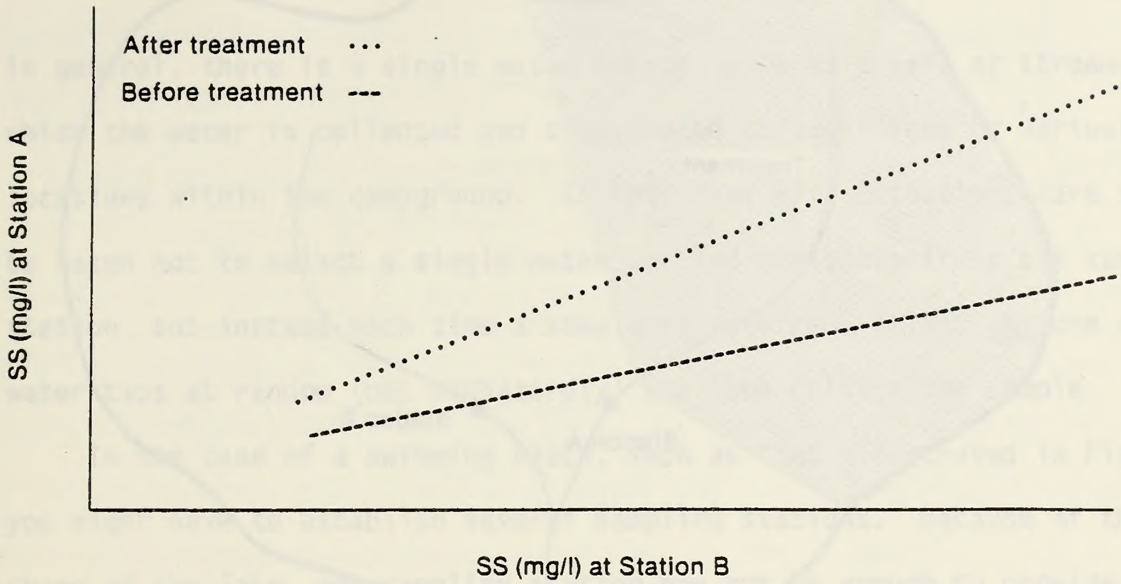


Figure 3. A paired-station plot for suspended solids concentration.

background variables that contribute to variance in the data, such as climatic and hydrologic variables, have been normalized at both stations. Consequently, this method enables us to make a better assessment of the treatment effects than any of the methods previously described. The actual statistical comparison is the same as that explained for the regression curves.

In some cases, we cannot isolate a treatment by placing stations above and below. Such an instance is illustrated in Figure 4. Here the treatment, which could be a vegetative conversion on a grazing allotment, covers an entire tributary system. There are two approaches to locating sampling stations in this case. The first is to simply position a station immediately below the treatment (such as Station A, Figure 4), and another one (such as Station B, Figure 4) on a watershed which is similar to the treated watershed in all respects (that is climate, geology, soils, vegetation, land use, etc.) except it is not influenced by the treatment.

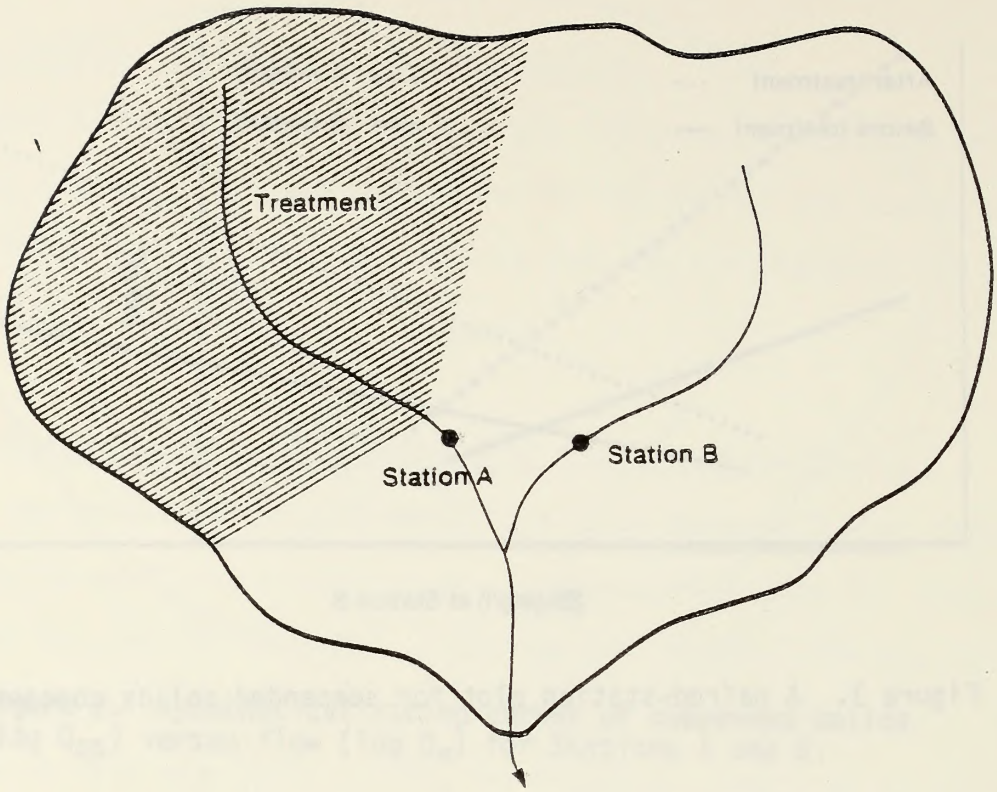


Figure 4. Sample station location for the paired watershed approach.

With either approach, a valid assessment of the treatment effect would require sampling both before and after the treatment. If only one station is established, the statistical comparison will be made using the before and after means or regression lines. If two stations are established, the comparisons can be made using the before and after means or paired-station regressions. The paired station approach is recommended over the single station approach because it allows you to account for year-to-year variation in climate and hydrology.

Compliance monitoring is generally performed to protect public health and to assure that waters draining from National Forest System lands meet State water quality standards. In general, station location involves the positioning of a single sampling station or a pair of stations. Consider the situation where the drinking water in a campground needs to be tested.

In general, there is a single water source, such as a well or stream, from which the water is collected and distributed through lines to various locations within the campground. In this type of a situation, care should be taken not to select a single water tap and designate it as the sampling station, but instead each time a sample is required, select <u>any</u> one of the water taps at random (not haphazardly) and then collect the sample.

In the case of a swimming beach, such as that illustrated in Figure 5, you might have to establish several sampling stations. Because of the shape of the lake, one sampling station may not be enough to provide a representative sample. Consequently, the area of concern may have to be divided into homogeneous strata, each of which is sampled separately. This type of sampling design enables you to make a direct comparison with the standard or compare the sample mean with the standard.

Sometimes compliance monitoring requires the surveillance of point sources. Consider, for example, a sewage lagoon which treats the waste from a campground and whose effluent drains into a perennial stream (Figure 6). There are two approaches to locating sampling stations in this situation. If the State standards require the effluent to be of a fixed quality or better, the station should be positioned to sample the effluent directly, such as in Case I, Figure 6. If the State standards require that the effluent not increase the stream's composite load by a certain difference, such as temperature by 2°C, stations would have to be positioned above and below the outfall (Case II, Figure 6).

Baseline monitoring is designed to provide information on water quality trends. In general, stations are positioned strategically throughout a Forest or District (such as at the mouths of major streams or confluences of major tributaries) to obtain trend information for a wide

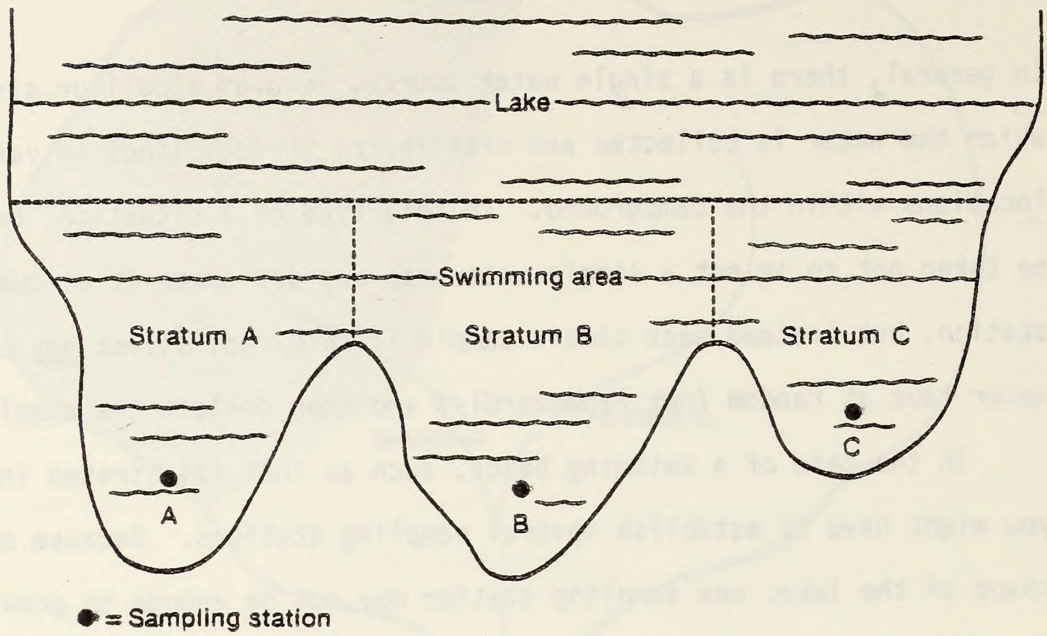


Figure 5. A plane view of a sampling station location at a swimming beach along a lake.

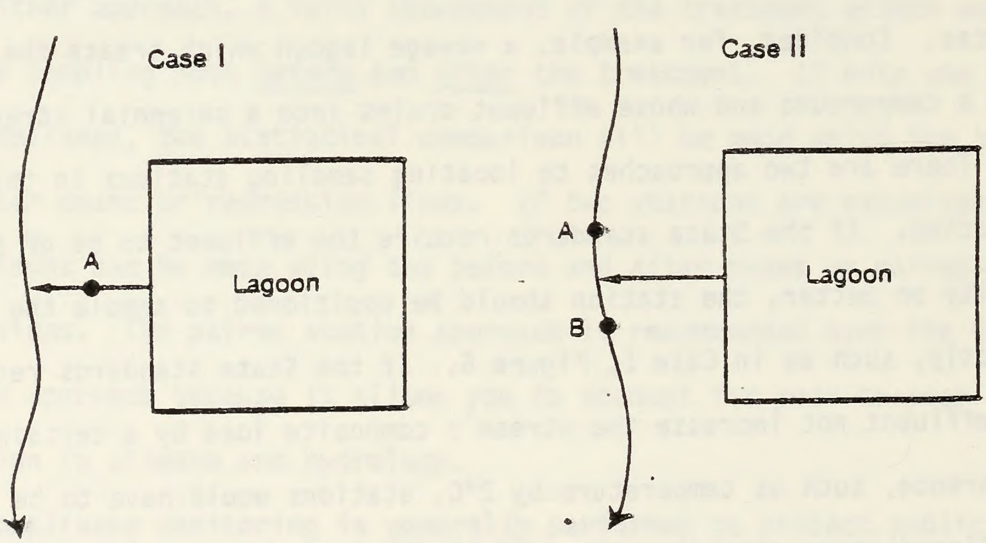


Figure 6. Sampling station location for two cases, I and II, in which a point source effluent is draining into a stream.

range of conditions, such as climate, topography, geology, soils, vegetation and land use.

Inventory monitoring is designed to characterize the water quality of a Forest on a broad scale. Sampling stations are usually located on major streams at or near the Forest boundary or at other strategic locations within the Forest. These stations are often positioned so that they integrate several different land uses. As a result, the quality of water at these stations often times represents the cumulative impacts resulting from multi-resource management activities on the Forest.

6.1.2 Station Location as Influenced by the Water Type

In general, there are three types of water bodies of concern to the forest hydrologist: (1) streams, (2) lakes and reservoirs, and (3) groundwater. The establishment of sampling stations along or in any of these water bodies is directly related to the characteristics that control the movement of water and distribution of water quality parameters in that water body.

There are several factors that you should consider when you are locating sampling stations in streams: (1) tributaries, (2) mixing characteristics, (3) suitability for discharge measurements, (4) accessibility, and (5) suitability for biological monitoring. Tributaries should always be considered in locating sampling stations because of the effect they can have on the receiving water. The question, however, is whether or not a specific tributary should be included in the monitoring program. In general, tributaries involved in cause-and-effect and compliance monitoring studies should be monitored. If they are not included, it is very difficult to isolate constituents of concern and minimize variability. An example of station location for a cause-and-effect study in which a tributary is involved is presented in Figure 7. By placing sampling stations above and below the clearcuts (treatment of concern) on both the mainstem and tributary allows us to assess the effect of logging on stream quality and to exclude the effects of the pasture and the mountain home development.

The problem lies with baseline, inventory, and mixed monitoring studies where large areas are involved. It is not practical to include every tributary in our monitoring network, yet, how do we decide which ones to include? Ideally, the best way to make this assessment is to carry out a preliminary reconnaissance and sample all the tributaries at least once.

However, most of the time this is not possible because of constraints in manpower, time, and money. The hydrologist, therefore, must consider each tributary separately and develop a list of potential tributaries to sample. Averett (1976) suggests you consider the following guidelines when performing this task.

1. Be thoroughly familiar with the physical characteristics of the system you are studying. Consider such things as drainage area, geology, soils, vegetative type and land use. A large variation of any of these factors in a tributary from the conditions of the mainstem calls for the tributary to be included in the sampling network.

2. Consider the dissolved solids concentration or the electrical conductivity of the tributary. If during low flow periods electrical conductivity or dissolved solids are higher or lower when compared to the mainstem flow, then you have strong reason to consider monitoring the tributary.

3. Look for sediment plumes and sand and gravel bars near the mouth of tributaries. The presence of these features is an indicator of erosion upstream and is reason to consider monitoring the tributary.

4. If a tributary provides a proportionately large volume of flow to the mainstem, you should consider establishing a monitoring station at its mouth. An upstream tributary may be small compared to the downstream mainstem. However, in its upstream

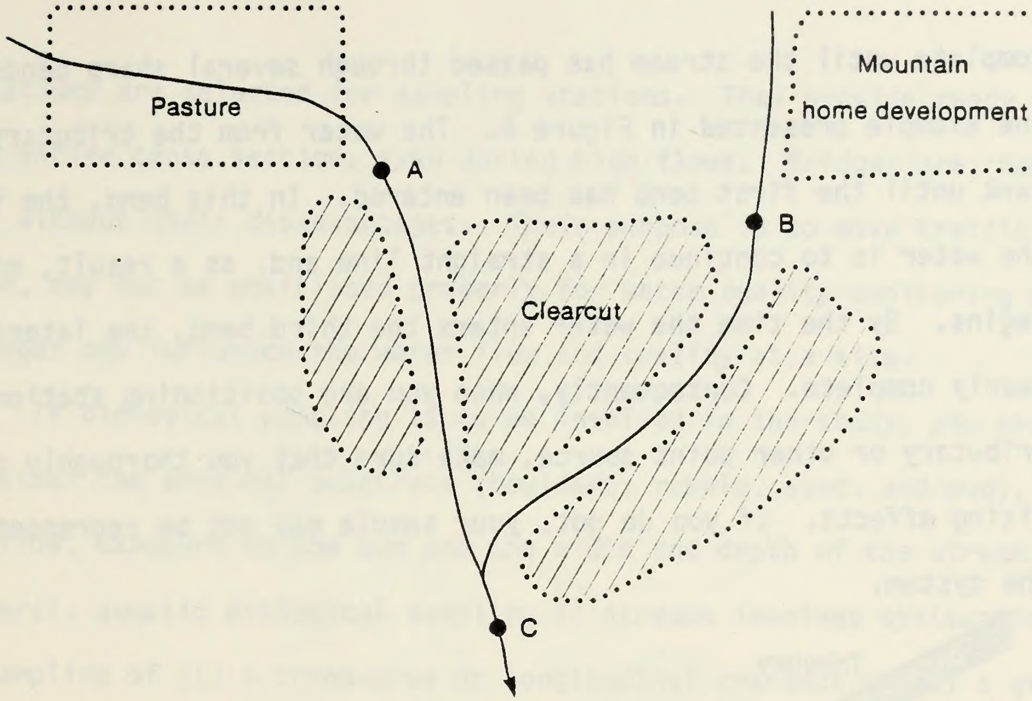


Figure 7. Example of sampling station location for a cause-and-effect monitoring study in which a tributary is involved. Stations A and C lie on the mainstem while Station B is on the tributary.

location, the tributary may contribute substantially to the mainstem both in quantity and quality. In other words, you should not select tributaries for sampling based upon volume of flow alone, but rather based on their volume relative to the mainstem at the confluence.

5. If a tributary is of sufficient volume and different water quality to influence the mainstem, it may be useful to establish some stations on the tributary other than at its mouth.

How well-mixed a water quality constituent is in a stream is dependent upon the physical and chemical nature of the constituent as well as the physical characteristics of the stream. The physical characteristics of the stream which affect mixing include temperature, depth, velocity, turbulence, slope, changes in direction, and roughness of the bottom.

In general, if the sampling point of interest is some distance downstream from a tributary or other point source, such as a sewage outfall or irrigation return flow, the water quality is usually fairly well mixed across the cross section. Most sampling problems involve mixing below tributaries and other point sources. Vertical mixing (from surface to bottom) is usually quite rapid due to the turbulence of mountain streams. Lateral mixing (from one side to the other), on the other hand, may not be complete until the stream has passed through several sharp bends. Consider the example presented in Figure 8. The water from the tributary "hugs" the bank until the first bend has been entered. In this bend, the tendency of the water is to continue in a straight line and, as a result, mixing begins. By the time the water enters the third bend, the lateral mixing is nearly complete. Consequently, when you are positioning stations below a tributary or other point source, make sure that you thoroughly consider the mixing effects. If you do not, your sample may not be representative of the system.

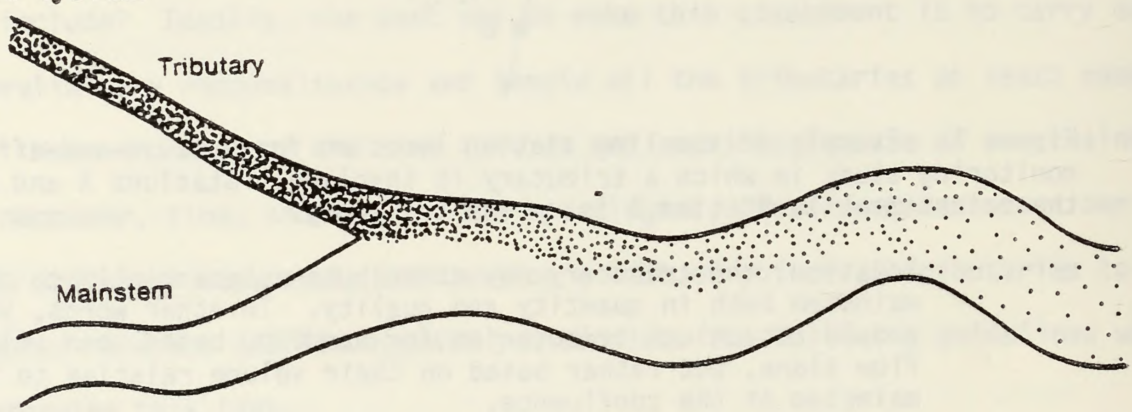


Figure 8. An illustration of lateral mixing.

When establishing sampling stations in the field, it is important that you consider the suitability of each station for discharge measurements. Many water quality studies on streams have been of little use because discharge measurements were not made and most water quality constituents are flow dependent. Without discharge measurements, you cannot perform a mass balance or determine mass yield, both of which are important water quality data analysis techniques.

Another concern when locating stations is accessibility. If a sampling station is located a substantial distance from a road, make sure time and manpower costs of sampling are considered. In many cases, bridge locations are selected for sampling stations. They provide ready access to the entire cross section, even during high flows. Bridges are, however, not without their disadvantages. Their purpose is to move traffic and, as such, may not be positioned properly for water quality monitoring purposes. Bridges may influence the water flow and quality at a site.

If biological sampling is to be involved in the study, you should consider the physical substrate (boulders, rubble, sand, and mud), velocity of flow, exposure to the sun and the width and depth of the stream. In general, aquatic biological sampling in streams involves systematic resampling of (1) a transverse or longitudinal transect or (2) a grid or quadrant system. Transect sampling consists of collecting samples either along a section of stream length of in a line across the stream (Figure 9). Samples may be collected at uniform intervals along the transect line or at random. If the transect line is along the stream length and includes pools and riffles, each habitat is usually considered separately and sampled equally. A sampling grid or quadrant consists of an imaginary or physical rectangular arrangement of lines, covering all or part of a given habitat (Figure 9). A grid or quadrant sampling scheme should, as with the transect scheme, give equal consideration to the various habitat types.

When locating sampling stations in a lake or reservoir, you need to consider the (1) thermal stratification, (2) circulation of the water, and (3) morphology of the basin. Each of these factors strongly influences the spatial distribution of the water quality parameters throughout the lake or reservoir.

In temperate regions, lakes and reservoirs deep enough to stratify will typically develop a temperature profile similar to that in Figure 10. This profile consists of three zones, the epilimnion, the metalimnion, and

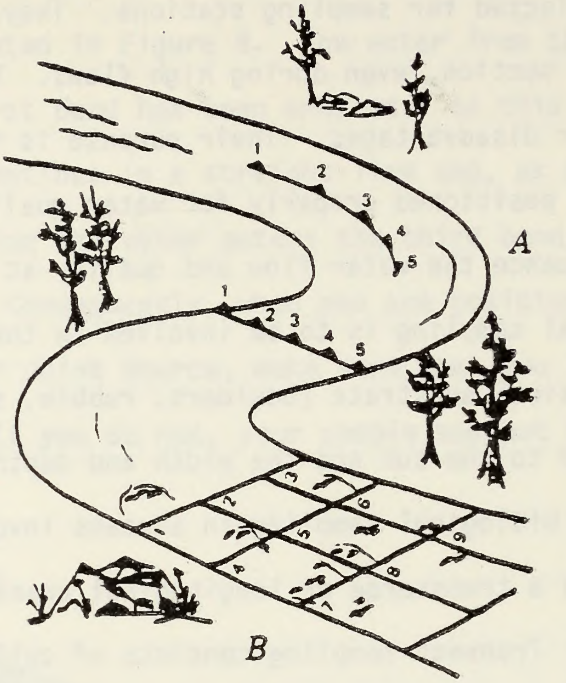


Figure 9. Examples of transect and grid sampling schemes. A illustrates longitudinal and transverse transects while B illustrates a grid of nine sampling sites (after Averett, 1977).

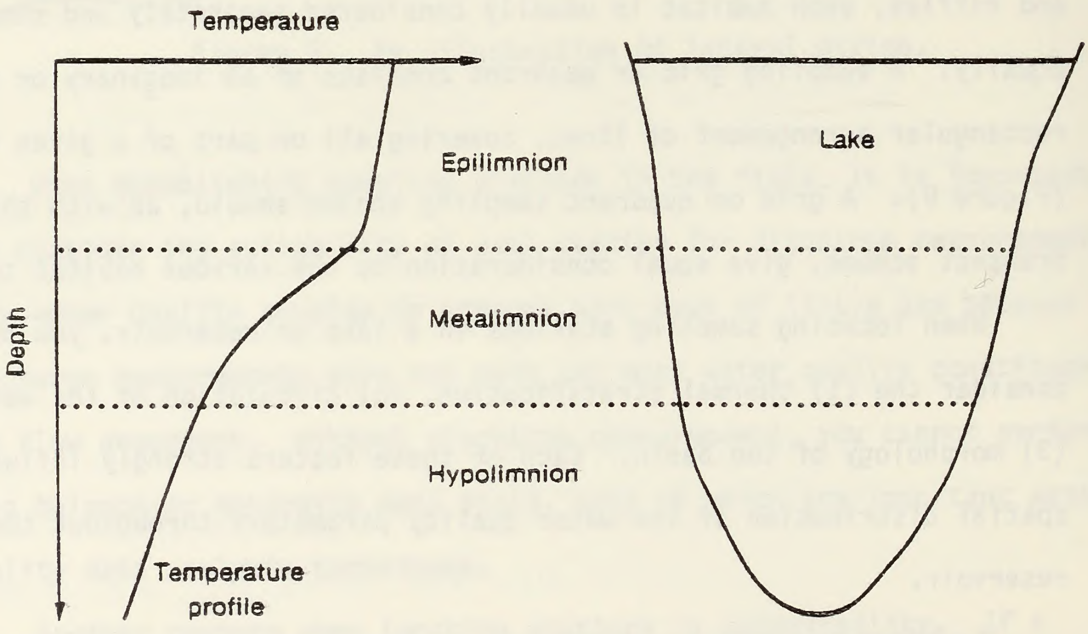


Figure 10. The three zones of a temperature profile in a stratified lake.

the hypolimnion, each defined by the rate of change in temperature with depth. In general, the epilimnion is a fairly wide zone consisting of warm water which has a moderate temperature gradient. The metalimnion is commonly a narrow zone characterized by a very rapid temperature change in depth. The hypolimnion spans from the base of the metalimnion to the bottom of the lake or reservoir and has a slight to moderate temperature gradient. Density differences of the water, which are related to the temperature, effectively isolate the hypolimnion from the zones above except for particle exchange due to gravity or movement of fish. If bacterial respiration is excessive in the hypolimnion, which is usually the case when the water body is in a eutrophic or enriched state, the dissolved oxygen can be depleted and anaerobic conditions may develop. If this condition occurs the dissolution of phosphorus, iron, manganese and other trace metals from the sediments can be expected.

The epilimnion and metalimnion are warmer than the hypolimnion and are the zones of phytoplankton production. As a result, the water quality in these zones may be substantially different than that of the hypolimnion.

The point to remember here is that the thermal zones in a lake or reservoir can have water quality quite different from one another. When a surface site is selected you must consider the thermal zones below it and make certain that the samples you obtain are representative of the system you think you are sampling. In many studies, you will find it necessary to establish several sampling stations along a depth profile (Figure 11). Temperature, dissolved oxygen, specific conductance, and pH are very useful measurements to make when deciding where to locate sampling stations along a depth profile.

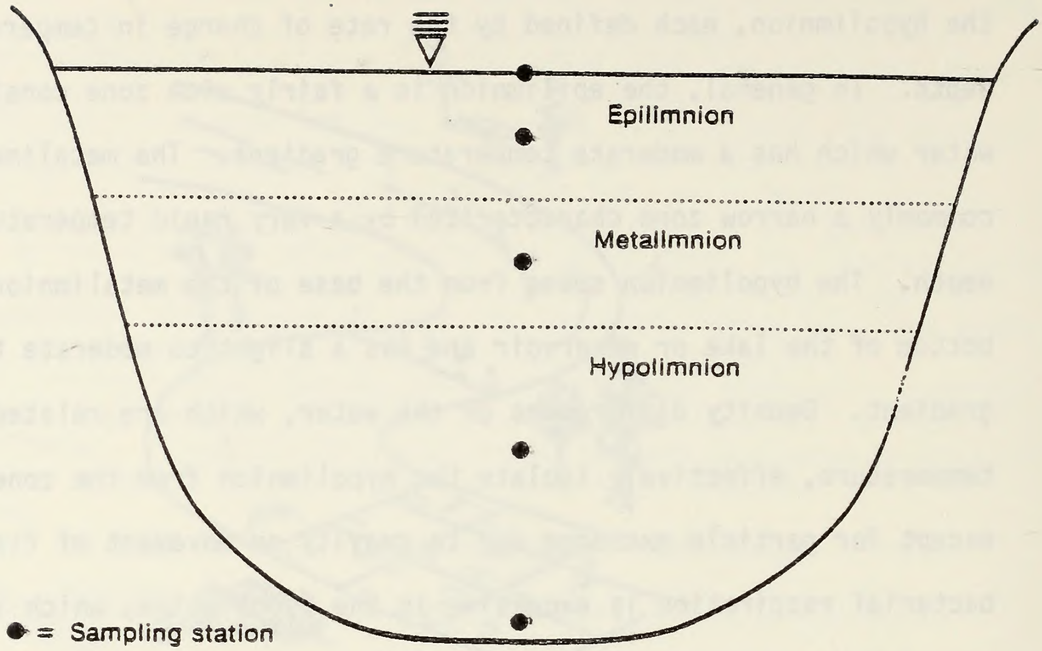


Figure 11. Illustration of sample locations along the depth profile in a stratified lake.

Circulation of the water is another factor that you need to consider when locating stations in lakes and reservoirs. During the spring and fall, the water mass overturns, due to a density change derived from the seasonal cooling or warming, and the water obtains a uniform temperature throughout the entire depth profile (Figure 12). At this time, the water quality is generally uniform throughout the depth of the lake and a single sample collected at 0.5 to 1.0 meters depth may be representative of the water column.

Wind will generally cause the water in the epilimnion to circulate and facilitates the mixing of water quality constituents throughout this zone (Figure 13). In the case of a circular lake where wind mixing has occurred, a sample collected at the lake's outlet would probably be as representative of the water quality of the epilimnion as a sample collected at the center of this zone.

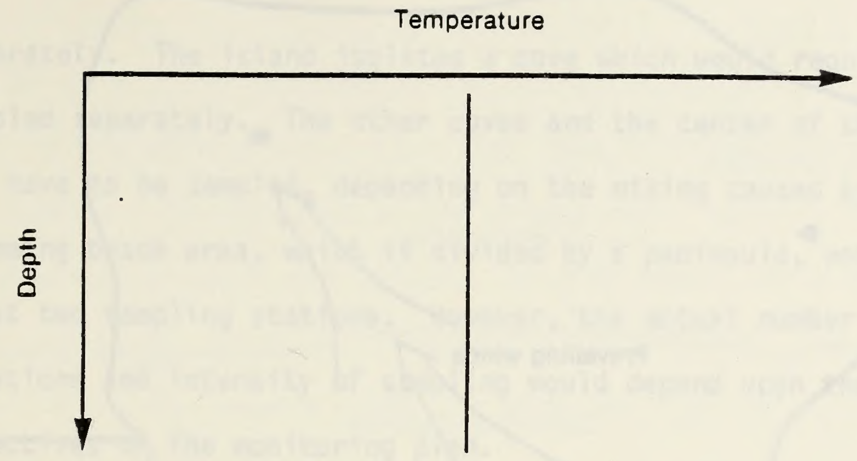


Figure 12. Temperature profile in a lake or reservoir during the period of overturn, either in the spring or fall.

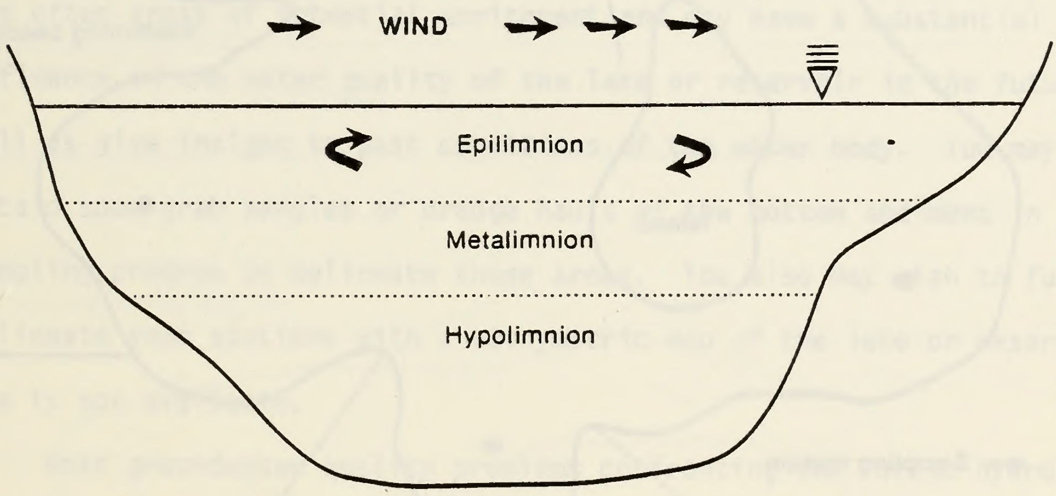


Figure 13. An illustration of the effect of wind on the mixing of water in the epilimnion.

If the morphology of a lake or reservoir is irregular, the mixing patterns of the epilimnion by the wind may vary substantially. As a result, several sampling stations may be required to characterize the water quality of the lake. For example, consider the lake illustrated in Figure 14. Here we have several land uses located around a lake which is irregularly shaped. The area around the recreational home development is shaped like an hour glass and should probably have each "bulb" sampled

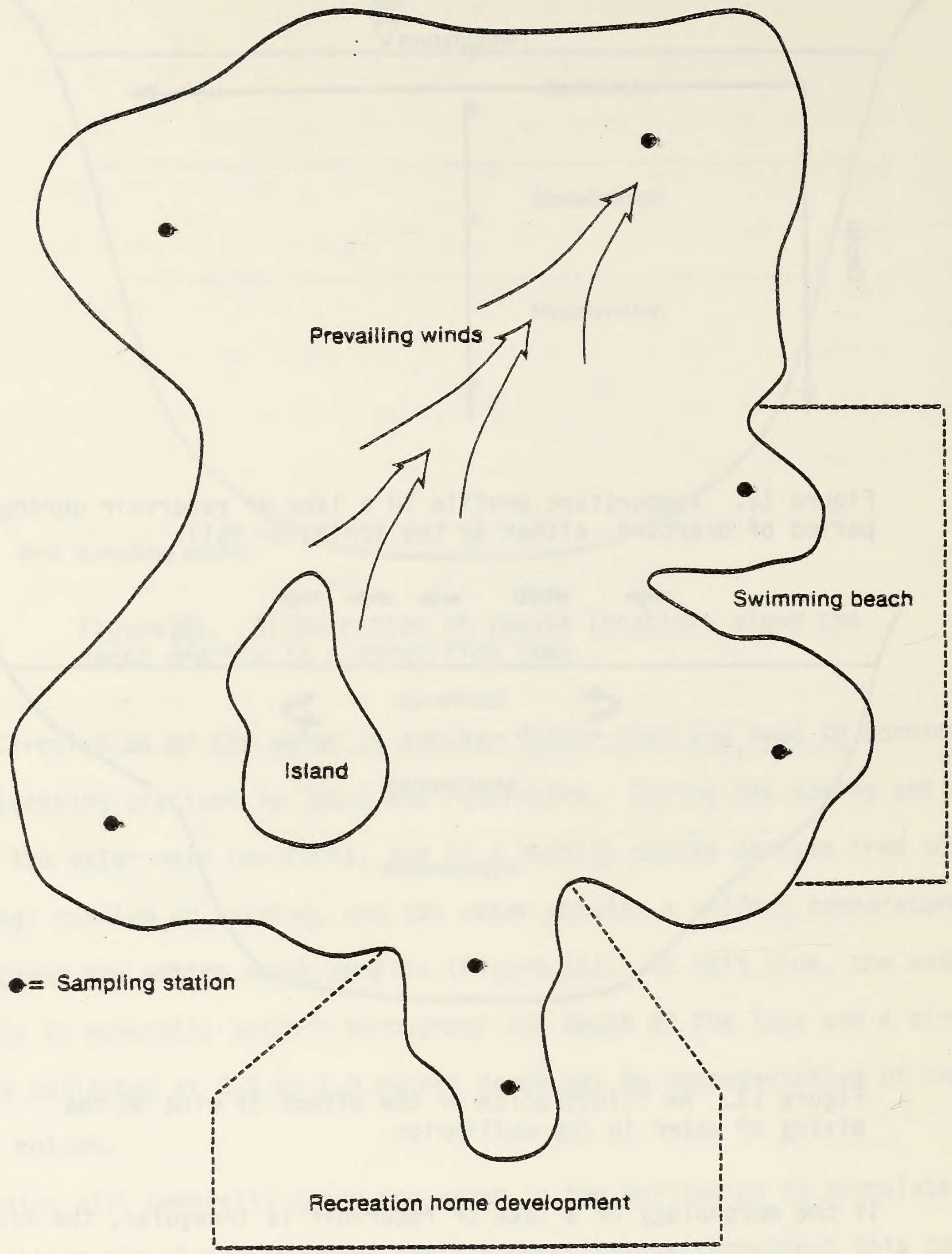


Figure 14. A hypothetical example of where to locate sampling stations to monitor surface water quality on a multiple use lake.

separately. The island isolates a cove which would require that it be sampled separately. The other coves and the center of the lake may or may not have to be sampled, depending on the mixing caused by the wind. The swimming beach area, which is divided by a peninsula, would require at least two sampling stations. However, the actual number of sampling locations and intensity of sampling would depend upon the original objectives of the monitoring plan.

When locating sampling stations in lakes and reservoirs, be careful not to overlook the areas of sediment deposition (Averett, 1976). These are often areas of potential enrichment and may have a substantial influence on the water quality of the lake or reservoir in the future as well as give insight to past conditions of the water body. You may need to obtain some grab samples or dredge hauls of the bottom sediment in your sampling program to delineate these areas. You also may wish to further delineate your stations with a bathymetric map of the lake or reservoir if one is not available.

Most groundwater quality problems confronting the forest hydrologist involve the contamination of unconfined or water table aquifers from point sources, such as solid waste disposals or leach fields below sewage treatment facilities. When locating your sampling stations for this type of problem, you need to consider the soils and geology of the area, flow direction of the ground water and accessibility. Consider the example illustrated in Figure 15 where we have a solid waste disposal site. Precipitation leaches through the disposal, picks up metals and other contaminants and transports them to the water table. The soil and geology of the area influence the rate at which leachate moves toward the water table. Depending on the nature of the contaminant, the soil and geology

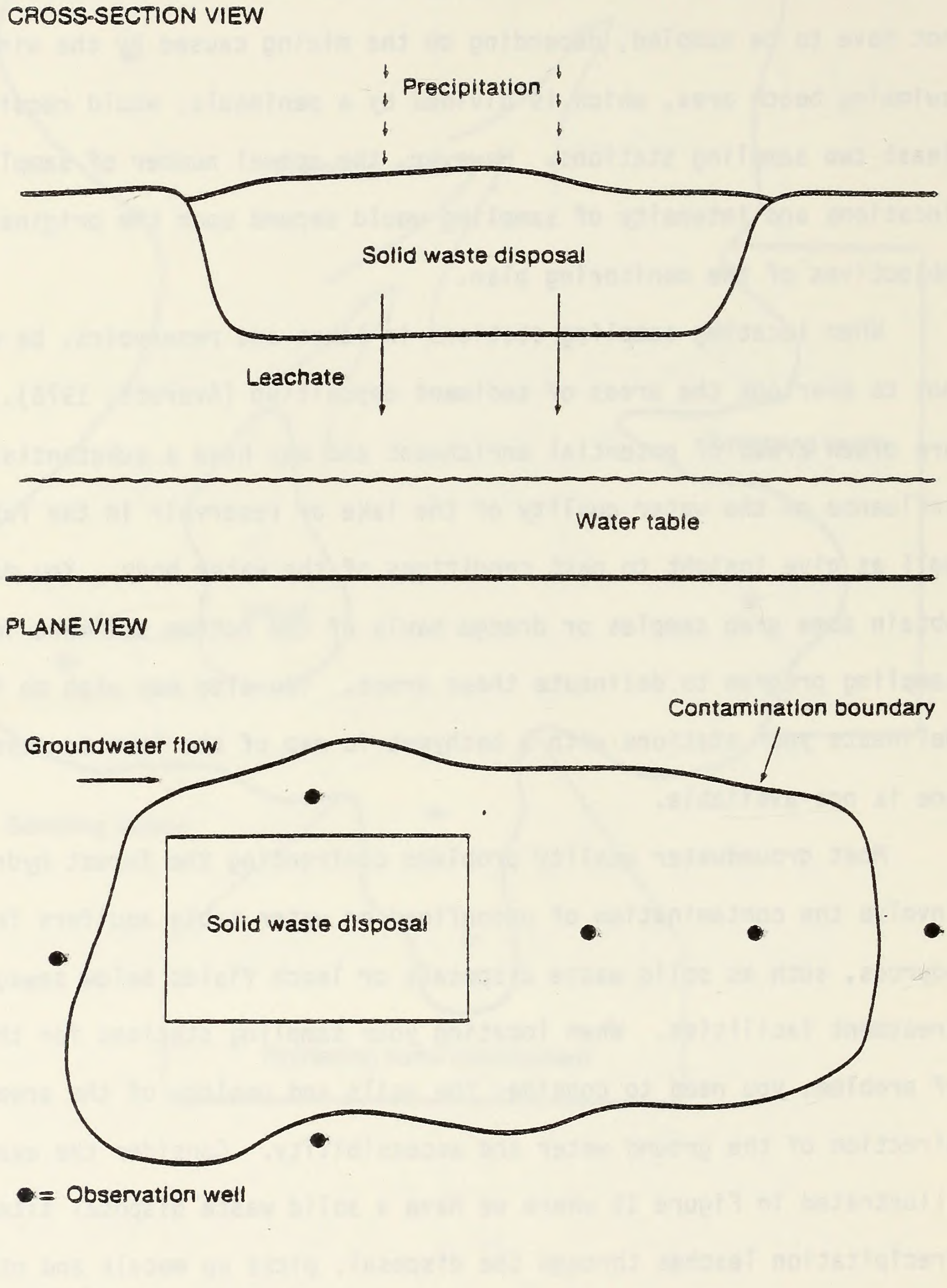


Figure 15. Location of sampling stations around a solid waste disposal site.

may act as a filter and reduce the concentration of the contaminant reaching the water table. If a clay lens is present, a perched water table may develop. The movement of the ground water strongly influences where the observation wells are placed. In many cases, wells are simply located above and below the source to quantify the effect of the treatment. In other cases, the concern might lie with the rate and extent of contamination which would require a more extensive monitoring program (Figure 15). Sometimes, we are not even sure which way the ground water flows and must position our observation wells in a radial pattern around the source (Figure 16).

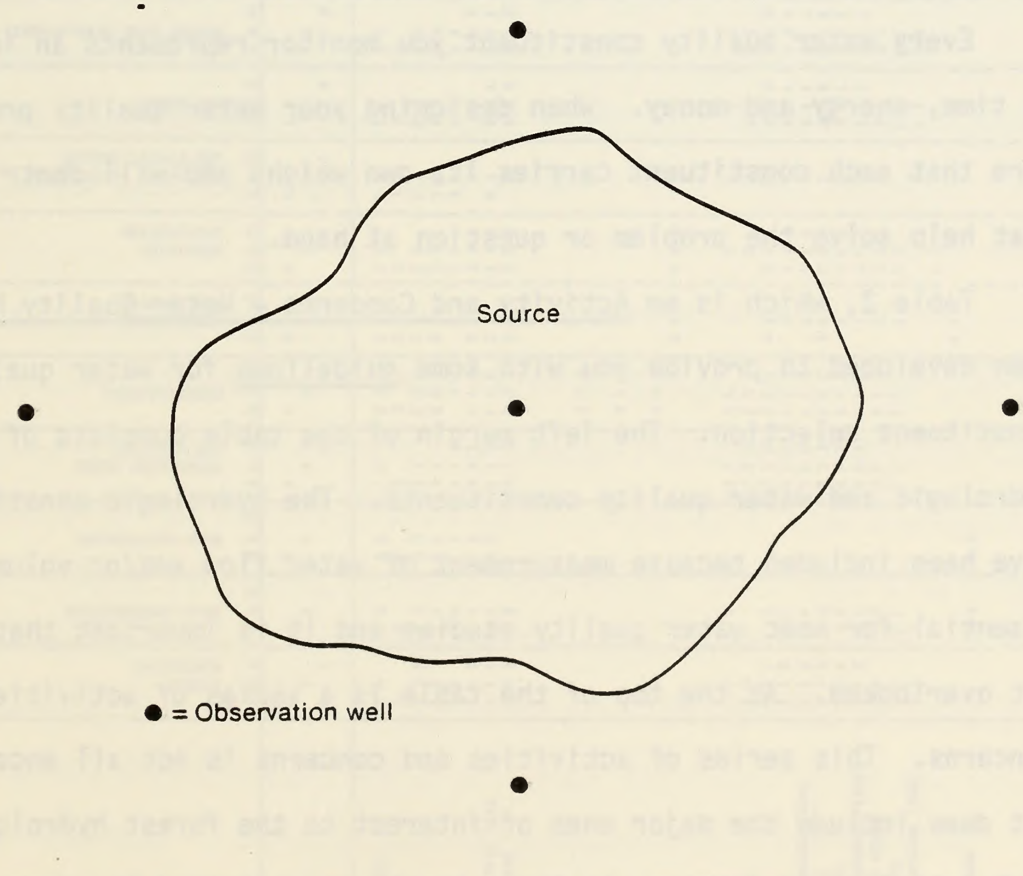


Figure 16. Radial design of observation wells around a point source.

If the groundwater problem involves a confined aquifer, it is important that you obtain knowledge of the aquifer in question. At a minimum this should include the areal extent of the aquifer, its width and its transmissibility. Walton (1970) and Freeze and Cherry (1979) present several excellent illustrative examples of groundwater monitoring.

In general, access is limited to existing wells and as a result, we can only obtain sketchy information about the system. The cost of drilling new wells is usually prohibitive. However, if the opportunity arises to establish a well for monitoring purposes, you should consult a geologist about placement.

6.2 Selecting Water Quality Constituents

Every water quality constituent you monitor represents an investment in time, energy and money. When designing your water quality program be sure that each constituent carries its own weight and will contribute data that help solve the problem or question at hand.

Table 2, which is an Activity and Concerns - Water Quality Matrix, has been developed to provide you with some guidelines for water quality constituent selection. The left margin of the table consists of pertinent hydrologic and water quality constituents. The hydrologic constituents have been included because measurement of water flow and/or volume is essential for most water quality studies and it is important that they are not overlooked. At the top of the table is a series of activities and concerns. This series of activities and concerns is not all encompassing, but does include the major ones of interest to the forest hydrologist. Each activity and concern, in turn, has been subdivided by water type: stream (S), lake or reservoir (L), and ground water (G). For each

Table 2. Activities and Concerns - Water Quality Matrix

ACTIVITIES AND CONCERNS

Constituent	TIMBER HARVESTING a/			ROAD CONSTRUCTION			ROAD MAINTENANCE			PRESCRIBED BURNS AND WILDFIRE			FERTILIZATION		
	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G
HYDROLOGIC CONSTITUENTS															
STREAMFLOW	c/ 1			1			1			1			1		
LAKE WATER LEVEL		1			1			1			1			1	
GROUND WATER LEVEL			3			-			-			3			2
WATER QUALITY CONSTITUENTS															
SUSPENDED SOLIDS (SS)	1	1		1	1		1	1		1	1		2	2	
BEDLOAD (BL)	1			2			2			2			2		
SEDIMENT CORE	3	3	d/	3	3		3	3		3	3		2	2	
TURBIDITY (TURB)	1	1		1	1		1	1		1	1		2	2	
TEMPERATURE (TEMP)	1	1		1	1			1		1	1			1	
HYDROGEN ION (pH)	1	1	2 e/	3	1			1		1	1	2	1	1	2
ELECTRICAL CONDUCTIVITY (EC)	1	1	1	1	1		3	3		1	1	1	1	1	1
TOTAL DISSOLVED SOLIDS	3	3	3	3	3					3	3	3	3	3	3
CALCIUM (Ca)															
MAGNESIUM (Mg)															
SODIUM (Na)															
POTASSIUM (k)													3	3	3
BICARBONATE (HCO_3)															
SULFATE (SO_4)													3	3	3
CARBONATE (CO_3)															
CHLORIDE (Cl)													3	3	3
BORON (B)															
IRON (Fe)															
SELECTED METALS															
ALKALINITY		1			2					2	1		1	1	
AMMONIA ($NH_3 + NH_4$)	3	2								3	2	3	2	2	2
NITRATE (NO_3)	2	2	1		2					2	2	2	2	2	1
TOTAL NITROGEN (TN)	1	1	2	3	1					1	1	1	1	1	2
TOTAL DISSOLVED NITROGEN (TDN)	1	1	2	3	1					1	1	1	1	1	2
ORTHOPHOSPHATE (PO_4)	2	2	3		2					2	2	3	2	2	2
TOTAL PHOSPHORUS (TP)	1	1	2	3	1					1	1	1	1	1	2
TOTAL DISSOLVED PHOSPHORUS (TDP)	1	1	2	3	1					1	1	1	1	1	2
TOTAL ORGANIC CARBON (TOC)	2	1			2					2	1		2	1	3
DISSOLVED OXYGEN (DO)	1	1		2	1					2	1		3	1	
BIOCHEMICAL OXYGEN DEMAND (BOD)	3	3		3											
HERBICIDES															
INSECTICIDES															
PETROLEUM HYDROCARBONS				3	1		3	3							
RADIONUCLIDES															
TOTAL COLIFORM (TC)															
FECAL COLIFORM (FC)															
FECAL STREPTOCOCCI (FS)															
MACROINVERTEBRATES	3	3		3	3					3	3				
ALGAE		2											2	2	

Constituent	INSECTICIDE APPLICATION			HERBICIDE APPLICATION			DEVELOPED CAMPGROUNDS AND PICNIC AREAS b/			SKI AREAS			SECOND HOME DEVELOPMENTS		
	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G
HYDROLOGIC CONSTITUENTS															
STREAMFLOW	1			1			1			1			1		
LAKE WATER LEVEL		1			1			1			1			1	
GROUND WATER LEVEL			1			1			2			3			3
WATER QUALITY CONSTITUENTS															
SUSPENDED SOLIDS (SS)	1	1		1	1		1	1		1	1		1	1	
BEDLOAD (BL)	2			2			3			2			2		
SEDIMENT CORE	1	1		1	1		2	2		2	2		2	2	
TURBIDITY (TURB)	3	3		3	3		1	1		1	1		1	1	
TEMPERATURE (TEMP)		1		1	1		3	1		1	1		2	1	
HYDROGEN ION (pH)	2	1	2	2	1	2		1			1		3	1	3
ELECTRICAL CONDUCTIVITY (EC)	2	1		2	1	2	2	2		1	1	1	1	1	1
TOTAL DISSOLVED SOLIDS	3	2		3	2	3		3		3	3	3	3	3	3
CALCIUM (Ca)															
MAGNESIUM (Mg)															
SODIUM (Na)															
POTASSIUM (k)															
BICARBONATE (HCO_3)															
SULFATE (SO_4)															
CARBONATE (CO_3)															
CHLORIDE (Cl)															
BORON (B)	2	2	2	2	2	2									
IRON (Fe)															
SELECTED METALS															
ALKALINITY		1			1			1			1			1	
AMMONIA ($NH_3 + NH_4$)					2			3		3	3		3	2	
NITRATE (NO_3)	3	2		2	2	2		2		2	2	2	2	2	2
TOTAL NITROGEN (TN)		1		1	1	2		1		2	1	1	1	1	1
TOTAL DISSOLVED NITROGEN (TDN)		1		1	1	2		1		2	1	1	1	1	1
ORTHOPHOSPHATE (PO_4)	3	2		2	2			2		2	2	2	2	2	2
TOTAL PHOSPHORUS (TP)		1		1	1	2		1		2	1	1	1	1	1
TOTAL DISSOLVED PHOSPHORUS (TDP)		1		1	1	2		1		2	1	1	1	1	1
TOTAL ORGANIC CARBON (TOC)		2		2	1			2		3	1		3	1	
DISSOLVED OXYGEN (DO)		1		1	1					2	1		2	1	
BIOCHEMICAL OXYGEN DEMAND (BOD)										2	3		3	3	
HERBICIDES				1	1	1									
INSECTICIDES	1	1	1												
PETROLEUM HYDROCARBONS															
RADIONUCLIDES															
TOTAL COLIFORM (TC)							2	2		2	2		2	2	
FECAL COLIFORM (FC)							1	1		1	1		1	1	
FECAL STREPTOCOCCI (FS)							1	1		1	1		1	1	
MACROINVERTEBRATES	3	3		3	3					3	3				
ALGAE				2	2						3				

Constituent	SEWAGE DISPOSAL			REFUSE DISPOSAL			COAL AND METAL MINING			URANIUM MINING			GRAZING		
	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G
HYDROLOGIC CONSTITUENTS															
STREAMFLOW	1			-			1			1			1		
LAKE WATER LEVEL		1			-			1			1			1	
GROUND WATER LEVEL			1			1			2			1			3
WATER QUALITY CONSTITUENTS															
SUSPENDED SOLIDS (SS)	2	2					1	1		1	1		1	1	
BEDLOAD (BL)							2			2			3		
SEDIMENT CORE							2	2		2	2		3	3	
TURBIDITY (TURB)	1	1					1	1		1	1		1	1	
TEMPERATURE (TEMP)	1	1				1	1	1	1	1	1	1	3	1	1
HYDROGEN ION (pH)	1	1	1			1	1	1	1	1	1	1		1	
ELECTRICAL CONDUCTIVITY (EC)	1	1	1			1	1	1	1	1	1	1	1	1	1
TOTAL DISSOLVED SOLIDS	3	3	2			2	2	2	2	2	2	2	3	3	3
CALCIUM (Ca)							3	3	3	3	3	3			
MAGNESIUM (Mg)							3	3	3	3	3	3			
SODIUM (Na)	3	3	3				3	3	3	3	3	3			
POTASSIUM (k)							3	3	3	3	3	3			
BICARBONATE (HCO_3)							3	3	3	3	3	3			
SULFATE (SO_4)							3	3	3	3	3	3			
CARBONATE (CO_3)							3	3	3	3	3	3			
CHLORIDE (Cl)	2	2	2				3	3	3	3	3	3			
BORON (B)	2	2	2												
IRON (Fe)							2	2	2						
SELECTED METALS	3	3	3			2	2	2	2	2	2	2			
ALKALINITY		1					1	1		1	1				
AMMONIA ($NH_3 + NH_4$)	2	2	1										2	2	
NITRATE (NO_3)	2	2	1			3							2	2	2
TOTAL NITROGEN (TN)	1	1	2			2							1	1	1
TOTAL DISSOLVED NITROGEN (TDN)	1	1				2							1	1	1
ORTHOPHOSPHATE (PO_4)	2	2	1			3							2	2	2
TOTAL PHOSPHORUS (TP)	1	1	1			2							1	1	1
TOTAL DISSOLVED PHOSPHORUS (TDP)	1	1				2							1	1	1
TOTAL ORGANIC CARBON (TOC)	2	1	3			3							2	1	2
DISSOLVED OXYGEN (DO)	1	1					2	1		2	1		1	1	
BIOCHEMICAL OXYGEN DEMAND (BOD)	1	1											3	3	
HERBICIDES															
INSECTICIDES															
PETROLEUM HYDROCARBONS															
RADIONUCLIDES										1	1	1			
TOTAL COLIFORM (TC)	1	1	1												
FECAL COLIFORM (FC)	1	1	1										1	1	1
FECAL STREPTOCOCCI (FS)	1	1	1										1	1	1
MACROINVERTEBRATES	3	3					3	3		3	3		3	3	
ALGAE		2												2	

Constituent	IMPOUNDMENT CONSTRUCTION			SWIMMING AREAS			ACID PRECIPITATION			RECONNAISSANCE SURVEYS			DRINKING WATER SUPPLIES		
	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G
HYDROLOGIC CONSTITUENTS															
STREAMFLOW	1			1			1			1			1		
LAKE WATER LEVEL		-			1			1			1			1	
GROUND WATER LEVEL			2			-			1			1			1
WATER QUALITY CONSTITUENTS															
SUSPENDED SOLIDS (SS)	1									1	1				
BEDLOAD (BL)	2									3					
SEDIMENT CORE	2									3	3				
TURBIDITY (TURB)	1									1	1		1	1	1
TEMPERATURE (TEMP)	1						1	1		1	1	1		1	
HYDROGEN ION (pH)							1	1		1	1	1	2	1	2
ELECTRICAL CONDUCTIVITY (EC)	3		3				1	1		1	1	1	1	1	1
TOTAL DISSOLVED SOLIDS							2	2		2	2	2	3	3	3
CALCIUM (Ca)							3	3		3	3	3			
MAGNESIUM (Mg)							3	3		3	3	3			
SODIUM (Na)							3	3		3	3	3			
POTASSIUM (k)							1	1		3	3	3			
BICARBONATE (HCO_3)							1	1		3	3	3			
SULFATE (SO_4)							3	3		3	3	3			
CARBONATE (CO_3)							3	3		3	3	3			
CHLORIDE (Cl)							3	3		3	3	3			
BORON (B)															
IRON (Fe)															
SELECTED METALS										3	3	3			
ALKALINITY							1	1		1	1	1			
AMMONIA ($NH_3 + NH_4$)							3	3		3	3	3			
NITRATE (NO_3)							3	3		2	2	2	1	1	1
TOTAL NITROGEN (TN)							2	2		1	1	2			
TOTAL DISSOLVED NITROGEN (TDN)							1	2		1	1	2			
ORTHOPHOSPHATE (PO_4)										2	2	2			
TOTAL PHOSPHORUS (TP)										1	1	2			
TOTAL DISSOLVED PHOSPHORUS (TDP)										1	1	2			
TOTAL ORGANIC CARBON (TOC)										2	1	2			
DISSOLVED OXYGEN (DO)							3	1		1	1	3			
BIOCHEMICAL OXYGEN DEMAND (BOD)										3	3				
HERBICIDES															
INSECTICIDES															
PETROLEUM HYDROCARBONS															
RADIONUCLIDES															
TOTAL COLIFORM (TC)				1	1					2	2	2	1	1	1
FECAL COLIFORM (FC)				1	1					1	1	1	1	1	1
FECAL STREPTOCOCCI (FS)				1	1					1	1	1	1	1	1
MACROINVERTEBRATES							3	3		3	3				
ALGAE										3	3				

Notes: a/ "S" denotes streams, "L" denotes lakes and reservoirs, and "G" denotes groundwater.
b/ Does not include sewage treatment.
c/ Primary sampling code.
d/ Tertiary sampling code.
e/ Secondary sampling code.

combination of activity or concern, water quality type, and constituent, there is one of four priority codes: 1, 2, 3 or blank. A primary code, 1, suggests that it is very important that the constituent be monitored. Sampling these constituents will provide information which is necessary to meet study objectives. A secondary code, 2, suggests that it is important that a constituent be monitored, however, if funds are restricted, these constituents should be considered a lower priority than those coded by a 1. These constituents usually supply supporting information which address the study objectives. A tertiary code, 3, means that this constituent probably will contribute little direct information to the study objectives, but may be useful for other purposes. A blank suggests there is no need to monitor the constituent.

Please keep in mind that these priority codes are presented only as guidelines. The specific needs and objectives of your study objectives of your study may require more emphasis be placed on certain constituents and less on others.

For individuals interested in a review of the various water quality constituents, their significance to beneficial uses and land use-water quality interactions, the following literature is suggested: Brown (1972), U.S. EPA (1977, 1976a, 1976b, 1973 and 1971), U.S. Forest Service (in press), Greeson, et al (1977), Guy (1970), Hem (1970), Krygier and Hall (1971), McKee and Wolf (1963), McNeely, Neimans and Dwyer (1979), and Thatcher, Janzer and Edwards (1977).

6.3 Guidelines for Determining Sampling Frequency

The frequency of sample collection should be designed to provide the data necessary to (1) calculate an estimate of a specific population parameter, such as the mean, and/or (2) develop a regression relationship. In either case, we want our parameter and regression estimators to fall within some pre-established bound of reliability. As a result, sampling frequency should be directly related to the variance of the water quality constituent of concern. In other words, the more variable a constituent is in time and space, the more frequently it must be sampled to achieve a given level of reliability.

In this subsection, guidelines for determining sampling frequency for several different sampling methods are presented. It should be noted that emphasis has been placed on application of the methods opposed to the intricacies of the underlying statistical theory. For a more detailed discussion of each method, including the underlying theory, two references are suggested: Mendenhall, Ott, and Schaeffer (1971) and Cochran (1963). Much of what follows in this subsection has been taken from Freese (1962), with minor modifications.

6.3.1 <u>Systematic Sampling</u>

Systematic sampling is easily carried out and under some circumstances is a useful method. It consists of randomly selecting the first time of sampling and then selecting the remaining samples at some pre-determined interval, such as weekly, biweekly or monthly. While this simple method can be easily used in most water quality studies, it has serious limitations in that the data <u>may</u> be biased. If the data are biased, the statistical analysis may lead to erroneous inferences about the water body being examined.

6.3.2 Simple Random Sampling

The fundamental principle in simple random sampling is that, in choosing a sample of "n" observations, every possible combination of "n" observations should have an equal chance of being selected. For example, if you plan on collecting 25 daily samples over a period of one year, you must choose the 25 days of sample collection in a random manner.

The question of interest here is, How do we determine "n"? More often than not, "n" has been arbitrarily selected by a sampler basing the decision of what "looks right." Fortunately, a simple, objective procedure exists for determining "n" when using the simple random sampling method. The procedure is based on the level of risk the sampler is willing to take when estimating the mean. The level of risk, in turn, is directly related to the beneficial use of water. Obviously, if you are dealing with a drinking water supply you would be more concerned with the accuracy of your estimate than if you were dealing with a stock watering tank.

In planning a water quality survey, we might state that unless the 1-in-20 chance ($\alpha = 0.05$) occurs, we would like our sample estimate of the mean to be within some specified error range of the population mean such as $\pm$ E mg/l. Since the small sample confidence limits are computed as

$$\bar{X} = \pm t_{\alpha} s_{\bar{x}} \qquad (1)$$

where $\bar{X}$ is the mean, t denotes the Student's t value for a specified α and $s_{\bar{X}}$ is the standard error of the mean, this is equivalent to stating that we want

$$E = t_{\alpha} s_{\bar{x}} \qquad (2)$$

For a simple random sample the standard error of the mean can be determined by

$$s_{\bar{x}} = \sqrt{\frac{s^2}{n}\left(1 - \frac{n}{N}\right)} \qquad (3)$$

where s^2 is the sample variance, "n" the number of units sampled and N is the total number of units in the population. Substituting equation (3) into equation (2) and solving for "n" yields equation (4).

$$n = \frac{1}{\frac{E^2}{t^2 s_{\bar{x}}^2} + \frac{1}{N}} \tag{4}$$

To determine "n", we must have some estimate of the population variance, s^2. Sometimes the information is available from previous surveys. In the absence of this information, a small preliminary survey might be made in order to obtain an estimate of the variance. When, as often happens, neither of these solutions is feasible, a very crude estimate can be made using equation (5) where R is the estimated range from the smallest to the

$$s^2 = \left(\frac{R}{4}\right)^2 \tag{5}$$

largest concentration (mass) likely to be encountered in sampling. This approximation procedure should be used only when no other estimate of the variance is available and the observations are approximately normally distributed.

Having specified a value of E and obtained an estimate of the variance, the last piece of information required is the value of t. Here we hit a circular problem. To use t we must know the number of degrees of freedom. However, the number of degrees of freedom is "n-1" and "n" is not known and cannot be determined without knowing t.

An iterative approach can be used to solve this problem. The procedure is to guess at a value of "n," use the guessed value to get the degrees of freedom for t and then substitute the appropriate t value into the sample-size formula (equation 4) and solve for a first approximation of n. Selecting a new "n" somewhere between the guessed value and the first approximation, but closer to the latter, we compute a second approximation. The procedure is repeated until successive values of "n" are nearly the same; usually three trials will suffice.

If the sampling fraction is likely to be small ($\frac{n}{N} < 0.05$) the term $1-\frac{n}{N}$ of the standard error formula (3) can be ignored and the sample size formula (4) simplifies to

$$n = \frac{t_\alpha^2 s^2}{E^2} \qquad (6)$$

Examples 2a and 2b illustrate the estimation of sample size for the simple random sampling method.

Example 2a

Estimating Sample Size for the Simple Random Sampling Method

Problem:

Blue Spruce Reservoir, which is underlain by gypsum bearing rock formations, drains into Camp Creek. There is some concern by downstream users that the sulfate concentrations are excessively high. The Forest Supervisor would like an estimate, within 15 mg/l, of the mean annual SO_4 concentration passing the stream gage immediately below the outlet spillway with a fairly high degree of reliability ($\alpha = 0.05$). There is little fluctuation in the discharge from the dam, therefore, simple random sampling can be applied. Assume the SO_4 concentration varies between 20 and 100 mg/l during the year. Estimate the necessary sample size, n.

Solution:

If the sample size is less than 18, then we may use the simplified formula since 18/365 = 0.049 < 0.05.

$$n = \frac{t_\alpha^2 s^2}{E^2}$$

We know from the problem that E = 15 mg/l, $\alpha = 0.05$ and R = 80 mg/l. The variance can be estimated as follows.

$$s^2 = \left(\frac{R}{4}\right)^2 = \left(\frac{80}{4}\right)^2 = 400$$

To determine t we can use as a first approximation n = 18 which yields 17 d.f. and $t_{.05(17)} = 2.110$ (See Appendix Table A, Values of t). The first estimate on n can now be calculated.

$$n = \frac{t_\alpha^2 s^2}{E^2}$$

$$n = \frac{(2.110)^2 (400)}{15^2}$$

$$n = 7.91$$

The correct solution is somewhere between 7.91 and 18, but much closer to 7.91. For our second trial we select n = 8. The value of t now becomes 2.365.

$$n = \frac{(2.365)^2\, 400}{(15)^2}$$

$$n = 9.94$$

We now know the correct solution lies between 8 and 9.94. Repeated trials will give values between 9.1 and 9.94. Since the sample size, n, must be an integral value and, because 9 is too small, a sample of n = 10 observations would be required for the desired precision.

Example 2b

Estimating Sample Size for Simple Random Sampling

Problem:

A preliminary sample (10 observations) of electrical conductivity in the epilimnion of Elk Lake yielded the following statistics.

$$\bar{X} = 187 \qquad s = 35$$

What sample size would be required to estimate the mean EC in the epilimnion of Elk Lake within plus or minus 10 percent, with a 1-in-20 chance of being wrong in the conclusion that you have done so. Assume simple random sampling is to be employed and $\frac{n}{N}$ is less than 0.05.

Solution:

The confidence limits on the mean are given by

$$\bar{X} \pm t_{\alpha} \frac{s}{\sqrt{n}}$$

Therefore:

$$187 \pm t_{05} \frac{35}{\sqrt{n}}$$

The 95 percent confidence limits of plus or minus 10 percent of the mean gives

$$18.7 = t_{05} \frac{35}{\sqrt{n}}$$

Solving for "n" yields

$$n = \frac{t_{05}^2 (35)^2}{(18.7)^2}$$

For our first trial we select n = 25 which gives us 24 d.f.; therefore $t_{.05(24)} = 2.064$.

$$n = \frac{(2.064)^2 (35)^2}{(18.7)^2}$$

$$n = 14.9$$

We know the correct solution lies between 14.9 and 25, but closer to 14.9. For our second trial n is set at 16.

$$n = \frac{(2.131)^2 (35)^2}{(18.7)^2}$$

$$n = 15.9$$

From repeated trials we find little difference in the calculated n, therefore we select 16 as the sample size.

In some cases you may want to determine your sample size based on a pre-established estimate of the magnitude of change (difference) in the concentration or mass of a water quality constituent between paired stations. As with other procedures used to estimate sample size when simple random sampling is employed, this method is also based on a good estimate of the sample variance. The method outlined below is discussed in detail by Snedecor and Cochran (1967) and has been summarized by Potyondy (1977).

The procedure requires you to select a value, d, which represents the size of difference between the paired stations that is regarded as important. If the difference is as large as d, we would like the monitoring program to have a high probability (probabilities of 0.80 and 0.90 are common) of showing a statistically significant difference between the paired stations. In statistical jargon, the calculation allows the selection of the confidence level of the test ($1 - \alpha$) as well as the power of the test ($1 - \beta$) and combines these two elements in determination of the sample size.

The following example taken from Potyondy (1977) is used to illustrate the mechanics of this procedure. Consider the following sample statistics from a set of turbidity data collected on the East Fork Smiths Fork Barometer Watershed in Utah and Wyoming: $\bar{X}$ = 4.5 JTU; s = 2.83. (It should be noted that an underlying assumption of this procedure is that the data are normally distributed.) The standard deviation, s, can be expressed as a percent of the mean, referred to as the coefficient of variation, CV. Therefore:

$$CV = (s/\bar{X})100 = (2.83/4.5)100 = 63\% \qquad (7)$$

The standard deviation of the difference, s_d, is estimated as:

$$s_d = 2\sqrt{CV} = 2\sqrt{(63)} = 89\% \quad (8)$$

Suppose we wish to detect a difference of 5 JTU's between the paired stations of interest. Expressed as a percent of the mean, the difference to be detected, d, is determined as follows:

$$d = (5.0/4.5)100 = 111\% \quad (9)$$

Assume that we want to be 90 percent certain of showing a statistically significant difference between means in a two-tailed t-test at the $\alpha = 0.05$ level of significance.

The following formulas apply:

$$n_i = (s_d^2/d^2)\, M_{(1-\beta,\alpha)} \quad (10)$$

where $M_{(0.90,0.05)}$ is a multiplier from Table 3 which is equal to 10.5. Substituting and solving for n_i yields:

$$n_i = (89^2/111^2)(10.5) = 6.75$$

which is rounded up to the next highest integer

$$n_i = 7$$

Degrees of freedom, ν, are determined as follows:

$$\nu = 2n_i - 2 = (2)(7) - 2 = 12 \quad (11)$$

The required sample size, n, can now be determined.

$$\text{Sample size} = n = (\nu + 3)\, n_i/(\nu + 1) = (15)(7)/(13) = 8.08 \quad (12)$$

The sample size to use is rounded to 8.

Table 3. Multiplier (M) of (s_d^2/d^2) to be used in paired comparitive sample size calculations (after Potyondy, 1977).

(1 - β)	Two-tailed Tests α level 0.01	0.05	0.10	One-tailed Tests α level 0.01	0.05	0.10
0.80	11.7	7.9	6.2	10.0	6.2	4.5
0.90	14.9	10.5	8.6	13.0	8.6	6.6
.95	17.8	13.0	10.8	15.8	10.8	8.6

Although simple random sampling has its place in water quality monitoring, it is limited because the watershed system under investigation is too variable with regard to its component parts. Fortunately the component parts of most watershed systems vary within a definite and repeated pattern and their variability can be reduced and better understood using stratified random sampling methods (Averett, 1976).

6.3.3 Stratified Random Sampling

Stratified random sampling is a commonly used sampling method in water quality studies. This method allows the hydrologist to take advantage of prior knowledge concerning the mechanisms and processes controlling the water quality in a watershed system. In stratified random sampling, the units of the population are grouped together on the basis of similarity of some characteristic, such as flow regime (that is baseflow, stormflow, snowmelt runoff, etc.) or temperature in a lake, such as the epilimnion and the hypolimnion. Each group or stratum is then sampled and the stratum estimates are combined to give a population estimate.

Stratified random sampling offers two primary advantages over simple random sampling. First, it provides separate estimates of the mean and variance of each stratum. Second, for a given sampling intensity, it generally gives more precise estimates of the population parameters than would a simple random sample of the same size. For this latter advantage, however, it is necessary that the strata be established so that the variability among sample values within the strata is less than the variability in the population as a whole.

Some drawbacks of stratified random sampling are that: (1) each unit in the population must be assigned to one and only one stratum; (2) the size of each stratum must be known; and (3) a simple random sample must be taken in each stratum. The most common barrier to the use of stratified random sampling is lack of knowledge of the strata sizes.

To illustrate the computational procedures required to determine the mean and its confidence limits from a stratified random sample consider the electrical conductivity data tabulated in Table 4. The flow regime was divided into three periods (strata): (1) winter baseflow (November 1/April 15); (2) snowmelt runoff (April 16/July 15); and (3) summer runoff (July 16/October 30). Grab samples were collected ten times during winter baseflow, 25 times during snowmelt runoff and 15 times during summer runoff. Only one sample was collected per day and each sample day was selected at random.

Table 4. Electrical conductivity data (μmhos/cm) collected from a Rocky Mountain stream.

Stratum	Observations				
I. Winter Baseflow	110	112			
	100	119			
Total = 1087	105	113			
$\bar{X}$ = 108.7	115	106			
s = 6.25	107	100			
II. Snowmelt Runoff	89	73	51	41	57
	72	54	43	47	69
Total = 1505	43	50	49	51	77
$\bar{X}$ = 60.2	51	62	68	63	81
s = 14.6	68	74	39	48	85
III. Summer Runoff	156	172	191		
	145	164	210		
Total = 2476	129	178	139		
$\bar{X}$ = 165.1	187	154	145		
s = 21.78	159	167	180		

The mean EC of the stratified sample is computed by the general equation

$$\bar{X}_{TS} = \frac{\sum_{h=1}^{L} N_h \bar{X}_h}{N} \qquad (13)$$

Where $\bar{X}_{TS}$ is the mean of the stratified sample, L the number of strata, N_h is the total size (number of possible observations) of stratum h, and N is the total number of observations in all strata. Using the data presented in Table 2, the mean can be calculated as follows:

$L = 3$

$N_I = 166$ $\qquad \bar{X}_I = 108.7$

$N_{II} = 91$ $\qquad \bar{X}_{II} = 60.2$

$N_{III} = 108$ $\qquad \bar{X}_{III} = 165.1$

$N = 365$

$$\overline{EC}_{TS} = \frac{166(108.7) + 91(60.2) + 108(165.1)}{365}$$

$$\overline{EC}_{TS} = 113 \ \mu\text{mhos/cm}$$

The mean $\overline{EC}$ computed here is basically a time weighted average which is the average daily EC of the water passing the point of measurement.

The standard error of the mean of a stratified random sample is calculated by the general equation

$$s_{\bar{X}T} = \sqrt{\frac{1}{N^2} \sum_{h=1}^{L} \left[\frac{N_h^2 s_h^2}{n_h} \left(1 - \frac{n_h}{N_h}\right)\right]} \qquad (14)$$

where n_h is the number of observations in stratum h, s^2_h is the variance of sample from stratum h and the other terms are as previously defined. If the sampling fraction within a particular stratum (n_h/N_h) is small (that is less than 0.05), the term ($1-n_h/N_h$) can be omitted for that particular stratum when calculating the standard error of the mean. For the electrical conductivity example the standard error can be calculated as follows:

$$s_{\bar{x}_T} = \sqrt{\frac{1}{(365)^2}\left[\frac{(166)^2\,(6.25)^2}{10}\left(1-\frac{10}{166}\right)+\frac{(91)^2\,(14.6)^2}{25}\left(1-\frac{25}{91}\right)+\frac{(108)^2\,(21.78)^2}{15}\left(1-\frac{15}{108}\right)\right]}$$

$$s_{\bar{x}_T} = 1.88$$

A rough estimate of the 95% confidence interval about the mean can be obtained using equation (15).

$$\bar{X}_{ST} \pm 2(s_{\bar{x}_T}). \qquad (15)$$

For our electrical conductivity example, the confidence interval would range from 109 to 117 μmhos/cm.

Before an estimate of the total sample size can be made, the hydrologist must select the method of sample allocation. Basically, there are two methods of sample allocation: proportional and optimal. In the proportional allocation procedure, the proportion of the sample that is selected in the h^{th} stratum is made equal to the proportion of all units in the population which fall in that stratum. If a stratum contains half of the units in the population, half of the samples would be collected in that stratum. In equation form, if the total number of sample units is to be "n," then for proportional allocation the number to be observed in stratum "h" is

$$n_h = \left(\frac{N_h}{N}\right) n \qquad (16)$$

In optimum allocation the observations are allocated to the strata so as to give the smallest standard error possible with a total of "n" observations. For a sample size "n," the optimum allocation is

$$n_h = \left(\frac{N_h s_h}{\sum_{h=1}^{L} N_h s_h} \right) n \tag{17}$$

The best way to allocate a sample among the various strata depends on the study objectives and our information about the population. The optimum allocation is preferable if the objective is to get the most precise estimate of the population mean for a given cost. If we want separate estimates for each stratum and the overall estimate is of secondary importance, we may want to sample heavily in the strata having high-value information. Then we would ignore both optimum and proportional allocation and place our observations so as to give the degree of precision desired for the particular strata.

The procedure for estimating the total size of sample (n) needed in stratified random sample can now be addressed. Basically three pieces of information are required:

(1) a reasonably good estimate of the variance (s_h^2) or standard deviation (s_h) among individuals within each stratum.

(2) the method of sample allocation.

(3) a statement of the desired size of the standard error of mean, symbolized by D.

Some preliminary sampling is generally required to determine the desired size of the standard error of the mean. The estimate of D in the sample size equations is generally taken to be some portion, such as two-thirds or one-half, of the standard error calculated from the preliminary sample.

Given this hard-to-obtain information, the stratified random sample size can be estimated by the following equations.

For proportional allocation:

$$n = \frac{t_o^2 N \sum_{h=1}^{L} N_h s_h^2}{N^2 D^2 + t_o^2 \sum_{h=1}^{L} N_h s_h^2} \qquad (18)$$

For optimum allocation:

$$n = \frac{t_o^2 \left(\sum_{h=1}^{L} N_h s_h \right)^2}{N^2 D^2 + t_o^2 \sum_{h=1}^{L} N_h s_h^2} \qquad (19)$$

The value "2" is commonly used as an estimate of the Student's t value. When sampling fractions (n_h/N_h) are likely to be very small for all strata, the second term of the denominators of the above equations may be omitted leaving only N^2D^2.

If the optimum allocation formula indicates a sample (n_h) greater than the total number of units (N_h) in a particular stratum, n_h is usually made equal to N_h. The previously estimated sample size (n) should then be dropped, and the total sample size and allocation for the remaining strata recomputed omitting the N_h and s_h values for the offending stratum, but leaving N and D unchanged.

Example 3 illustrates how to estimate the sample size for a stratified random sample.

Example 3

Estimating Sample Size for a Stratified Random Sample

Problem:

The mean daily electrical conductivity is to be determined at the mouth of Cabin Creek which is located in the northern Colorado Rockies. Estimate the sample size that would be required and distribute the samples over a one year period.

Solution:

The flow regime can be divided into three periods (strata): winter baseflow (November 1/April 15); snowmelt runoff (April 16/July 15); and summer runoff (July 1/ October 30). Data collected on a nearby stream provided information about the variance.

Stratum (h)	N_h	s_h
1 (WB)	166	8
2 (SM)	91	24
3 (SRO)	108	41

An estimate of the standard error of the mean, $s_{\bar{X}}$, was made from past data.

$$s_{\bar{X}} = 5.05$$

The desired D is set equal to one-half of $s_{\bar{X}}$. Therefore, D = 2.53. In addition, the optimal allocation method is selected to allocate the samples.

The sample size, n, can now be determined using the optimal allocation method.

$$n = \frac{\left[(2)^2\left(\sum_{h=1}^{L} N_h s_h\right)\right]^2 \Big/ N^2 D^2}{1 + \left[(2)^2 \sum_{h=1}^{L} N_h s_h^2\right] \Big/ N^2 D^2} = \frac{296}{2.15} = 138$$

The determined n is the sample size necessary to estimate the sample mean with a standard error of 2.53. However, because of budgetary constraints, it may not be possible to sample the stream 138 times. If that is the case, then we would have to lower the reliability constraint on the estimate of the mean. If we set $D = s_{\bar{X}}$ the required sample size becomes

$$n \approx 58.$$

In this hypothetical problem assume that n = 58 is accepted. The next step is to allocate the sample by strata. This is achieved as follows [from equation (19)].

Strata 1.

(winter)

$$n_1 = \frac{(166)\,(8)\,(58)}{7940} \approx 10$$

Strata 2.

(snowmelt runoff)

$$n_2 = \frac{(91)\,(24)\,(58)}{7940} \approx 16$$

Strata 3.

(summer)

$$n_3 = \frac{(108)\,(41)\,(58)}{7940} \approx 33$$

At this point you should look at the allocation and ask yourself if it looks right. In this case, most of the samples are allocated to the summer runoff period. This is the period of greatest variation in the water quality and, hence, the period that should be sampled most intensely. On the other hand, the water quality is fairly stable during baseflow and requires the least amount of sampling. Snowmelt varies twice as much as baseflow but occurs over a period equal to two-thirds of the period for baseflow. As a result, the sampling of snowmelt looks about right. It is decided that the allocation is acceptable.

7.0 Guidelines for Collecting and Handling of Water Quality Samples

Obtaining representative samples and then maintaining the integrity of the constituents is an integral part of any wildland water quality program. If the samples are not collected and handled properly the data will be of little value no matter how well the sampling program was designed.

Although analytical techniques have been standardized to a very high degree (American Public Health Association (APHA) 1976), at this time, there are no established standards for USDA-Forest Service hydrologists to follow when collecting and handling water quality samples even though the National Handbook of Recommended Methods of Water Data Acquisition (USGS, 1977) exists. As a result, collection methods may differ between hydrologists. When analyzing data, it is generally taken for granted that the data are representative of the water body from which the sample was obtained. However, this assumption can result in erroneous inferences about the quality of water body being studied, especially if several different individuals were involved in the collection of the samples. Before you compare data collected by different individuals, satisfy yourself that the samples were collected and handled properly and that the data are truly representative of the water body from which they were collected. The methods of sample collection and handling as well as the analytical methods used to measure each constituent, should be clearly documented in the Water Quality Monitoring Plan of Operation.

The purpose of this subsection is to discuss the types of sampling and to present guidelines for collecting and handling water quality samples.

7.1 Types of Samples

7.1.1 Grab Samples

A grab sample is a sample collected at a particular time and place. Strictly speaking, a grab sample can represent only the composition of the water body at that time and place. However, when a water body is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then a grab sample may be said to represent a longer time period or a larger volume, or both, than the specific point at which it was collected (APHA, et al, 1976). When a water body is known to vary with time, grab samples collected at suitable intervals and analyzed separately can be of great value in documenting the extent, frequency and duration of these variations. Sampling intervals should be selected on the basis of the frequency with which changes are expected.

7.1.2 Composite Samples

In most cases, the term "composite sample" refers to a mixture of grab samples collected at the same sampling point at different times or to a sample formed by continuously collecting a portion of the flow. The formation of a composite sample serves as an alternative to the separate analysis of a large number of grab samples, followed by computation of the average. Composite sampling can represent a substantial saving in laboratory effort and funds; however, it should be noted that this savings in energy and money is sometimes obtained at the expense of data resolution.

Composite samples can only be used for constituents that do not change appreciably in character during the interval from collection to analysis.

Under no circumstances should microbiological samples be composited. If preservatives are used, add them to the sample bottle initially so that all portions of the composite are preserved as soon as collected.

7.2 Sample Collection

When samples are collected from a stream, the sampler must consider the variability of constituent concentration with streamflow, depth, water velocity, distance from the bank and distance from one bank to the other. It is very important that samples be collected during representative flows over the time period of interest. If storm flows occur, it is important that they are sampled. In some cases, such as suspended solids, the majority of mass transport will occur during storm flow and/or snowmelt runoff. In some cases, data resolution will require sample collection on both the rising-limb and falling-limb of the hydrograph.

If equipment is available, it is best to take an "integrated" stream sample from the water surface to the stream bottom at selected intervals across the channel in such a way that the sample is made composite according to flow. If only a grab sample can be collected, it is best to take it in the middle of the stream at the 0.6 depth. Brown and others (1970), Guy (1970) and Greeson and others (1977) discuss the various types of sampling equipment in detail.

Lakes and reservoirs are subject to considerable variations in water quality from normal causes, such as seasonal stratification, precipitation, runoff and wind. The choice of location, depth and frequency of sampling will depend on local conditions and the purpose of the investigation. A detailed discussion of sample collection methods in lakes and reservoirs and equipment used to collect the samples is presented by Lind (1979), Schwoerbel (1970) and Welch (1948).

The chemical quality of ground water at a sampling point may vary in response to changes in rate of water movement, to pumpage, or to differences in rate and chemical composition of recharge from precipitation and from the surrounding area (Brown and others, 1970). Although concentrations of dissolved constituents in ground water from any one well may vary widely, sometimes several fold, in general the changes take place much slower than those commonly associated with surface water. Usually, it is safer to assume that the quality of the water from a well fluctuates rather than that it is uniform for long periods of time. Changes in ground water quality usually can be described satisfactorily by a monthly, seasonal or annual sampling schedule. For more information about sampling ground water, see Hem (1970), Walton (1970) and Freeze and Cherry (1979).

Samples should be collected from wells only after the well has been pumped sufficiently to insure that the sample represents the ground water that feeds the well. Before samples are collected from distribution systems, such as water lines in a campground, flush the lines sufficiently to insure that the sample is representative of the water supply and sterilize the water tap.

In all cases, sampling points should be fixed by detailed description, by maps, or with the aid of stakes, buoys or landmarks in such a manner as to permit their identification by other persons without reliance upon memory or personal guidance.

7.3 Sample Handling

A record should be made of every sample collected and every sample container should be identified, preferably by attaching an appropriately inscribed tag or label (APHA, et al, 1976). The record should contain sufficient information to provide positive identification of the sample at a later date as well as the name of the sample collector, the date, hour and exact location, the water temperature, how the sample was handled (that is refrigeration, acidification, degassing, etc.), and any other data which may be needed in the future for correlation, such as weather conditions, water level, stream flow, or the like.

After the sample has been collected, care must be exercised to protect the integrity of the sample to assure at the time of analysis that it is representative of the water body from which it was collected. In general, the shorter the time that elapses between collection of a sample and its analysis, the more reliable will be the analytical results. For certain constituents, such as pH, immediate analysis in the field is required to obtain dependable results because the sample composition may change before it arrives at the laboratory.

It is impossible to state exactly how much time may be allowed to elapse between collection of a sample and its analysis; this depends on the character of the sample, the particular analyses to be made and the conditions of storage. Changes caused by the growth of organisms are greatly retarded by keeping the sample in the dark and at a low temperature until analysis. Where the interval between sample collection and analysis is long enough to produce changes in either the concentration or the physical state of the constituent to be measured, follow the preservation

Table 5. Summary of special sampling or sample requirements (APHA and others, 1976; Stainton and others, 1977). a/

Determination	Container b/	Minimum Sample Size, ml.	Storage and/or Preservation
Acidity	P, G(B)	100	24 hr; refrigerate
Alkalinity	P, G(B)	200	24 hr; refrigerate
BOD	P, G	1,000	6 hr; refrigerate
Boron	P	100	-
Carbon, organic, total	G(brown)	100	Analyze as soon as possible, refrigerate or add HCl to pH $\leq$ 2
Carbon dioxide	G	100	Analyze immediately
Dissolved Organic Carbon	G	100	Analyze as soon as possible, filter, refrigerate
COD	P, G	100	Analyze as soon as possible, add H_2SO_4 to pH $\leq$ 2
Chlorine dioxide	P, G	500	Analyze immediately
Chlorine, residual	P, G	500	Analyze immediately
Chlorophyll	P, G	500	30 days in dark; freeze
Color	G	500	-
Cyanide	P, G	500	24 hr; add NaOH to pH 12; refrigerate
Fluoride	P	300	-
Fluvial sediment c/			
Grease and oil	G, wide-mouth, calibrated	1,000	Add HCl to pH $\leq$ 2
Iodine	P, G	500	Analyze immediately
Metals	P, G	-	For dissolved metals separate by filtration immediately; add 5 ml conc HNO_3/l
Nitrogen			
Ammonia	P, G	500	Analyze as soon as possible; add 0.8 ml conc H_2SO_4/l; refrigerate
Nitrate	P, G	100	Analyze as soon as possible; filter, add 0.8 ml conc H_2SO_4/l; refrigerate
Nitrite	P, G	100	Analyze as soon as possible; filter, add 40 mg $HgCl_2$/l and refrigerate or freeze at -20°C

Table 5 continued

Determination	Container b/	Minimum Sample Size, ml.	Storage and/or Preservation
Total Dissolved Nitrogen	P, G	100	Analyze as soon as possible; add 40 mg $HgCl_2$/l and filter, refrigerate
Organic	P, G	500	Analyze as soon as possible; refrigerate or add 0.8 ml conc H_2SO_4/l
Microbiological	P, G	500	6 hr; refrigerate
Odor	G	500	Analyze as soon as possible; refrigerate
Oxygen, dissolved	G, BOD bottle	300	Analyze immediately
Pesticides (organic)	G(S)	-	-
pH	P, G(B)	-	-
Phenol	G	500	24 hr; add H_3PO_4 to pH $\leq$ 4.0 and 1 g $CuSO_4 \cdot H_2O$/l; refrigerate
Phosphorus (dissolved)	G(A)	100	Analyze as soon as possible; For dissolved phosphates separate by filtration immediately, freeze at $\leq$ -10°C and/or add 40 mg $HgCl_2$/l
Orthophosphate (dissolved)	G(A)	100	Analyze as soon as possible; filter immediately, add 40 mg $HgCl_2$, refrigerate.
Total Dissolved Phosphorus	G(A)	100	Analyze as soon as possible, filter immediately, add 40 mg $HgCl_2$/l, refrigerate.
Residue (TDS)	P, G(B)	100	-
Salinity	G, wax seal	240	Analyze immediately or use wax seal
Silica	P	-	-
Sulfate	P, G	-	Refrigerate
Sulfide	P, G	100	Add 4 drops 2N zinc acetate/100 ml
Sulfite	P, G	-	Analyze immediately
Taste	G	500	Analyze as soon as possible; refrigerate

Table 5 continued

Determination	Container b/	Minimum Sample Size, ml.	Storage and/or Preservation
Temperature	-	-	Analyze immediately
Turbidity	P, G	-	Analyze same day; store in dark for up to 24 hr

a/ See Standard Methods (APHA et al, 1976) and The Chemical Analysis of Fresh Water (Stainton et al, 1977) for additional details. Use glass or plastic containers, preferably refrigerate during storage and analyze as soon as possible. Samples for cation and anion analysis should be filtered in the field. For the design of a portable unit for filtering water samples at field sites, see Kennedy and others (1976).

b/ P = plastic (polyethylene or equivalent); G = glass; G(A) or P(A) = rinsed with 1+1 HNO_3; G(B) = glass, borosilicate; G(S) = glass, rinsed with organic solvents.

c/ Follow USGS methods (Guy and Norman, 1970).

practices outlined in Table 5. Record the time elapsed between sampling and analysis, and which preservative, if any, was added.

Stainton and others (1977) suggest several special precautions when sampling for nutrient elements. The usually low levels of these elements in upland water resources make contamination a significant problem. While the need for clean samples and sample containers is obvious, there are several other contamination sources which must be avoided. Small amounts of tobacco ash, dandruff and perspiration contributed by field personnel, or plant pollen and other atmospheric particulates all can introduce significant errors into nutrient element analysis. Field personnel must be made aware of these and other possible sources of contamination.

The foregoing discussion is by no means all inclusive. It is impossible to prescribe absolute rules for the prevention of all possible changes. Some advice will be found in the discussions of methods of determination of various constituents in Standard Methods (APHA and others, 1976) and The Chemical Analysis of Fresh Water (Stainton and others, 1977). However, to a large degree, the dependability of water quality data must rest on the experience and good judgement of the samples and analyst.

practices outlined in Table 5. Record the time elapsed between sampling and analysis, and which preservative, if any, was added.

Stainton and others (1977) suggest several special precautions when sampling for nutrient elements. The usually low levels of these elements in upland water resources make contamination a significant problem. While the need for clean samples and sample containers is obvious, there are several other contamination sources which must be avoided. Small amounts of tobacco ash, dandruff and perspiration contributed by field personnel, or plant pollen and other atmospheric particulates are enough to introduce significant errors into nutrient element analysis. Field personnel must be made aware of these and other possible sources of contamination.

The foregoing discussion is by no means all inclusive. It is impossible to provide absolute rules for the prevention of all possible changes. Some advice will be found in the discussions of each type of determination for various constituents in Standard Methods (APHA and others, 1976) and The Chemical Analysis of Fresh Water (Stainton and others, 1977). However, to a large degree, the dependability of water quality data must depend on the experience and good judgement of the samplers and analyst.

8.0 Literature Cited

American Public Health Association, Inc. and others 1976. Standard methods for the analysis for water and waste water. 13th ed. Am. Public Health Assoc. 874 p.

Averett, R.C. 1979. The use of select parametric statistical methods for the analysis of water quality data. Presented at the USGS-BLM Conference on Water Quality in Energy Areas. January 10-11, Denver, Colorado. 16 p.

Averett, R.C. 1977. Biological sampling and statistics. In methods for the collection and analysis of aquatic biological and microbiological samples: U.S. Geol. Survey Techniques Water-Resources Inv., Book 5, Chap. A4, p. 3-19.

Averett, R.C. 1976. A guide to the design of data programs and interpretive projects. U.S. Geological Survey, Water Resources Division, Central Region, Lakewood, Colorado 80225. 100 p.

Brown, G. 1972. Forestry and water quality. Oregon State University. 74 p.

Brown, E., M.W. Skougstad and M.J. Fishman. 1970. Methods for collection and analysis of water samples for dissolved minerals and gases. U.S. Geol. Survey Techniques Water-Resources Inv., Book 5, Chap. A1, 160 p.

Boynton, J.L. 1972. Managing for quality - A plan for developing water quality surveillance programs on National Forests in California. In the Proceedings of a Symposium on "Watersheds in Transition" held at Fort Collins, Colorado, June 19-22. AWRA Proceedings series No. 14. p. 84-90.

Busby, J.F. 1980. The design and execution of a groundwater geochemical study. A class handout, U.S. Geological Survey, Water Resources Division, Northern Great Plains Aquifer System Assessment, Mail Stop 418, Denver Federal Center, Lakewood, Colorado 80225. 52 p.

Cochran, W.G. 1963. Sampling techniques. John Wiley and Sons, Inc., New York, New York. 413 p.

Freese, F. 1962. Elementary forest sampling. Agricultural Handbook No. 232. USDA-Forest Service. 91 p.

Freeze, A.R. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc. 604 p.

Greeson, P.E., et al. 1977. Methods for the collection and analysis of aquatic biological and microbiological samples: U.S. Geol. Survey Techniques Water-Resources Inv., Book 5, Chap. A4, 165 p.

Guy, H.P. 1970. Fluvial sediment concepts: U.S. Geol. Survey Techniques Water Resources Inv., Book 3, Chap. C1, 55 p.

Guy, H.P. and V.W. Norman. 1970. Field methods for measurement of fluvial sediment: U.S. Geol. Survey Techniques Water-Resources Inv., Book 3, Chap. C2, 59 p.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural water. U.S. Geol. Survey Water Supply Paper 1473. 363 p.

Huibregtse, K.R. and J.H. Moser. 1976. Handbook for sampling and sample preservation of water and waste water. U.S. Department of Commerce, National Technical Information Service. PB-259-946. 257 p.

Kennedy, V.C., E.A. Jenne and J.M. Burchard. 1976. Backflushing filters for field processing of water samples prior to trace-element analysis. U.S. Geological Survey, Open file report 76-126. 11 p.

Krygier, J.T. and J.D. Hall. 1971. Proceedings of a symposium forest land uses and stream environment. Oregon State University. 252 p.

Lind, O.T. 1979. Handbook of common methods in limnology. Mosby Company, St. Louis, Missouri. 199 p.

McKee, J.E. and H.W. Wolf. 1963. Water quality criteria. California State Water Resources Control Board. Publication No. 3-A. 548 p.

McNeely, R.N., V.P. Neimanis and L. Dwyer. 1979. Water quality sourcebook - a guide to water quality parameters. Inland Water Directorate, Water Quality Branch, Ottawa, Canada. Cat. No. En 37-541 1979. 89 p.

Mendenhall, W., L. Ott and R.L. Schaeffer. 1971. Elementary survey sampling. Wadsworth Publishing Company, Inc., Belmont, California. 247 p.

Ponce, S.L. 1980. Statistical methods commonly used in water quality data analysis. WSDG Technical Paper WSDG-TP-00001. WSDG, USDA - Forest Service, 3825 E. Mulberry St., Fort Collins, CO 80524. 152 p.

Potyondy, J. 1977. Guidelines for water quality sampling. Determination of detection limits and sample sizes. WQ-3 East Fork Smiths Fork Barometer Watershed, Wasatch National Forest, Intermountain Region, USDA Forest Service, Ogden, Utah. 8 p.

Potyondy, J. 1980. Guidelines for water quality monitoring plans. Draft USDA-Forest Service, Intermountain Region, Soil and Water Management, 324 25th Street, Ogden, UT 84401 49 p.

Schwoerbel, J. 1970. Methods of hydrobiology. Pergamon Press, Limited. Oxford, England. 200 p.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods, 6th ed., Iowa State Univ. Press, Ames, Iowa. 593 p.

Stainton, M.P., M.J. Capel, and F.A.J. Armstrong. 1977. The chemical analysis of freshwater. Fisheries and Environment Canada. Fisheries and Marine Service. Misc. Spec. Pub. No. 25. Winnipeg, Manitoba 180 p.

Thatcher, L.L., V.J. Janzer and K.W. Edwards. 1977. Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geol. Survey Techniques Water Resources Inv., Book 5, Chap. A5. 95 p.

U.S. EPA. 1971. Studies on effects of watershed practices on streams. Prepared Oregon State University School of Forestry. 13010 EGA 02/71. 173 p.

U.S. EPA. 1973. Processes, procedures and methods to control pollution resulting from silvicultural activities. EPA 430/9-73-010. 91 p.

U.S. EPA. 1976a. Forest harvest, residue treatment, reforestation and protection of water quality. EPA 910/9-76-020. 273 p.

U.S. EPA. 1976b. Quality criteria for water. Washington, D.C. 256 p.

U.S. EPA. 1977. Silvicultural chemicals and protection of water quality. EPA 910/9-77-036. 224 p.

U.S. Forest Service. 1980. An approach to water resources evaluation non-point sources silviculture. Produced under USFS-EPA amended interagency agreement EPA-IAG-D6-0660. 816 p.

USGS. 1977. National handbook of recommended methods for water-data acquisition. U.S. Department of Interior. Reston, Virginia.

Walton, W.C. 1970. Groundwater resource evaluation. McGraw-Hill. N.Y., N.Y. 664 p.

Welch, P.S. 1948. Limnological Methods. McGraw-Hill. N.Y., N.Y. 381 p.

APPENDIX

Table A-1. Values of t (Steel and Torrie, 1960).

df	Probability of a larger value of *t*, sign ignored								
	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.001
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	.718	.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291
df	0.25	0.2	0.15	0.1	0.05	0.025	0.01	0.005	0.0005
	Probability of a larger value of *t*, sign considered								

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981—779-389/285 Region no. 8

THE USE OF THE PAIRED-BASIN TECHNIQUE IN FLOW-RELATED WILDLAND WATER-QUALITY STUDIES

Stanley L. Ponce
Watershed Systems Development Group
USDA Forest Service
Fort Collins, Colorado

David W. Schindler
Department of Fisheries and Oceans
Freshwater Institute
Winnipeg, Manitoba

Robert C. Averett
Water Resources Division - Central Region
U.S. Geological Survey
Denver Federal Center
Denver, Colorado

WSDG Report
WSDG-TP-00004
April 1982

USDA Forest Service
Watershed Systems Development Group
3825 East Mulberry Street
Fort Collins, Colorado 80524

THE USE OF THE PAIRED-BASIN TECHNIQUE IN FLOW-RELATED WILDLAND WATER-QUALITY STUDIES

By

Stanley L. Ponce
Watershed Systems Development Group
USDA Forest Service
Fort Collins, Colorado

David W. Schindler
Department of Fisheries and Oceans
Freshwater Institute
Winnipeg, Manitoba

Robert C. Averett
Water Resources Division - Central Region
U.S. Geological Survey
Denver Federal Center
Denver, Colorado

WSDG Report
WSDG-TP-00004
April 1982

USDA Forest Service
Watershed Systems Development Group
3825 East Mulberry Street
Fort Collins, Colorado 80524

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THE USE OF THE PAIRED-BASIN TECHNIQUE IN FLOW-RELATED WILDLAND WATER-QUALITY STUDIES

INTRODUCTION

One of the responsibilities of a forest hydrologist is to provide the line officer with reliable information concerning the quality of the water resource. This information is used to (1) evaluate the effectiveness of soil and water conservation practices, (2) determine if compliance to public health standards and/or contractual obligations is being accomplished, (3) determine water quality trends, and/or (4) evaluate the existing condition of water quality. The problem, of course, is how to provide this information at an acceptable level of reliability when constraints on time, manpower, and money limit the number of water quality samples that can be collected and analyzed each year.

The success of the monitoring activity is dependent on the monitoring design and the method selected for data analysis. Once the study objectives have been defined, the goal is to obtain the required information at a predetermined level of reliability with a minimum expenditure of resources. This requires that the monitoring program and subsequent data analysis be designed to minimize unexplained variation. In studies involving streams, most water-quality constituents of interest to the wildland hydrologist are strongly related to discharge. To account for the variation due to flow, hydrologists commonly use regression techniques to evaluate possible cause-and-effect relationships as well as temporal trends.

The most frequently used regression is simply a plot of the discharge against the concentration of a given water-quality constituent. An application of this approach is illustrated below.

The question confronting the hydrologist was: "Does the harvested area significantly affect the suspended sediment loading in Trout Creek during water year 1980?" Sampling stations were placed upstream and downstream from the harvested area (Figure 1). Suspended-sediment concentrations were measured at both stations such that each part of the annual streamflow (baseflow, snowmelt, stormflow, etc.) was sampled during water year 1980. The data were then fit to the regression model:

$$\log SS = \log b_0 + b_1 \log Q$$

where:

SS = suspended-sediment concentration, in milligrams per liter;

b_0 = regression coefficient;

b_1 = regression coefficient; and

Q = discharge, in cubic feet per second.

The results were then used to develop the sediment-rating curves illustrated in Figure 2.

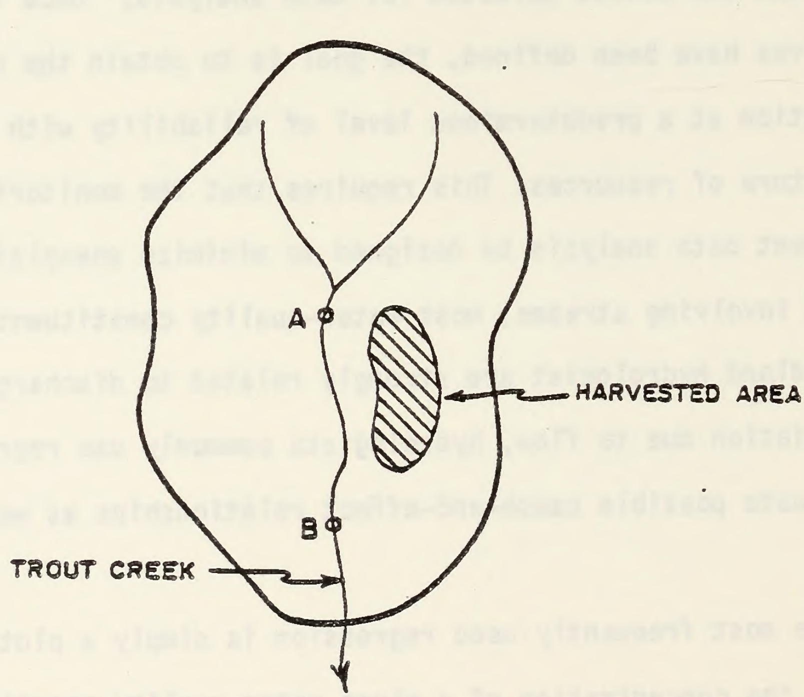


Figure 1. Locations of stations A and B in relation to the harvested area on Trout Creek.

It should be noted that the data are widely scattered about the regression lines (Figure 2). The coefficient of determination (r^2) generally ranges between 0.60 and 0.85 for most rating-curve regressions involving water quality constituents. The unexplained variation ($1 - r^2$) in the regression is due to factors not accounted for by the relationship, such as watershed conditioning, climate, and/or physical and biologic factors (Beschta et al. 1981). Although hydrologists typically seek to minimize the unexplained variation by judiciously selecting sampling periods, it is rare that the r^2 will exceed 0.85. The statistical difference between A and B can be determined with the analysis of covariance (ANCOVA) test of a common line or with the Chow test (Wilson 1978) if the data meet the underlying assumptions of the statistical tests.

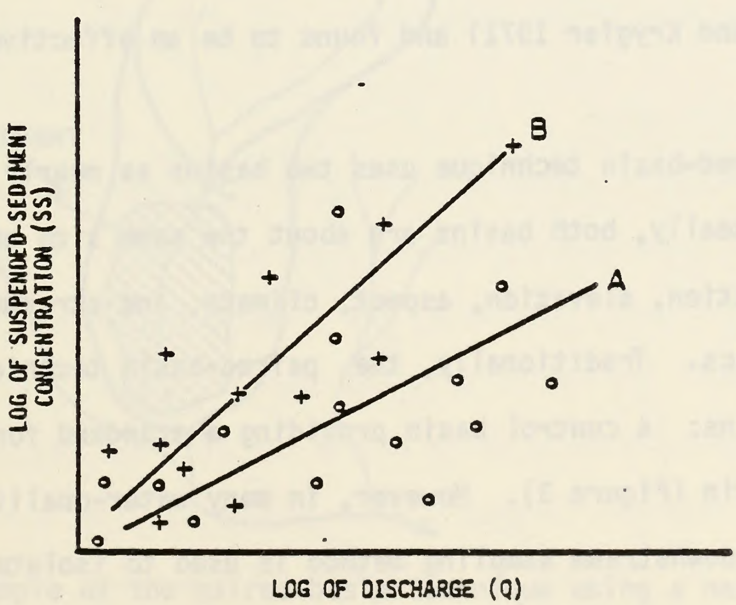


Figure 2. Suspended sediment (SS) rating curves for stations A and B. Data collected at station A are denoted by °, where as data collected at station B are denoted by +.

We have found that in some situations an extension of the paired-basin technique, to be discussed in the section that follows, provides for greater statistical control and enables the hydrologist to maximize information gained while minimizing time, manpower, and other economic expenditures. The purpose of this paper is to discuss the paired-basin technique and illustrate its use for possible cause-and-effect evaluation, trend analysis, and assessment of cumulative impacts.

THE PAIRED BASIN TECHNIQUE

The paired-basin technique was first used by U.S. Forest Service hydrologists on the "Wagon Wheel Gap Streamflow Experiment" (Bates and Henry 1928). Today the technique commonly is used by hydrologists to quantify the effects of land-use practices on the volume and timing of streamflow. In recent years, the technique has been extended to flow-related, water-quality studies by a few investigators (Averett, Ponce, and Schindler 1981; Schindler et al. 1980; Singh and Kalra 1972; Thut and Haydu 1971; Brown and Krygier 1971) and found to be an effective data analysis tool.

The paired-basin technique uses two basins as nearly alike as possible. Ideally, both basins are about the same size and have similar soils, vegetation, elevation, aspect, climate, and streamflow characteristics. Traditionally, the paired-basin technique uses two separate basins: a control basin providing a standard for comparison and a treatment basin (Figure 3). However, in many water-quality studies an upstream and downstream sampling method is used to isolate a treatment area along a stream reach (Figure 4). The paired-basin technique also can be used in this situation. Instead of two completely separate basins, the control basin (that drainage area upstream from the upper sampling site) is nested within the treatment basin.

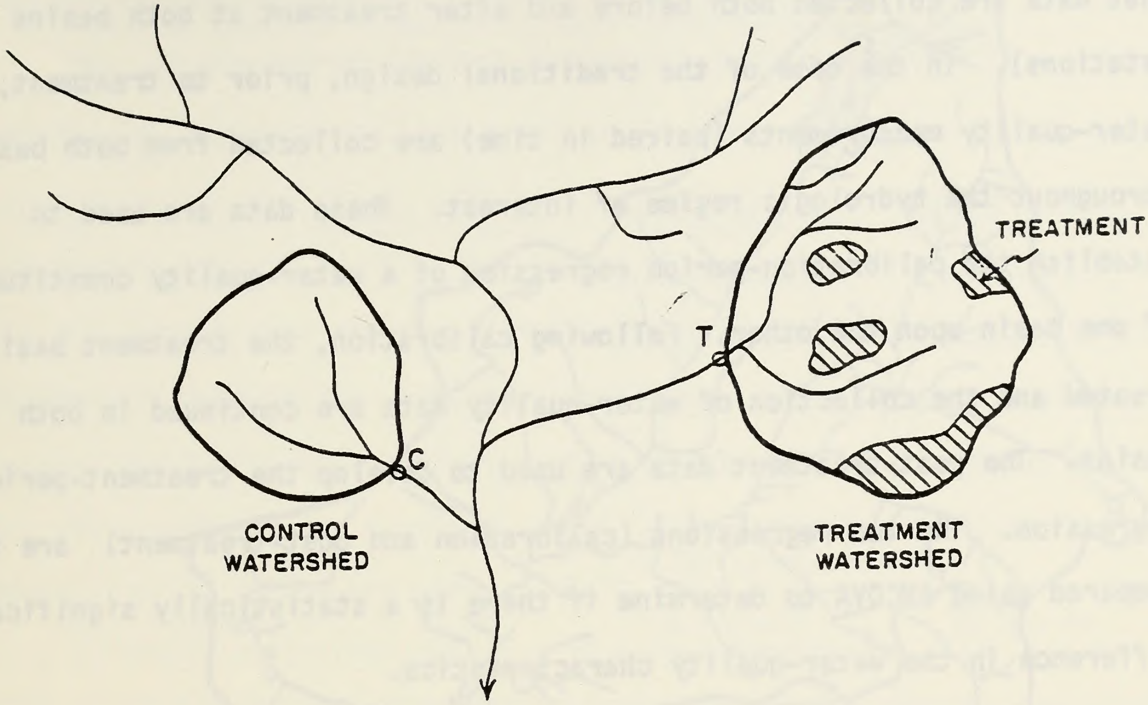


Figure 3. An example of the paired-basin technique using two separate basins.

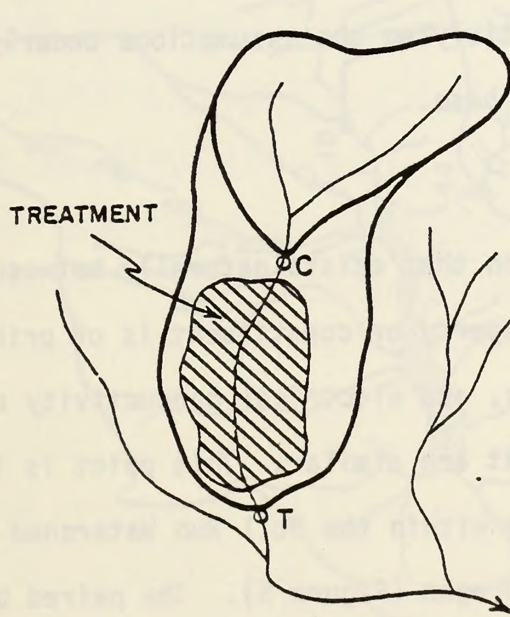


Figure 4. An example of the paired-basin technique using a nested subbasin.

In either case, traditional or nested design, the technique requires that data are collected both before and after treatment at both basins (stations). In the case of the traditional design, prior to treatment, water-quality measurements (paired in time) are collected from both basins throughout the hydrologic regime of interest. These data are used to establish the calibration-period regression of a water-quality constituent of one basin upon the other. Following calibration, the treatment basin is treated and the collection of water-quality data are continued in both basins. The post-treatment data are used to develop the treatment-period regression. The two regressions (calibration and post-treatment) are then compared using ANCOVA to determine if there is a statistically significant difference in the water-quality characteristics.

There are several factors that affect the success of the paired-basin technique (Reinhart 1967). Those that need to be considered carefully when applying the technique include natural correlation, stability of the control, satisfying the assumptions underlying ANCOVA, and quality and size of the data base.

Natural Correlation

The degree of correlation that exists naturally between paired basins for a given water-quality property or constituent is of primary importance. Suspended sediment, turbidity, and electrical conductivity usually correlate well for basins that are similar. This point is illustrated using two sets of basin pairs within the Bull Run Watershed on the Mount Hood National Forest, Oregon (Figure 5). The paired basins used met the underlying criteria of similarity in elevation, aspect, soils, vegetation, climate, and streamflow. Basin 44 served as the control and was paired with treatment basins 18 and 35 (Table 1).

Figure 5. Location of principal sampling stations on the Bull Run Watershed, Mount Hood National Forest, Oregon.

Table 1. Coefficients of determination (r^2) for selected water-quality characteristics from paired-basin analysis in the Bull Run Watershed, Mount Hood National Forest.

Paired Basins	Charcteristic	Years of Record	r^2	n
44 and 18	Suspended Solids	76-79	0.98	90
44 and 35	Suspended Solids	76-79	0.94	98
44 and 18	Turbidity	76-79	0.95	72
44 and 35	Turbidity	76-79	0.87	163
44 and 18	Electrical Conductivity	76-79	0.91	185
44 and 35	Electrical Conductivity	76-79	0.90	191

In general, a decrease in similarity between basins results in a decreased degree of correlation. For example, during stormflow it is likely that the hydrographs will be out of phase if the paired basins are not similar in size. Consequently, at a given point in time the flow characteristics at each sampling station will be different rather than similar. Such a condition will add unwanted variation to the relationship and reduce the strength of the procedure.

Stability of the Control

It is important that the control basin remain as stable as possible. Any factor that changes the character of the control will detract from the usefulness of the method. Consequently, when selecting a control basin care needs to be taken to select one in or as near a state of equilibrium as possible. Often it is useful to select two control basins in case one is altered during the study period, such as by fire or some other catastrophic event.

Satisfying the Assumptions Underlying the ANCOVA

The validity of the inferences drawn from the results of the ANCOVA is related, to a greater or lesser extent, to whether the underlying assumptions are satisfied. The relevant question is not whether the ANCOVA assumptions are met exactly, but rather whether the plausible violations of the assumptions have serious consequences on the validity of probability statements based on the standard assumptions. The primary assumptions that need to be considered are (1) independence of errors, (2) normality, and (3) homogeneity of the variances. The consequences of violation of assumptions of ANCOVA are summarized in Table 2.

It should be pointed out that it is not uncommon to find in a time series of hydrologic data that an observation at one time period (t) is correlated with the observation in the preceeding time period (t - 1) or time periods (t - 2, etc.). In other words, an observation collected at time t may not be independent of one collected at time t - 1 or t - 2, etc. when the time intervals are short. Such dependency is termed serial correlation or autocorrelation.

What is the effect of serial correlation on tests of significance regarding regression equations? Essentially, if a significant level of serial correlation exists the data are not independent and tests of significance regarding any regression equations have limited utility (Table 2).

This raises the question: "How frequently can observations be collected while still maintaining independence?" Unfortunately there is not a simple answer to this question. Identifying the characteristics and structure of serial correlation in time series data of water quality constituents represents one of the important areas of research facing statisticians. However, it is suggested by Beschta (1981) that

Table 2. Summary of Consequences of Violation of Assumptions of ANCOVA (Glass, Peckham, and Sanders 1972).

Type of Violation	Equal n's: Effect on Level of Significance (α)	Equal n's: Effect on Power	Unequal n's: Effect on Level of Significance (α)	Unequal n's: Effect on Power
Non-independence of errors	Non-independence of errors seriously affects both the level of significance and power of the F-test regardless whether n's are equal or unequal.			
Non-normality				
Skewness	Skewed populations have very little effect on either the level of significance or the power of the fixed-effects model F-test; distortions of nominal significance levels of power values are rarely greater than a few hundredths. (However, skewed populations can seriously affect the level of significance and power of directional - or "one-tailed" - tests.)			
Kurtosis	Actual α is less than nominal α when populations are leptokurtic (i.e., $\beta_2>3$). Actual α exceeds nominal α for platykurtic populations. (Effects are slight.)	Actual power is less than nominal power when populations are platykurtic. Actual power exceeds nominal power when populations are leptokurtic. Effects can be substantial for small n.	Actual α is less than nominal α when populations are leptokurtic (i.e., $\beta_2>3$). Actual α exceeds nominal α for platykurtic populations. (Effects are slight.)	Actual power is less than nominal power when populations are platykurtic. Actual power exceeds nominal power when populations are leptokurtic. Effects can be substantial for small n's.
Heterogeneous Variances	Very slight effect on α, which is seldom distorted by more than a few hundredths. Actual α seems always to be slightly increased over the nominal α.	(No theoretical power value exists when variances are heterogeneous.)	α may be seriously affected. Actual α exceeds nominal α when smaller samples are drawn from more variable populations; actual α is less than nominal α when smaller samples are drawn from less variable populations.	(No theoretical power value exists when variances are heterogeneous.)
Combined non-normality and heterogeneous variances	Non-normality and heterogeneous variances appear to combine additively ("non-interactively") to affect either level of significance or power. (For example, the depressing effect on α of leptokurtosis could be expected to be counteracted by the elevating effect on α of having drawn smaller samples from the more variable, leptokurtic populations.)			

observations collected during stormflow should have an interval of three or more hours. During snowmelt runoff and low flow periods, it appears that observations need to be obtained two or more weeks apart to assure independence. If the observations are equally spaced in time, the serial correlations can be tested using the BMDP2T Program (BMDP 1981) which is readily available on the computer at the Fort Collins Computer Center.

For further reading about the assumptions underlying the ANCOVA, see Elashoff (1969); Glass, Peckham, and Sanders (1972); and Wildt and Ahtola (1978).

Quality and Size of Data Base

Adequate and correct data are essential to the success of any study. No extent of statistical maneuvering can make up for sloppy data. Because many individuals may be involved in data collection, it is good practice to establish written data-collection standards and insure that they are adhered to throughout the study.

In general, the larger the statistical sample, the more precise the paired-basin regression relationship will be. Wilm (1949), Kovner and Evans (1954), and Kovner (1968) describe methods for determining the minimum length of streamflow experiments using the paired basin technique. However, these methods cannot be applied to water quality experiments for determination of the sample size which will yield regression estimates at a predetermined level of statistical reliability because they assume equal variances and/or that the slopes of the regression lines are the same for the calibration and treatment periods.

At this time, we know of no procedures available to the hydrologist to determine a specific sample size which will permit a comparison test at a predetermined level of statistical reliability. Our advice is that a minimum of 15 observations be collected per station per year. It is important, of course, that the samples are collected throughout the sampling period relative to the relationship between the flow characteristics and water quality constituent of concern.

APPLICATIONS OF THE PAIRED-BASIN TECHNIQUE

Cause-and-Effect Evaluation

The paired-basin technique is ideal for evaluating possible cause-and-effect relationships. Consider the situation illustrated in Figure 6. Here we have a treatment isolated by placing stations upstream (station A) and downstream (station B) from the treatment. The problem is to determine the effect of the treatment on a specific water-quality characteristic, such as suspended sediment. The strategy to be used in this situation is to establish a pair of basins (stations) A and B and collect data before and after the treatment.

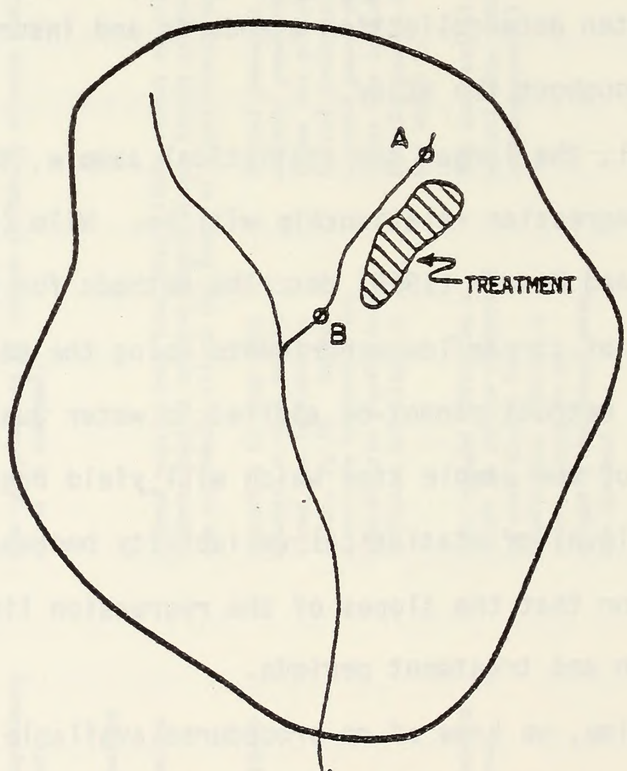


Figure 6. An example of cause-and-effect monitoring when the treatment can be isolated.

The data can be related as illustrated in Figure 7. Analysis of covariance can be used to determine if the treatment had a statistically significant effect on the suspended sediment of the system.

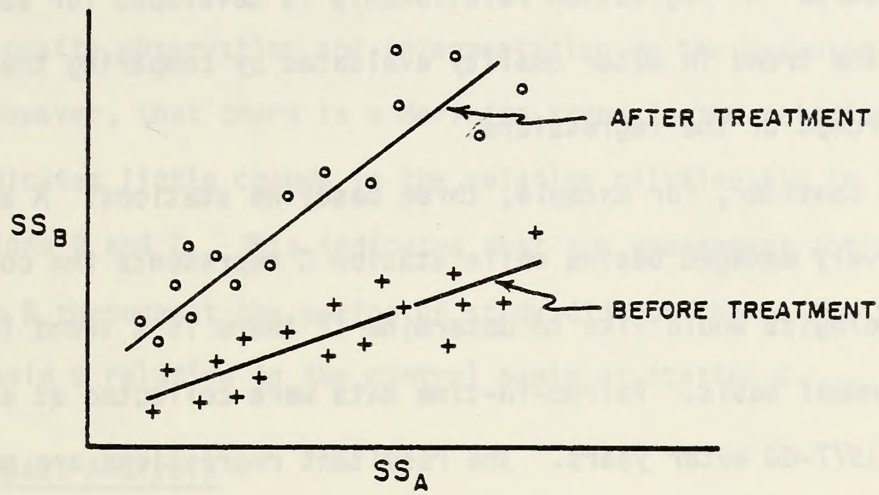


Figure 7. Before and after treatment regressions of suspended sediment at station A (SS_A) against suspended sediment at station B (SS_B).

Another example of possible cause-and-effect evaluation is presented in Figure 8. In this example, the treatment cannot be isolated by placing stations upstream and downstream from it. Consequently, a control basin (A in Figure 8) needs to be selected and data collected both before and after the treatment. Data analysis would be similar to that previously described.

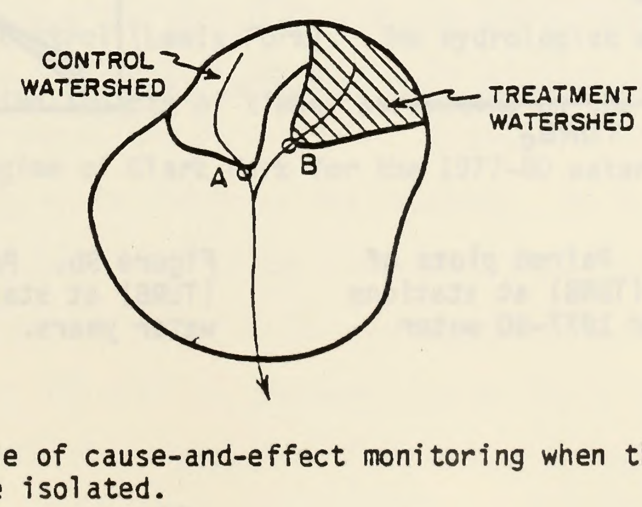


Figure 8. An example of cause-and-effect monitoring when the treatment cannot be isolated.

Trend Analysis

The paired-basin technique can also be used for trend analysis. The data from the test station is compared with the data from the control station throughout a series of time intervals of interest, such as seasons or years. A regression relationship is developed for each time interval and the trend in water quality evaluated by comparing the slope and intercept of the regressions.

Consider, for example, three baseline stations: A and B represent actively managed basins while station C represents the control basin. The hydrologist would like to determine if there is a trend in the turbidity on an annual basis. Paired-in-time data were collected at each station during the 1977-80 water years. The resultant regressions are presented in Figures 9a and 9b. The data can be analyzed using a multiple comparison approach where successive regressions are compared using ANCOVA.

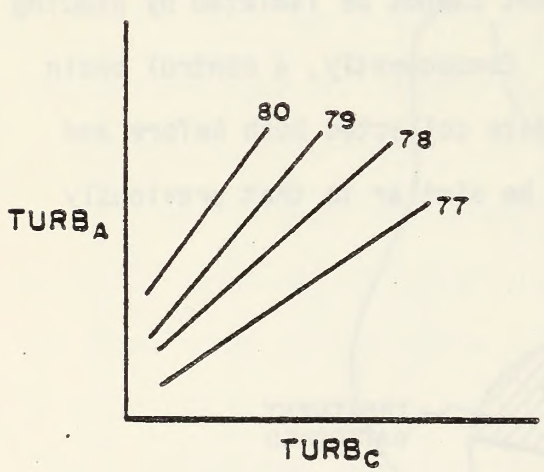


Figure 9a. Paired plots of turbidity (TURB) at stations A and C for 1977-80 water years.

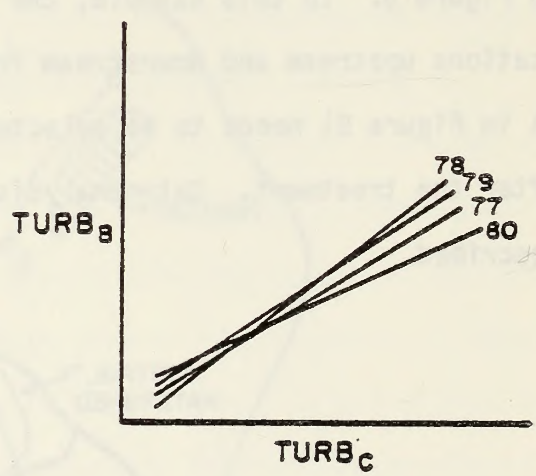


Figure 9b. Paired plots of turbidity (TURB) at stations B and C for 1977-80 water years.

Turbidity at station A is increasing annually relative to the turbidity at station C (Figure 9a). Whether or not the source is related to management activities cannot be determined from the paired plot alone but requires onsite observation and interpretation by the hydrologist. It is evident, however, that there is a definite trend in the relation. Figure 9b indicates little change in the relative relationship in turbidity between stations B and C. This indicates that the management activities used in basin B throughout the period of study did not change the turbidity yield from basin B relative to the control basin or station C.

<u>Cumulative-Impact Analysis</u>

The paired-basin technique can be an effective analysis tool for assessment of cumulative impacts. The procedure is to develop a series of nested stations (subbasins) throughout the basin. Paired sampling is used and the water quality at each station is correlated with that at a control station throughout a specified time interval. The relationships between stations are compared and related to land use and other factors affecting the system.

Consider the situation illustrated in Figure 10 where there are two basins, one being intensely managed for timber production (Clark Fork) and the other used for a control (Lewis Fork). The hydrologist wishes to determine the cumulative impacts of timber harvesting on the annual suspended sediment regime of Clark Fork for the 1977-80 water years.

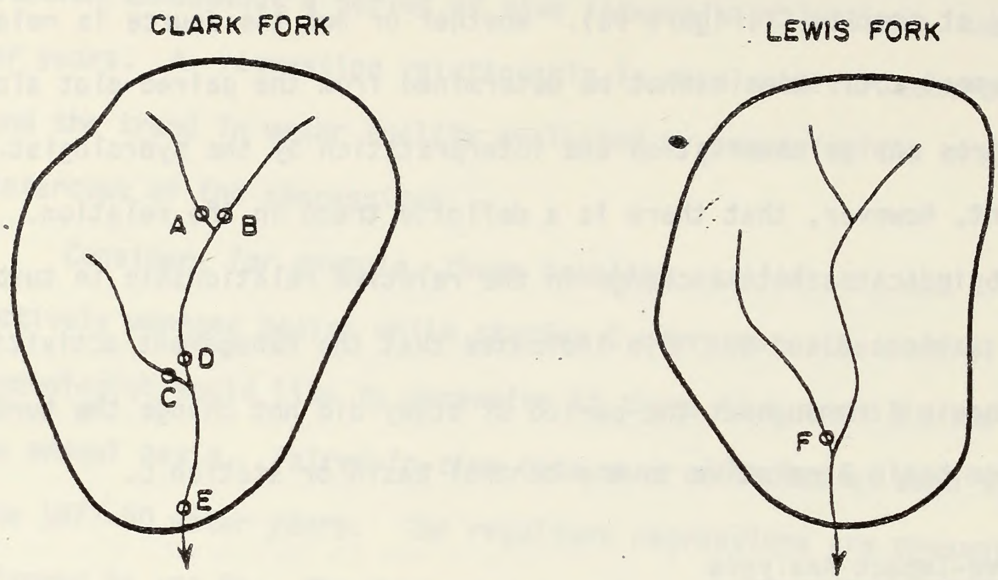


Figure 10. Nested station design for assessment of cumulative impacts. Station F is the control.

Suspended sediment samples were collected, paired-in-time, throughout the 4 water years of interest. At the end of each water year, the paired plots were developed (Figure 11) and the regression coefficients tabulated along with a series of stream, vegetative, and landform characteristics (see Table 3). The regression relationships between stations can then be compared and related to the stream, vegetative, and landform characteristics, and cumulative impacts may then be evaluated.

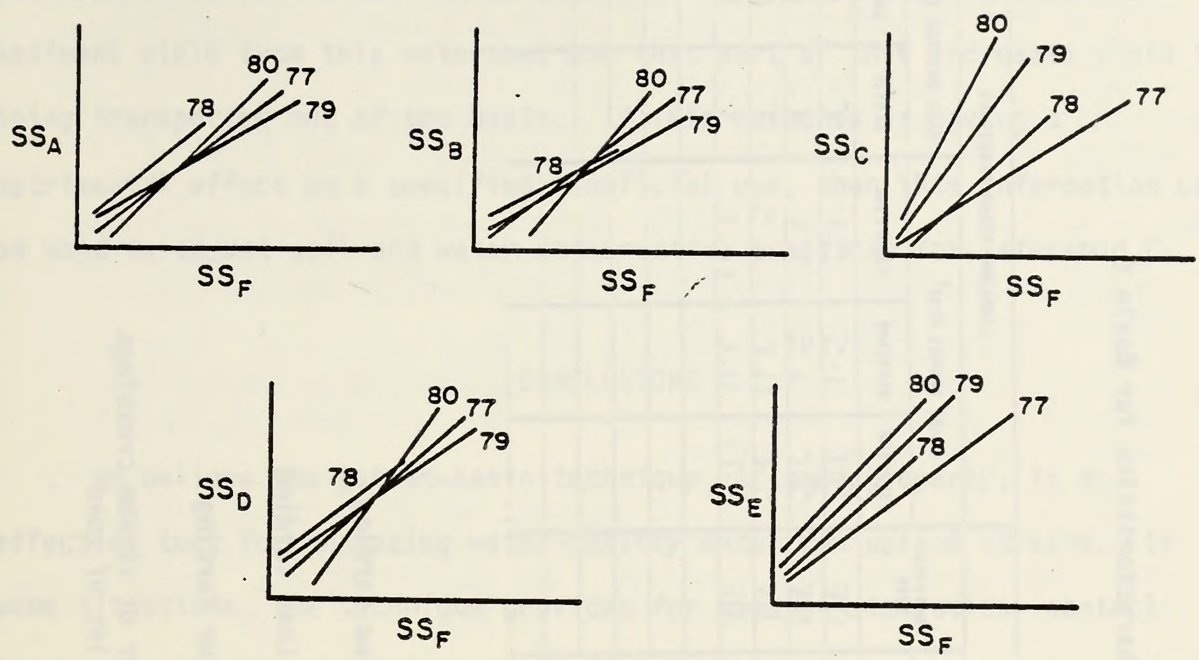


Figure 11. Suspended Sediment (SS) plots for stations located in the Clark Fork basin (A, B, C, D, and E) versus the control (station F) located in the Lewis Fork basin.

In this example, it appears in Figure 11 that the suspended-sediment yield at station E is increasing in relation to the control station. It is also apparent that the primary source of this increase is watershed C. The paired-basin, suspended-sediment regressions of stations A, B, and D with station F remain fairly consistent with time (no significant difference at the 0.10 level) while station C is increasing in relation to station F (significantly different at the 0.10 level). Examination of Table 3 provides some insight to the source of the problems. The b_1 regression coefficients (slope), percentage of the basin harvested, and area affected by roads increase with time while the channel-stability condition decreases, pool-and-riffle quality decrease, and condition of the riparian vegetation has degraded with time. This indicated that the silvicultural

Table 3. Regression Coefficients and Land-Use Characteristics for Basin C

SITE	WATER YEAR	REGRESSION COEFFICIENTS		STREAM CHARACTERISTICS			VEGETATIVE CHARACTERISTICS						LANDFORM CHARACTERISTICS				
							CRV[d]	PERCENT OF AREA HARVESTED				HABITAT TYPE	ROADS (CROSS MI)[i]			MASS WASTING (AC)(YI)	
		B_0	B_1	CSR[a]	PQ[b]	RQ[c]		SKY[e]	HL[f]	TRAC[g]	TOTAL		RIPARIAN	MIDSLOPE	RIDGELINE	ACTIVE	DORMANT
C	77	0.512	0.332	68	83	88	G	0	10	10	20	DF	5.0	1.5	5.0	0	0
C	78	0.131	0.431	81	75	81	G	0	20	10	30	DF	5.0	1.5	5.0	0	0
C	79	0.611	0.64	88	63	76	G/P	0	25	10	35	DF	5.0	11.0	7.5	0	0
C	80	0.213	0.14	90	52	71	G/P	3	25	10	38	DF	5.0	11.0	10.0	0	0

[a]Channel Stability Rating

[b]Pool/Riffle ratio

[c]Pool Quality

[d]Riffle Quality

[e]Condition of the Riparian Vegetation

[f]Skyline Yarding

[g]High Lead Yarding

[h]Tractor Yarding

[i]Number of stream crossings x miles of road

and road construction and maintenance practices are affecting suspended-sediment yield from this watershed and that part of this increased yield is being transported out of the basin. If this response is having a detrimental effect on a specified beneficial use, then this information can be used to adjust soil and water conservation practices for watershed C.

CONCLUSIONS

We believe the paired-basin technique, if used properly, is an effective tool for analyzing water-quality data from upland streams. In some situations, the technique provides for greater statistical control (minimizes the unexplained variation) and enables the watershed specialist to maximize information gained while minimizing time, manpower, and economic expenditures.

As with any statistical tool, the paired-basin technique will only provide you with "yes" and "no" answers. The regression relations will only provide you with insight to the hydrologic system and water quality response. Data interpretation is an intellectual activity requiring all the skills of a professional wildland hydrologist.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the numerous individuals in the Forest Service, U.S. Geological Survey, and the Bureau of Land Management who reviewed this report. A very special thanks is extended to Dr. Robert Thomas, Mathematical Statistician, of the Pacific Southwest Forest Experiment Station for his detailed review and helpful comments.

LITERATURE CITED

Averett, R. C., S. L. Ponce, and D. W. Schindler. 1981. A Report on: Bull Run Watershed Water-Quality Management. Bureau of Water Works, City of Portland, Oregon, 1800 S. W. Sixth Avenue, Portland, Oregon 97201. 53 p.

BMDP. 1981. BMDP Statistical Software 1981 Edition. University of California Press, LTD. Berkeley, California. 725 p.

Bates, C. G., and A. J. Henry. 1928. Forest and Streamflow Experiment at Wagon Wheel Gap, Colorado. Final report upon completion of the second phase of the experiment. U.S.D.A. Weather Bureau, Monthly Weather Review, Supplement No. 30. 79 p.

Beschta, R. L. 1981. Sediment and Bedload Sampling Study Design and Analysis. Lecture presented at the R-1 Soil and Hydrology Workshop. April 27-30, Missoula, Montana.

Beschta, R. L., S. J. O'Leary, R. E. Edwards, and K. O. Knoop. 1981. Sediment and Organic Matter Transport in Oregon Coast Range Streams. Water Resources Research Institute. OSU Report WRRI-70. Oregon State University, Corvallis, Oregon 97331. 67 p.

Brown, G. W., and J. T. Krygier. 1971. Clearcut Logging and Sediment Production in the Oregon Coast Range. Water Resources Research, 7(5):1189-1199.

Elashoff, J. C. 1969. Analysis of Covariance: A Delicate Instrument. American Educational Research Journal, 6:383-401.

Glass, G. V., P. D. Peckham, and J. R. Sanders. 1972. Consequences of Failure to Meet Assumptions Underlying the Fixed Effects of Variance and Covariance. Rev. Educ. Res., 42:237-288.

Kovner, J. L. 1968. Calibration of Paired Watersheds. Watershed Management Research: Semiannual Report. Rocky Mountain Forest and Range Experiment Station, April-September. p. RM1-RM4.

Kovner, J. L., and T. C. Evans. 1954. A Method for Determining the Minimum Duration of Watershed Experiments. Transactions, American Geophysical Union, 35(4):608-612.

Reinhart, K. G. 1967. Watershed Calibration Methods. Presented in Proceedings of a International Symposium on Forest Hydrology. Ed. by W. Sopper and H. Lull. Pennsylvania State University. p. 715-723.

Schindler, D. W., R. W. Newburg, K. G. Beaty, J. Prokopowich, T. Ruszczynski, and J. A. Dolton. 1980. Effects of a Windstorm and Forest Fire on Chemical Losses from Forested Watersheds and on the Quality of Receiving Streams. Can. J. Fish. Aquat. Sci., 37(3):328-334.

Singh, T., and Y. P. Kalra. 1972. Water Quality of an Experimental Watershed During the Calibration Period. Paper presented at the 19th annual meeting of the Pacific Northwest Region. American Geophysical Union, Vancouver, B.C. (October 16-17).

Thut, R. N. and E. P. Haydu. 1970. Effects of Forest Chemicals on Aquatic Life. Proceedings of a symposium: Forest Land Uses and Stream Environment. Oregon State University. Corvallis, Oregon (October 19-21). p. 159-171.

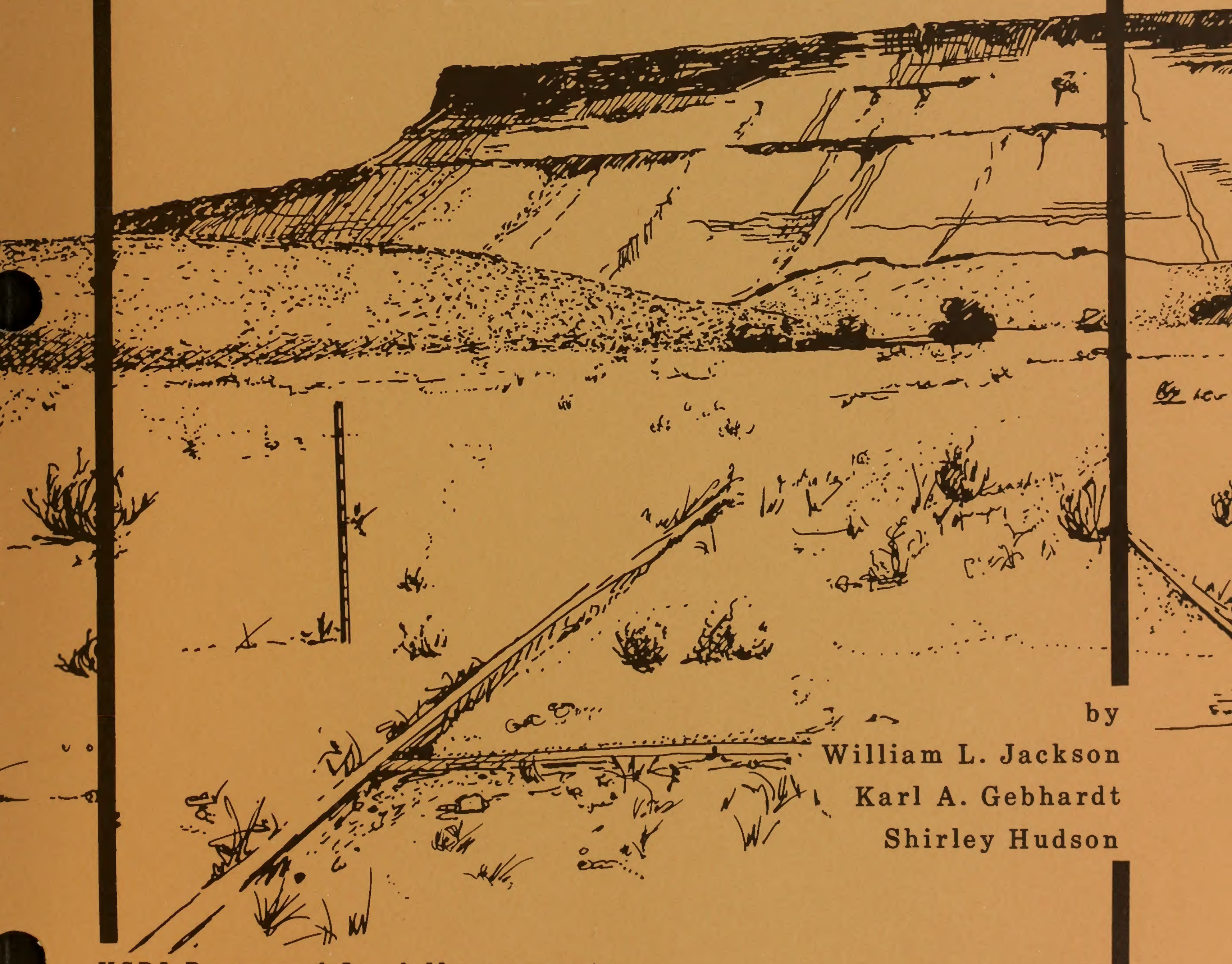
Wildt, A. R., and O. Ahtola. 1978. Analysis of Covariance. Sage Publications, Inc. Beverly Hills, Calif. 90212. 93 p.

Wilm, H. G. 1949. How Long Should Experimental Watersheds be Calibrated? Transactions, American Geophysical Union, 30(2): 272-278.

Wilson, A. L. 1978. When is the Chow Test UMP? The American Statistician. Vol. 32., No. 2. p. 66-68.

TECHNICAL NOTE 369

Considerations in Rangeland Watershed Monitoring



by
William L. Jackson
Karl A. Gebhardt
Shirley Hudson

USDI Bureau of Land Management
Denver, Colorado

September 1985

Technical Note No. 369

CONSIDERATIONS IN RANGELAND WATERSHED MONITORING

by

William L. Jackson [1]
Shirley Hudson [1]
and
Karl Gebhardt [2]

September 1985

BLM/YA/DT/85-006-4341

Available from: Printed Materials Distribution Section
BLM Service Center, Bldg. 50, D-558B
Denver, Colorado 80225

and

National Technical Information Service
Springfield, Virginia 22161

[1] Hydrologist and Statistician, Bureau of Land Management, Service Center, Denver, Colorado.

[2] Hydrologist, Bureau of Land Management, Idaho State Office, Boise, Idaho.

TABLE OF CONTENTS

I. INTRODUCTION

Monitoring is the orderly collection, analysis, and interpretation of resource data to evaluate progress in meeting management objectives. Rangeland watershed monitoring evaluates the achievement of soil and water resource management objectives identified in the Bureau of Land Management (BLM) Resource Management Planning (RMP) process. Rangeland watershed monitoring is used to determine what is happening to soil and water resources, why it is happening, and what adjustments in management might be required to meet soil and water resource management objectives. Thus, watershed monitoring is an integral feedback link in the RMP process.

It is useful to distinguish between monitoring and inventory. Inventories provide a broad quantification, characterization, or classification of resource conditions. While in some cases inventory data may be useful in establishing a base-line condition for monitoring, in most cases the sampling designs associated with broad inventories will be inadequate for quantifying the effects of management strategies on specific watershed values. Properly acquired, monitoring data quantifies the effects of land management strategies on watershed values, provides information for planning and watershed analysis, and validates or calibrates watershed models.

This technical note describes the components of a rangeland watershed monitoring plan, distinguishes between direct monitoring strategies (sampling) and indirect monitoring strategies (modeling), describes common watershed monitoring techniques, and discusses statistical considerations in sampling designs and data analysis. It also describes some monitoring principles and concepts, but does not prescribe specific monitoring programs. Monitoring programs will always have to be tailored individually to address the issues, management objectives, and conditions at the site of interest. Thus, careful analysis, planning, and judgment by the resource professional is integral to the design of watershed monitoring programs.

II. BACKGROUND

The RMP process is designed to be issue-driven. Resource management issues are identified and analyzed early in the planning process. Management objectives are established and alternative management strategies are evaluated. Management objectives are achieved through implementation of specific activity plans. Soil and water resource management prescriptions may be incorporated into plans associated with management of other resource activities such as livestock grazing or wildlife management. If the watershed issue is highly significant and untreatable through other activity plans, specific watershed activity plans are prepared. Thus, watershed monitoring may involve evaluating the achievement of watershed objectives as part of other activity plans or achievement of specific watershed activity plan objectives.

Rangeland Watershed Processes and Issues

Depending on the specific issue, a wide range of watershed processes may be the subject of monitoring programs. Rangeland watershed management issues occur when beneficial resource uses are impacted, or may be impacted, by manageable sedimentation and hydrologic processes. While certain water quality issues relating to salinity, nutrients, and bacteria are sometimes considered watershed management issues, they will not be discussed in this technical note.

Manageable upland sedimentation processes include rill and interrill erosion. Manageable instream sedimentation processes include channel bank erosion, incision, deposition and aggradation, and sediment transport. Issues related to those processes are diverse and include such things as reduced forage production, poor seed germination, lowered riparian water tables, changes in channel conditions, reductions in aquatic habitat, decreased flood flow capacities, increased reservoir siltation, and increased treatment costs to water users.

Manageable hydrologic processes which affect the volume or timing of runoff include infiltration, surface storage, interception, channel capacities, and both upslope and instream resistance to flow (sometimes referred to as "roughness"). Issues related to hydrologic processes include availability of soil water for plant growth, water supply for both instream and off-site uses, flood damage, stream channel maintenance and channel quality, sediment transport, and water quality.

Common Watershed Management Techniques

Vegetation cover is usually the most important management variable influencing runoff and erosion rates on rangelands. Therefore, vegetation management, either directly through vegetation manipulations or indirectly through the design and implementation of livestock grazing plans, is a common rangeland management technique. A common watershed monitoring objective is to determine whether scientifically-designed grazing systems implemented through allotment Management Plans achieve vegetation-cover objectives. Assumptions about the relationship of cover (or some other vegetation variable) to runoff, erosion, stream channel conditions, etc., are also tested as part of watershed monitoring programs.

In situations where watershed condition is so severely degraded that natural recovery will be inefficient, mechanical land treatments and structural alternatives may be the most effective runoff and erosion control techniques (Jackson, et al. 1985). Monitoring programs may be designed to quantify the extent and duration of benefits achieved through mechanical land treatments. Monitoring of structures may involve the monitoring of structure integrity and function as well as the achievement of both on-site and off-site management objectives.

III. WHEN TO MONITOR

In some situations, monitoring may be required by law or regulation. However, in the vast majority of rangeland situations, managers must decide when or what to monitor based upon the need for additional information for responsible management. Generally, the decision to monitor should be based on a thorough analysis of watershed condition including existing and potential resource values, resource-use conflicts, knowledge or information gaps, management costs, and applicable legal requirements.

When well-evaluated management prescriptions are applied to areas with low watershed values and no major resource-use conflicts, formal watershed monitoring may not be required. Instead, informal assessments by professional staff may be sufficient management feedback. However, when intensive management prescriptions address issues involving high watershed values or severely conflicting resource uses, and when a great deal of uncertainty exists about the likely effectiveness of the management action, well-designed monitoring programs may be required.

In considering when or what to monitor, it is also useful to distinguish between highly site-specific management issues, and more generalized management issues. When management issues are highly site-specific, monitoring may have to be tailored to each individual situation. However, where monitoring addresses general management strategies, coordinating monitoring programs between field offices insures that the information collected will resolve the overall monitoring question. In this case, representative management units should be selected for monitoring and uniform methods and designs employed.

IV. ESTABLISHING MONITORING OBJECTIVES

Watershed monitoring programs should answer the question, "Has the watershed management objective been achieved?" Thus monitoring objectives can be formulated as testable hypotheses regarding the achievement of management objectives. Also, the monitoring program should allude to why the objective was or was not achieved.

To properly formulate a monitoring objective, clear descriptions are required of (1) the prescribed management activity, (2) the affected resource, (3) the processes or variables which the management activity will influence, and (4) the "indicator" processes or variables which will test the attainment of the management objective. For example, the management objective may be to reduce upland soil loss by one ton per acre per year. The prescribed management activity may be a rest-rotation grazing system. The affected resource is the on-site soil resource. Management is attempting to influence raindrop splash erosion and rill and interrill erosion caused by reduced infiltration and increased surface runoff. Because an available validated model interprets vegetation cover in terms of soil loss, percent vegetation cover is selected as the "indicator" variable which will be tested to evaluate the achievement of the management objective. Had the cover vs. soil-loss model not been available, annual soil loss from 72 ft. plots may have been selected as the "indicator" variable. In other words, the indicator variable and the influenced processes may, in some situations, be the same.

The monitoring objective can now be formulated in terms of the management objective, the management activity, and the indicator variables. In the upland soil-loss example where vegetation cover was selected as the indicator variable, the monitoring objective might be: "To determine that a rest-rotation grazing system increases vegetation cover by X percent over the cover associated with the present continuous grazing system." In any case, the monitoring objective should be stated as concisely and quantitatively as possible. A well-formulated objective should clearly define testable hypotheses and lead directly to appropriate methods and sampling/study designs.

V. WATERSHED MONITORING PLANS

Monitoring plans help guide the formulation and implementation of formal watershed monitoring programs. A monitoring plan provides a clear, concise strategy for achieving the monitoring objective. While monitoring plans may be brief, and included as part of resource activity plans, they should always contain the following items:

1. Statement of the Management Problem: The problem statement should include brief descriptions of the management issue, the management action, and the affected resource values.

2. Monitoring Objective: Formulating monitoring objectives is discussed above. In general, monitoring objectives are formulated in terms of the management objective, management activity, and indicator variables. Testable hypotheses should be formulated at this point.

3. Methods: Monitoring methods, including procedures, equipment, sampling techniques, and sample handling and analysis techniques, should be described or referenced.

4. Data Acquisition Design: The data acquisition design may involve a sampling design for direct data acquisition programs, or an input data acquisition program, including data sources, for indirect monitoring programs. Direct monitoring sampling designs need to consider required significance levels, sampling location and frequency, useful co-variables, and improvements to be gained by blocking, nesting, and stratification. An input data acquisition program which relies on existing available data should identify the data source, its availability and reliability, and any required format modifications. When the watershed monitoring program relies on data collected as part of other resource monitoring programs, the watershed specialist needs to ensure that the data collected meet the requirements of both monitoring programs.

5. Data Analysis Plan: The data analysis plan identifies the specific techniques and procedures to summarize and analyze monitoring data. For direct monitoring data, this may involve identification of appropriate statistical or numerical techniques. For analysis schemes relying on analytical models, the specific model should be identified and its application in data analysis described.

6. Data Interpretation and Report Plan: Data analysis provides a numerical or statistical summary of monitoring results. However, the meaning of those results from a management perspective may require additional interpretation by professionals and resource managers. For example, a statistical analysis may show a highly significant 0.1 ton per acre per year increase in soil loss resulted when the management objective was to not increase soil loss. However, from an overall resource perspective, it could be concluded that an increase that small is not important and that the management program has accomplished its objective. In any case, all results, interpretations, conclusions, and recommendations should be reported to management in writing upon completion of a monitoring program and at interim periods as may be required. The reporting plan should be described in the overall monitoring plan.

7. Implementation Plan: The implementation plan provides the required schedules, tasks, and budget required to implement the monitoring program.

VI. DIRECT AND INDIRECT MONITORING CONCEPTS

As indicated above, monitoring objectives are formulated in terms of the prescribed management activity, the affected resource, the processes or variables to be influenced by management, and the indicator processes or variables which will be used to test the attainment of management objectives. Monitoring can be accomplished by

(1) direct monitoring: directly measuring the process or variable to be influenced by the management action, or

(2) indirect monitoring: measuring the effects of management on an indicator variable or variables and interpreting the effects on indicator variables in terms of the process or variable of interest to management. The interpretation step is usually accomplished by using descriptive or analytical models.

While directly monitoring key rangeland watershed processes is the most accurate and definite way of determining management effects on those processes, adequate sampling programs may be expensive and logistically difficult to implement. When direct sampling programs are scaled down to meet budget and manpower constraints, precision and statistical confidence is sacrificed. Thus, a reasonable alternative may be to identify appropriate indicator variables which can be more easily sampled and to interpret or translate information about the indicator variable into information about the variable of direct interest to management.

The interpretation process adds an additional source of error to the analysis. However, this can be compensated for, in part, by the improved precision associated with sampling an indicator variable as opposed to monitoring directly the process or variable which is the subject of a management action.

Models used in the interpretation process in indirect monitoring may be descriptive models, empirical models, or physically-based process models. In rangeland watershed management, most commonly used models are, to a large extent, empirical. The differences are mostly related to the extent to which sub-processes are handled individually, and the spatial scales to which the models are applied. Process-based, distributed parameter models are usually data-intensive and time-consuming to apply. Lumped-parameter, or "black-box" models are often simple to apply, but may not adequately account for all the variables of interest. Model accuracy tends to be highly dependent upon how well model assumptions fit the conditions at hand and how well the model has been tested and validated for the area where it will be applied.

Thus, an initial decision in designing a monitoring program is whether to use direct or indirect monitoring technologies. The decision will be based upon sampling considerations, costs, and the accuracy and availability of adequate interpretive models. In all cases, the approach selected should provide sufficient information to meet the monitoring objective.

VII. DIRECT MONITORING STRATEGIES

Direct monitoring quantifies or measures the process or variable of primary interest to management as part of the monitoring program. For example, if soil-loss is the variable of concern to management, then direct monitoring would directly measure soil-loss rates on the site of interest. If infiltration is the process of concern to management, then monitoring might involve the direct measurement of infiltration rates on the site of interest. Finally, if stream discharge, water quality, or downstream sediment yields are the variables of concern to management, monitoring would involve the instream measurement of those processes.

Most common rangeland watershed processes present special problems from both a sampling and logistical standpoint. From a sampling standpoint, processes such as soil-loss, infiltration, stream discharge, suspended sediment transport, and stream channel erosion are complex processes exhibiting a great deal of variability in both space and time. A sampling program which fails to account for and quantify that variability will lack sensitivity to management changes. From a logistical standpoint, most commonly accepted techniques for sampling sedimentation and hydrologic processes are both equipment and labor intensive, and not conducive to the sampling intensities required to adequately quantify processes.

Direct monitoring strategies are most easily classified as upslope plot (and transect) studies, and instream discharge and sediment transport studies. Monitoring techniques which utilize plots or transects are amenable with the sampling principles of randomization, replication, and control, and can thus effectively detect the effects of management activities on upslope watershed processes. Instream sampling techniques are well developed and provide an integrated measure of total watershed response at a point over time. However, in rangeland settings, instream monitoring may not be amenable to control, so changes in runoff or sediment transport may be difficult to attribute to management.

A third direct monitoring strategy, channel geometry surveys, provides a long-term integrated measure of watershed response over time, at a point, and is somewhat less difficult, logistically, than discharge and sediment transport studies. Channel geometry studies are best suited to alluvial or self-formed stream channels, and--like plot studies--are compatible with the sampling principles of randomization, replication, and control.

Upslope Runoff and Erosion Studies

The use of bordered plots for the direct measurement of surface runoff and soil loss from rangelands is thoroughly described in Bureau of Land Management Technical Note 368 (Jackson, et al., 1985). Plots are constructed so that all runoff and soil loss from them can be collected and measured. Runoff and erosion plots are most easily used for measuring annual runoff and soil-loss rates, but may be instrumented to record storm-period or instantaneous runoff and soil-loss rates. While there are no standard sizes for runoff plots, soil-loss plots should generally be at least 35 ft. in length, and preferably 72.2 ft. in length (USDA, 1981). In addition to providing direct monitoring data, data from soil-loss plots can be used to validate common soil-loss models, such as the Universal Soil Loss Equation (Wischmeyer and Smith, 1978).

Plots have certain advantages from a sampling standpoint in that they can be randomly located, replicated (i.e., at least two plots per treatment), and controlled. Control plots are generally located in an exclosure, or on an untreated area, at the selected monitoring site. The disadvantages to plots are (1) numerous plots are required to characterize the spatial variability within a given allotment, range-site, or small watershed, (2) upslope plot response to management activities is difficult to interpret in terms of instream or downstream processes, when those processes are of primary concern to management, and (3) the number of events required for suitable analysis may limit the plot's usefulness because of time constraints.

Depending on the variables or processes of interest to management, other upslope monitoring strategies are available which possess similar sampling attributes similar to plots. They include erosion pin surveys (soil loss), erosion net studies (soil loss), infiltrometer studies (infiltration capacities), and large-plot rainfall simulator studies (apparent infiltration capacities, soil-loss index). As with all monitoring programs, the proper selection of a monitoring technique will depend on the monitoring objective, site conditions, and budgetary and manpower constraints.

Instream Discharge and Sediment Transport Studies

The design of instream watershed monitoring programs is well described by Ponce (1980), and guidelines for the collection and analysis of sediment data are provided by Williams and Thomas (1984). Instream monitoring programs involve the collection of discharge and suspended sediment concentration data within the context of a basic study design.

Instream sampling stations generally provide a continuous measurement of stream discharge and periodic measurements of suspended sediment concentration. Suspended sediment is sampled either by hand on a predetermined schedule or automatically using programmable pumping samplers. Whereas instantaneous discharge is usually measured accurately, the quality of suspended sediment measurements depends upon the method used (point or depth-integrated) and the sampling frequency. A common analysis method is to develop a regression relationship between instantaneous discharge and suspended sediment concentration.

The key to effective instream monitoring is carefully identifying the variable or process of interest to management, and then developing a sampling design and data analysis program which will quantify the effects of management.

Discharge variables of interest to management include peak or design-flow discharge rates, seasonal low-flow discharge rates, and annual or seasonal water yields. Sediment transport variables of interest to management include suspended sediment concentrations and total sediment yields. Sediment yields may be measured directly using reservoir surveys but are more commonly calculated from discharge and sediment concentration data. Bedload sediment yields may be sampled by a variety of techniques, but are most often determined indirectly using bedload transport equations or by compensating for the "unmeasured" load in suspended sediment transport calculations (Graff, 1971).

Since instream sampling techniques are often not amenable to sampling designs involving randomization, replication, and control, several other study designs are usually recommended for instream monitoring programs (Ponce, 1981). Common study designs include paired watershed designs, upstream-downstream designs, and single-station pre- and post-treatment designs. Both the paired watershed and single-station designs require sampling both prior to and after applying the management action to be monitored. The upstream-downstream design assumes that the sampling station upstream of the management treatment represents the "pre-treatment" condition, and the station downstream of the management treatment represents the "post-treatment" condition. For the one-station design, pre- and post-treatment statistical comparisons would be made by comparing means of the measured variables or regression lines of developed relationships (e.g., discharge vs. suspended sediment concentration). For the paired or upstream-downstream designs, statistical comparisons can be made by comparing paired-station regressions. Ponce (1981) recommends a paired station approach because it can account for year-to-year variability caused by climate and hydrology.

Rangelands present special problems for paired station instream sampling designs. Paired watershed designs are often not possible when summer convectional storms produce high streamflow conditions, because most convectional storms are highly localized and will not be similar over two separate watersheds. Upstream-downstream designs are made difficult by the dispersed nature of livestock grazing--the most common rangeland land use. It is difficult to locate upstream and downstream sampling stations on relatively homogeneous stream reaches.

Whichever instream monitoring design is selected, a great deal of thought needs to be given during the planning stage to data analysis procedures and the interpretations various data analysis results will have regarding management effects.

Channel Geometry Studies

In alluvial or self-adjusting stream channels, channel hydraulic geometry variables, including width, depth, slope, sinuosity, bed sediment sizes, and resistance to flow all adjust to local hydrologic, geologic, and vegetation conditions. Thus, every channel assumes a unique set of geometric and hydraulic characteristics in response to its watershed condition. While there are no standardized methods of monitoring or interpreting hydraulic geometry, many studies document changes in hydraulic geometry in response to land use (e.g., Lyons and Beschta, 1983; Platts, 1981).

Collecting and analyzing channel cross-section data is discussed in Parsons and Hudson (1985). There is also evidence that other morphological features such as pool-riffle sequencing, sinuosity, and bed material composition may be useful monitoring variables (Jackson and Beschta, 1984; Beschta and Platts, 1985). Because monitoring using channel geometry methods is a relatively new technique, monitoring programs which utilize these techniques should be designed with great care. The roles and interactions of morphological features at a given site should be analyzed, controls should be identified, and a careful data analysis and interpretation plan should be developed so results can be interpretated in terms of management effects.

VIII. INDIRECT MONITORING STRATEGIES

Vegetation cover is the most important management variable influencing runoff and erosion rates on rangelands, and most common rangeland watershed management techniques influence vegetation cover. Cover may be defined as canopy cover, foliar cover, basal area cover, or point cover (USDI Bureau of Land Management, 1985b). It is important to clearly define cover and the method used for measuring cover when using it as an indicator variable. Since vegetation cover is relatively easy to monitor (USDI Bureau of Land Management, 1984) compared to most watershed processes, it follows that any analytical tools which relate vegetation cover to such processes as runoff, or soil loss, are useful watershed monitoring tools. A number of such models are currently available and include both simple lumped-parameter empirical models and more complex, process-driven systems models. Models commonly available for rangeland watershed monitoring programs are described below.

When selecting a model for a monitoring program, carefully consider the objective, model assumptions and data requirements, and the extent to which the model is validated for the intended area of use. Also, it is important that the watershed specialist help design the monitoring programs (e.g., vegetation monitoring programs) which will ultimately provide the indicator variables employed by the selected model. The specialist should be especially concerned that sampling locations are representative of important hydrologic units, that the principles of randomization, replication, and control are employed in the sampling design, and that the required cover parameters are sampled.

Simple Lumped-Parameter Models

The most commonly used rangeland watershed models for estimating runoff, soil loss, and sediment yields are, respectively: The Soil Conservation Service (SCS) Curve Number Runoff Model, the Universal Soil Loss Equation (USLE), and the Modified Universal Soil Loss Equation (MUSLE). In addition to being useful on their own, these models are often integral components of larger system models.

SCS Curve Number Model

The SCS Curve Number Model (US Soil Conservation Service, 1975) is, conceptually, a very simple rainfall runoff model. The model incorporates three fundamental assumptions about the functioning of a watershed. First, it assumes that runoff does not begin upon the initiation of rainfall, but rather the watershed absorbs all rainfall up to a point. This is termed the initial rainfall abstraction. Second, the model assumes that, following the initial abstraction, the ratio of runoff to rainfall is proportional to the ratio of actual to potential watershed storage. So, the more rainfall actually stored on the watershed, the higher the proportion of rainfall which appears as streamflow. Third, the model assumes that the initial abstraction is 0.2 times the potential watershed storage. This relationship is based upon the analysis of considerable runoff data. The actual SCS runoff equation is

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad (1)$$

where Q is a volume runoff, and S is the potential watershed storage and P is precipitation. The SCS chose to define S in terms of a runoff curve number, CN, which ranges between 0 and 100.

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

Using this definition of curve number, runoff goes up as curve number goes up.

Curve number selection is generally based upon hydrologic soil group, vegetation cover, land use, hydrologic condition, and antecedent soil moisture. Curve number selection is aided by tables and graphs. Recent studies suggest that curve number selection may be aided by remote sensing (Rango, 1985), or by correlation with soil-hydraulic properties and vegetation cover.

Given a runoff volume for a given design rainstorm, the SCS Curve Number Model constructs a synthetic triangular hydrograph by defining a peak flow, a time to peak, and a recession time. The time to peak, which was determined empirically, is defined in terms of a watershed time of concentration. Since the hydrograph is a triangle, peak flow is solved trigonometrically given the triangle base dimensions and area (volume runoff).

While the SCS Curve Number model, based upon years of actual rainfall-runoff data, is both conceptually and numerically simple; it lumps many important watershed variables and is highly sensitive to curve number selection. Therefore, it must be applied carefully and its results should be evaluated with a great deal of professional judgment.

Currently, rangeland relationships between curve number and vegetation cover are developed only in a general sense (i.e., in terms of hydrologic condition). Thus, the Curve Number Model has limitations as a monitoring tool. However, it may be used to evaluate rainfall-runoff data, and to quantify the long-term effects of land management on curve number. As the model becomes validated on a site-specific basis, its utility as a planning and monitoring tool will be enhanced.

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE), an empirical erosion model, computes long-term average annual soil losses from sheet and rill erosion (Wischmeier and Smith, 1978). Soil loss is calculated from Factors representing rainfall patterns, soil type, topography, vegetation cover, and management practices. Data from over 10,000 runoff and soil-loss plots, mostly located in the eastern and midwestern United States, were used to quantify each of the USLE factors. As they are defined, slope length, steepness, cover, and land management factors modify measured soil loss rates from reference plots 72.6 feet long on 9 percent slope, maintained in tilled, continuous fallow. Where reference plot data are unavailable, empirical techniques predict reference plot soil loss through correlation with soil type and rainfall characteristics.

The Universal Soil Loss Equation is

$$A = RKLSCP \quad (3)$$

where:

A is the computed soil loss expressed in tons per acre per year.

R, the rainfall and runoff factor, is the number of rainfall erosion index units for a normal year's rainfall and considers the effects of raindrop energy and maximum rainfall intensities.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil on a unit plot, which is defined as a 72.6-ft. length of uniform 9 percent slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft. long plot under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9 percent slope under identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled, continuous fallow.

P, the support practice factor, is the ratio of soil loss with a conservation practice such as contour furrowing to that with straight-row farming up and down the slope.

USLE calculates long-term average annual soil loss caused by sheet and rill erosion from rainfall and runoff. It may be used to (1) compare existing erosion condition to a predetermined standard or "tolerance," (2) predict the effects on soil loss of planned management alternatives given knowledge of how those management alternatives affect vegetation cover and soils condition, (3) indirectly monitor the management effects over time on erosion by using site and cover data to estimate soil loss, and (4) identify important or sensitive erosion areas and quantify spatial variations in watershed erosion.

The USLE procedure has several important limitations:

(1) The equation only estimates soil loss caused by sheet and rill erosion. It does not predict soil deposition, nor does it estimate gully or stream channel erosion, all of which are important rangeland sedimentation processes.

(2) The rainfall-runoff factor is an index of the erosive energy of rainfall and associated runoff. It does not account for the erosive forces of soil freeze-thaw, wind, or snowmelt. Wind can be an important erosive force on arid and semiarid rangelands. A procedure for estimating wind erosion is described in USDA (1976).

Snowmelt is generally not an important cause of sheet and rill erosion on most western United States' rangelands, although it may be important when soils are frozen or when rain occurs on a shallow snow-pack.

(3) The equation has not been well validated on western rangelands and its accuracy is unknown. While relative differences in soil loss estimates should be meaningful in planning and monitoring programs, soil loss estimates used for engineering designs or economic analyses may involve a significant, though unknown degree of inaccuracy.

As a monitoring tool, USLE is sensitive to changes in vegetation type, canopy cover, and ground cover. Presently, however, rangeland cover relationships are not well developed. The goal of an ongoing program by BLM and the Agricultural Research Service is to improve the applicability of USLE to rangelands, and in particular, providing improved determinations of the Cover, "C", factor.

Modified Universal Soil Loss Equation

USLE (Williams, 1975) was modified to permit its application in calculating storm-period sediment yields. In its modified form, the rainfall factor in USLE is replaced by a runoff factor. The runoff factor is defined empirically in terms of total runoff volume, Q, and peak runoff rate, q_p. The Modified Universal Soil Loss Equation, MUSLE, is

$$y = 11.8\ (Qq_p)\ 0.56\ KLSCP \qquad (4)$$

where all terms are as defined above and y is sediment yield, in tons.

MUSLE, a fairly new equation, is still undergoing validation. While it shares many of the same shortcomings of USLE, preliminary validation results suggest it may be a useful predictor of sediment yields. Like USLE and the SCS Curve Number model, MUSLE is commonly a component of larger watershed systems models.

MUSLE was designed to predict storm-period sediment yields on a field scale. Longer term sediment yields from larger watersheds are often estimated using a method developed by the Pacific Southwest Inter-Agency Committee (1968).

<u>Integrated Systems Models</u>

Within the range and watershed science a few models are available and many are in the final development stages. Most models analyze surface runoff, subsurface runoff, percolation, erosion, sediment yield, plant growth, or a combination of these factors.

In range monitoring, a model's usefulness depends on the specialists' needs. Several broad areas of modeling applications include:

1. Quantify the response of a factor such as plant growth or runoff to an environmental condition.

2. Normalize a response to an "average" set of conditions.

3. Create historical response curves based on weather records or other observations.

4. Create response curves that reflect the probability of a particular occurrence (i.e., floods, low production, unacceptable erosion).

5. Improve monitoring efficiency by estimating: (a) magnitude of a response (is it within measurable limits?), (b) factors most sensitive to change, (c) influence of soils on changes, (d) sensitivity of a monitoring plan to a management action, and (e) optimum time for field data collection.

6. Provide an analysis tool to interpret monitoring data.

The specialists' knowledge of a site's complex interrelationships will dictate the use of a particular model in range and watershed monitoring. Rangeland models will never replace sound professional judgment, but they can support judgments and provide additional analysis tools. Four models, each with a great deal of promise, are described briefly below.

Water Resources Simulator

The Simulator for Water Resources in Rural Basins (SWRRB) model simulates hydrologic and sedimentation processes in rural basins (Arnold and Williams, 1985). SWRRB simulates daily, monthly, or yearly runoff and sediment yield on large complex basins, including routing through reservoirs, ponds, and channels.

A weather generator is included which allows the model to operate when daily precipitation and temperature data are not available. Surface runoff is generated using the SCS curve number methods, with curve number continuously corrected for daily soil moisture content. Evapotranspiration is estimated daily. Sediment yield is simulated by the MUSLE (Williams, 1975) and a sediment routing model. The model, currently available for microcomputers, has interactive data entry capabilities.

Erosion and Productivity Impact Calculator

The Erosion and Productivity Impact Calculator (EPIC) simulates soil loss and crop production (Williams, 1985). The model is especially useful in providing an understanding between soil-loss and nutrient-loss effects on long-term productivity. EPIC is a field-scale model with nine major conponents--hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, plant environment, and economics.

The hydrology component is based upon the SCS curve number method and accounts for both variable soil layer thickness and runoff from frozen soil. Both percolation, lateral subsurface flow and evapotranspiration are accounted for. The erosion component is based upon the USLE. Weather input can be simulated as the model can be run for long time periods (greater than 100 years). While EPIC was originally developed for croplands, it may be applicable to rangelands. Validation efforts on rangelands are ongoing.

Rangeland Hydrology and Yield

The Ekalaka Rangeland Hydrology and Yield Model (ERHYM) models soil moisture, runoff, and annual herbage yield on northern Great Plains Rangelands (Wight and Neff, 1983). The model currently is being validated for broad application on rangelands. ERHYM can simulate any year's observed hydrologic and vegetation response using actual daily climate data, or it can simulate a current year's growing condition and forecast future peak standing crop. If unavailable, the model is capable of generating temperature and solar radiation data.

ERHYM separates precipitation into runoff and water available for soil-water recharge based upon the SCS curve number method. It then provides a daily accounting of soil-water content. Evaporation is calculated as a function of potential evaporation and the time since the soil was last wetted. Transpiration removes water from each soil layer based upon the potential transpiration soil-water content, root distribution, and soil temperature. Herbage yields are based upon average or potential site productivity and are modified by the ratio of actual transpiration to potential transpiration.

Production and Utilization on Rangelands

The simulation of Production and Utilization on Rangelands (SPUR) model was developed by the Agricultural Research Service to represent state-of-the-art in rangeland ecosystem models (Wight and Springer, 1985). SPUR is a physically-based model which simulates grazing of up to seven individual plant species on up to nine range sites. The model can account for wildlife consumption, plant competition, and livestock and plant site preference.

SPUR has five basic components: (1) climate, (2) hydrology, (3) plant, (4) animal, and (5) economic. The model requires climate data that can be from historic records or generated within the model. The hydrology component is based upon the SCS curve number method, but has enhanced capability to deal with snowmelt, and water and sediment routing. The plant growth model is more sophisticated than that in ERHYM and simulates the dynamics of phytomass and nitrogen in the soil-plant system. Both a pasture-scale and basin-scale version of SPUR have been developed. The model is currently being refined and validated and is available for research applications.

Precipitation-Runoff Modeling System

The Precipitation-Runoff Modeling System (PRMS), developed by the U.S. Geological Survey, evaluates the impacts of precipitation, climate, and land-use on surface water runoff and general small basin hydrology (Leavesley et al., 1983). The model has a modular design which allows the user to design and construct a model which meets his needs from a general library of subroutines.

PRMS can function as either a lumped or distributed parameter model and can simulate both mean-daily and stormflow hydrographs. The model is applied to small watersheds which have been divided into hydrologic response units (HRUs) based upon gross basin characteristics such as slope, aspect, soils, and vegetation. A water and energy balance is then maintained for each HRU. Streamflow is generated by surface, subsurface (interflow), and ground water flow components, and then routed through the channel system. Net precipitation is partitioned into surface runoff using a form of the Green and Ampt infiltration equation. Snowmelt is computed by an energy balance method. Soil-water can be evaporated, transpired, or routed--either to the streams or to a ground water zone.

The model is highly physically based and is very data-intensive. As a result, it generally requires calibrating to individual watersheds. Calibration and parameter optimization have been performed on a large number of rangeland watersheds in U.S. coal regions.

IX. STATISTICAL CONSIDERATIONS IN WATERSHED MONITORING

Controls, replication, and randomization are important considerations in watershed monitoring plans and all are necessary to evaluate the effect of a management action.

Controls

Controls are necessary to attribute a detected change (or lack thereof) to a management action. If the management action and control areas are located so that the management action is the only difference between two areas, then any change can be attributed to the management action rather than to a pre-existing difference between the two areas. If an area receiving a management action changed significantly over time, it will be difficult to prove that the management action caused the change unless a comparable control area was monitored.

Replication

Statistical tests are based on variability. Statistical tests compute the variability within a group of measurements and compare this "within" variability to the variability between groups of measurements. If the variability between groups is much larger than the variability within groups (as measured by an F test), the groups are significantly different.

Thus, at least two independent plots, samples, or observations per management action and per control area are required to compute the within group variability. It is not acceptable to use one plot or sample and measure it year after year. The years are not replications, but are repeated observations on the same plot. Statistics books refer to these as repeated measures or nested designs (Winer, 1971). If only one plot, sample, or observation is used, statistical methods cannot be applied to the data analysis.

The number of samples or plots required to detect differences between management action and control areas depends upon the computed variance.

The F test, or variance ratio test, tests whether a difference between two or more mean values, such as the mean sediment yield for an exclosure and a control area, is statistically significant. As sample size increases, the tabulated F values, which must be exceeded for a given level of significance to apply, decrease.

Because both the variance and tabled F values decrease rapidly as the number of samples or plots increase from two to four, even one more sample or plot than the minimum of two will result in a much more sensitive statistical test. If the difference between the management action and control areas is large, then a small number of samples or plots will detect the difference. However, if the measured difference is small, then a large number of samples will be needed to detect a difference. Most statistics books, such as Sokal and Rohlf (1969) or Snedecor and Cochran (1976) give formulas to estimate the sample size needed to detect a difference between two means.

Randomization

The purpose of randomization is to remove bias. Randomization gives each potential plot location an equal chance of selection. The area included in the randomization process is the same area where any conclusions will apply. If the area where the management action will be applied is chosen rather than randomized, conclusions will apply only to that particular area, and not to any surrounding area, no matter how similar that surrounding area might be.

If, within a grazed pasture and within an ungrazed pasture, erosion plot locations are randomly selected from among all the possible plot locations with a slope of 2 to 3 percent on the xyz soil, then conclusions will apply to all areas within the grazed and ungrazed pastures with 2 to 3 percent slopes on the xyz soil. If, however, the grazed and ungrazed pastures were randomly chosen from among all pastures within a larger allotment, then conclusions will apply to all parts of the allotment with 2 to 3 percent slopes on the xyz soil.

When randomization is done over larger areas, the variability increases as more diverse areas are included within the randomization area. If the number of replications is small, i.e., two or three, then sites should be very similar so that the variability will be as small as possible.

Two packaged statistical programs, SPSS and BMDP, are available as batch programs on BLM's Honeywell DPS-8 and will perform all these analyses. Statpack, an interactive statistical package, will perform some of the analyses.

X. SAMPLE DESIGN AND DATA ANALYSIS

Sample Designs

Plot studies should be designed with controls, plots should be randomly located, and samples should be replicated to provide a desired level of statistical significance to the data analysis. A thorough discussion of sampling designs for upslope plot studies is provided in Jackson, et al. (1985).

Instream studies are also best designed with a statistical control so that paired-sample analyses can be performed on the data. Ponce (1981) provides a thorough discussion of sampling designs for instream water quality studies.

Data Analysis

The sampling design generally dictates the data analysis methods which can be used. Most upslope or instream studies are analyzed using one or more of four common statistical methods: T-tests, Analysis of Variance (ANOVA), Regression Analysis (including trend analysis), and Covariance Analysis. Each of these methods is described below.

Three major assumptions shared by the four methods are independence of observations, normality of the underlying distributions, and equality of within group variances. Independence is the most important and the most often violated criterion. Typically, violation of the independence assumption overestimates the statistical significance of change and/or differences. Violation of the normality and equality of variance assumptions can often be corrected by transforming the data and when not corrected, tends to underestimate the significance of statistical tests.

Time-series analyses can also be used to fit and forecast hydrologic data, and are described below. A time series approach to analyze hydrologic data, which is often correlated with time, is generally warranted since the independence of observations assumption is relaxed. Presently, time series analysis is not often used in hydrologic analyses, though the recent availability of easily used computer programs may encourage its use.

T-test

A T-test assesses the significance of a difference between two sample means. One form of the test, often called a two-sample T-test, is used with independent samples while another form of the test is used with paired or dependent samples. With an independent sample, observations or measurements are classified into two groups and a test of mean differences is performed. If the observations within a sample are paired or correlated, one of the sets of observations is subtracted, pairwise, from the other and resulting values are tested for a difference from zero.

The paired T-test is quite sensitive, since pairing removes outside influences on the measured variables. If the total number of observations is very small, i.e., less than eight, a paired test is not as sensitive as a two-sample test.

Analysis of Variance

Analysis of Variance (ANOVA) assesses the effects of one or more factors upon a continuous dependent variable. A one-way ANOVA, which has only one factor, is merely an extension of the T-test to more than two groups. Typical watershed monitoring factors are grazing intensity, season of the year, soil type, and vegetation cover, while total storm runoff, sediment yield, and TDS are common dependent variables.

The most important special class of designs for watershed monitoring is that class which has repeated testing or measuring of the same object or individual, such as daily readings from a stream gage or several years' runoff values from erosion plots. The repeated measure designs also assess the significance of a trend over time.

Regression Analysis

Regression analysis predicts one variable (the dependent variable) in terms of one or more other variables (the independent variables). The coefficient of multiple determination, r^2, measures the prediction accuracy and strength of the linear association.

Regression analysis can be performed upon a fixed number of independent variables, or a stepwise technique which allows variables into the regression equation sequentially, depending on their predicting ability, can be used.

Covariance Analysis

Covariance analysis combines the features of analysis of variance and regression, and is often used to determine if one regression relationship is different from another. The analysis has one continuous dependent variable, but the independent variables include both the types described above under regression and analysis of variance. The dependent variable is adjusted by the "regression type" independent variables before an ANOVA assesses the influence of the "ANOVA type" independent variables. The "regression type" independent variables must not influence the "ANOVA type" independent variables, but should influence the dependent variable directly.

In watershed monitoring, the main use of this statistical technique is correcting for uncontrolled influences such as rainfall. Properly used, this technique increases the sensitivity of an analysis of variance.

Time Series

Time series analysis characterizes the way measurements, made at equidistant points, vary over time. The measurements may be correlated, with the correlation between measurements depending on the time interval separating them. The analysis allows for the presence of a trend in the data. Generally, the three steps to model a time series are: (1) identify a tentative model, (2) estimate the parameters and examine diagnostic statistics and plots, and (3) forecast using the model, if it is deemed acceptable (SPSS, Inc., 1983).

XI. INTERPRETATIONS FROM MONITORING DATA

The purpose of monitoring is to determine whether or not management objectives are being achieved by implementing land use management plans. Therefore, the final and key step in watershed monitoring is to ensure that not only the results of monitoring programs, but interpretations, analyses, and alternative recommendations are fed back into the planning system. Even when it is determined that management objectives are being met, the results of a monitoring program may indicate that management modifications are required, or even that modifications in the original watershed management objectives should be considered.

Well planned and well-implemented monitoring programs will do more than meet monitoring objectives. They will enhance our understanding of both natural systems and the effects of management prescriptions. As such, they will provide additional, useful information to all steps of the resource management planning process.

LITERATURE CITED

Arnold, J.E., and J.R. Williams, 1985. Validation of SWRRB - A Simulator for Water Resources in Rural Basins. In: E. B. Jones and T. J. Ward, ed., Watershed Management in the Eighties, ASCE, New York, NY, pp. 107-114.

Beschta, R.L., 1985. Conceptual Model of Sediment Transport in Streams. In: C. Thorne, ed., Proceedings of the International Workshop on Problems of Sediment Transport in Gravel-Bed Rivers, Aug. 12-17, Colorado State University, Pingh Park, CO.

____________, and W.S. Platts, 1985. Morphological Features of Small Streams: Significance and Function. Paper Presented at 21st Annual Amer. Water Res. Ann. Conference, August 12-15, Tucson, AZ.

Branson, F.A., R.F. Miller, and I.S. McQueen, 1966. Contour Furrowing, Pitting, and Ripping on Rangelands in the Western United States. J. Range Manage., 19(4):182-190.

Gebhardt, K.A., 1985. Erosion, Productivity, and Rangeland Watershed Planning. In: E.B. Jones and T.J. Ward, ed., Watershed Management in the Eighties, ASCE, New York, NY, pp. 175-82.

Gifford, G.F., and R.A. Hawkins, 1978. Hydrologic Impact of Grazing on Infiltration: A Critical Review. Water Resources Research, 14(2):305-313.

Graff, W.H., 1971. Hydraulics of Sediment Transport. McGraw-Hill Book Co., New York, NY, 513 pp.

Heede, B.H., 1981. Rehabilitation of Disturbed Watersheds Through Vegetation Treatment and Physical Structures. In: D.M. Baumgartner, ed., Proceedings, Interior West Watershed Management Symposiums, Washington State University, Pullman, WA, pp. 257-68.

Jackson, W.L., K.A. Knoop, J. Szalona, and S. Hudson, 1985. A Technique for Monitoring Runoff and Soil Loss from Rangelands Using Paired Plots. USDI Bureau of Land Management, Technical Note 368, 20 pp.

____________, B.A. Van Haveren, E.B. Janes, 1985b. Managing Headwater Areas for the Control of Sediment and Salt Production from Western Rangelands. IN: Proceedings, Prespectives on Nonpoint Source Pollution, In Press.

____________, and R.L. Beschta, 1984. Influences of Increased Sand Delivery on the Morphology of Sand and Gravel Channels. Water Resources Bull. 20(4):527-533.

Leavesley, G.H., R.W. Lichty, B.M. Troutman, and L.G. Saindon, 1983. Precipitation-Runoff Modeling System: Users Manual. USGS Water Resources Investigations 83-4238, Denver, CO, 207 pp.

Lusby, G.C., 1979. Effects of Grazing on Runoff and Sediment Yield from Desert Rangeland at Badger Wash in Western Colorado, 1953-73. USGS Water-Supply Paper, 1532-I, 134 pp.

Lyons, J.K., and R,.L. Beschta, 1983. Land Use, Floods and Channel Changes: Upper Middle Fork Willamette River, Oregon (1936-1980). Water Resources Res., 19:463-471.

Miller, R.F., I.S. McQueen, F.A. Branson, L.M. Shown, and W. Buller, 1969. An Evaluation of Range Floodwater Spreaders. J. Range Manage., 22(4):246-257.

Pacific Southwest Inter-Agency Committee, 1968. Factors Affecting Sediment Yield in the Pacific Southwest Area. Report of the Water Management Subcommittee, 10 pp.

Parsons, S., and S. Hudson, 1985. Channel Cross-Section Surveys and Data Analysis. USDI Bureau of Land Management, Denver Service Center, Denver, CO, 48 pp.

Platts, W.S., 1981. Effects of Sheep Grazing on a Riparian Stream Environment. USDA, Forest Service Research Note INT-307, 5 pp.

Ponce, S.L., 1981. Water Quality Monitoring Programs. USDA Tech. Paper TP-00002. Forest Service Watershed Systems Development Group, Ft. Collins, CO, 66 pp.

Rango, A., 1985. Assessment of Remote Sensing Input to Hydrologic Models. Water Resources Bull., 21(3):423-32.

Smith, S.J., J.R. Williams, R.G. Menzel, and G.A. Coleman, 1984. Prediction of Sediment Yield from Northern Plains Grasslands with the Modified Universal Soil Loss Equations. J. Range Manage., 37(4):295-297.

Snedecor, G.W., and W.G. Cochran, 1967. Statistical Methods. Iowa State Univ. Press, Ames, IA, 593 pp.

Sokal, R.R., and F.J. Rohlf, 1969. Biometry, the Principles and Practice of Statistics in Biological Research. W.H. Freeman and Co., San Francisco, CA, 776 pp.

Soloman, R.M., J.R. Maxwell, and L.J. Schmidt, 1982. Determining Watershed Conditions and Treatment Priorities. In: Proceedings, 1982 Arizona-Nevada Academy of Sciences, Hydrology Section (Vol. 12), 10 pp.

SPSS, Inc., 1983. SPSSX User's Guide. McGraw-Hill, New York, NY, 805 pp.

U.S. Soil Conservation Service, 1975. Urban Hydrology on Small Watersheds. Technical Release No. 55, Washington, D.C.

USDA Agricultural Research Service, 1982. Estimating Erosion and Sediment Yield on Rangelands. ARM-W-26, Oakland, CA, 228 pp.

USDI Bureau of Land Management, 1984. Rangeland Monitoring; Utilization Studies. Technical Ref. TR4400-3, 105 pp.

______________________________, 1985. Rangeland Monitoring; Trend Studies. Technical Ref. TR4400-3, 105 pp.

USDI Bureau of Land Management, 1985b. Rangeland Monitoring; Analysis, Interpretation, and Evaluation. Technical Ref. TR4400-5.

Wight, J.R., and E.L. Neff, 1983. Soil-Vegetation-Hydrology Studies, Vol. II. A User Manual for ERHYM: The Ekalaka Rangeland Hydrology and Yield Model, USDA Agr. Research Serv., AAR-W-29, 30 pp.

__________, and E.P. Springer, 1985. SPUR - Simulation of Production and Utilization of Rangelands. In: Proceedings of the National Resources Modeling Symposium, USDA-Agr. Research Serv., ARS-30, Ft. Collins, CO, pp. 49-55.

Williams, J.R., 1975. Sediment-Yield Prediction with Universal Equation Using Runoff Energy Factor. In: Present and Prospective Technology for Predicting Sediment Yields and Sources, U.S. Dept. Agr., ARS-S-40.

__________, 1985. The EPIC Model: An Overview. In: Proceedings of the Natural Resources Modeling Symposium, USDA Agr. Research Serv., ARS-30, Ft. Collins, CO, pp. 23-30.

Williams, O., and R.B. Thomas, 1984. Guidelines for Collection and Analysis of Sediment Data. USDA Forest Service Watershed Systems Development Group, Ft. Collins, CO, Draft report, 108 pp.

Winer, B.J., 1971. Statistical Principles in Experimental Design. 2nd ed., New York, NY, McGraw-Hill, 907 pp.

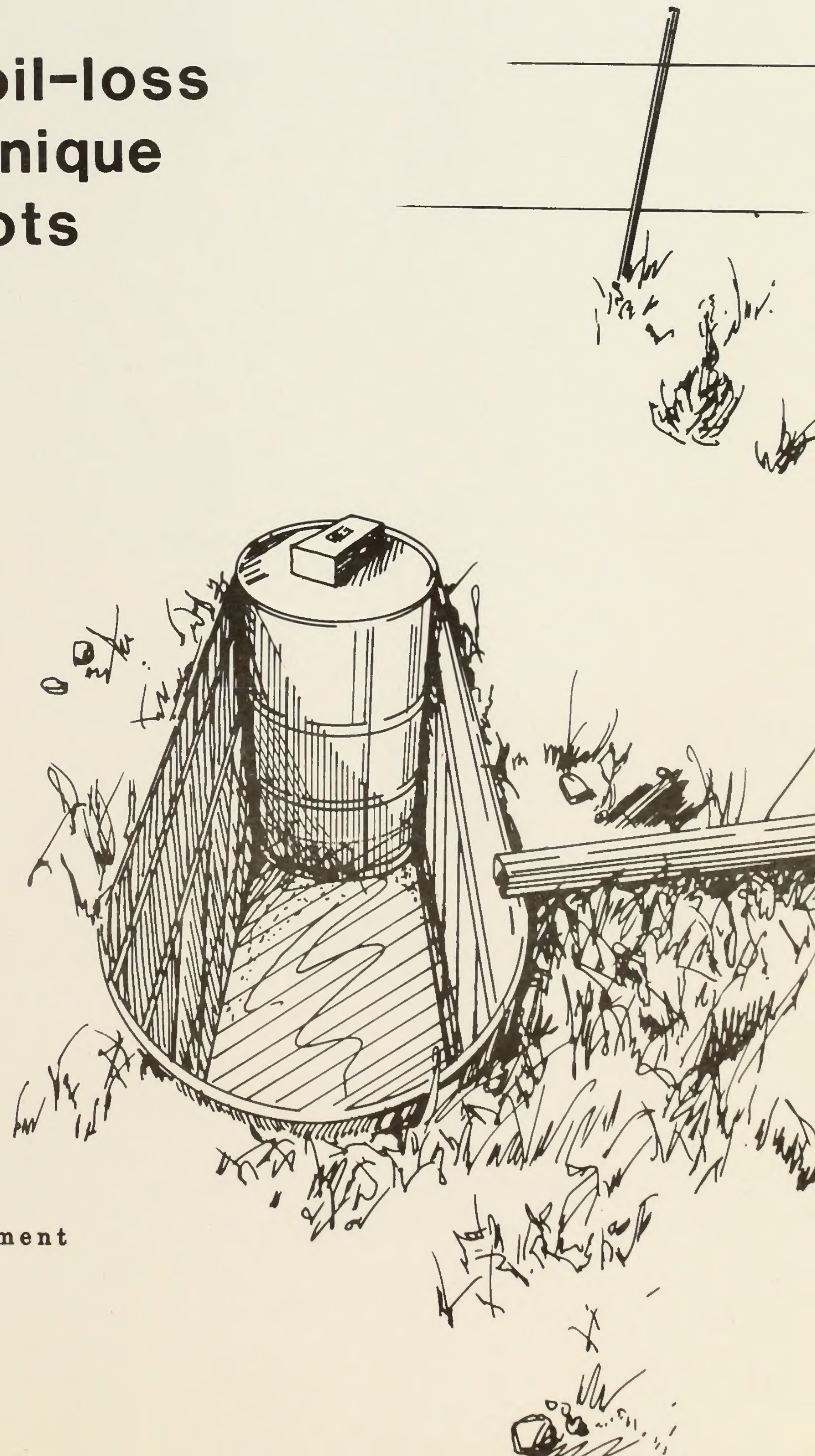
Wischmeier, W.H., and D.D. Smith, 1978. Predicting Rainfall Erosion Losses. USDA Agr. Handbook 537, Washington, DC, 58 pp.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1985—580-504/25376 REGION NO. 8

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

TECHNICAL NOTE 368

A Runoff and Soil-loss Monitoring Technique Using Paired Plots



by
William L. Jackson
Karla Knoop
Joseph J. Szalona
Shirley Hudson

USDI Bureau of Land Management
Denver, Colorado

August 1985

Technical Note 368

A Runoff and Soil-Loss Monitoring Technique Using Paired Plots

by
William L. Jackson[1]
Karla Knoop[2]
Joe Szalona[3]
Shirley Hudson[4]

August, 1985

BLM/YA/PT/85-005-4341

Available from: Printed Materials Distribution Section
BLM Service Center, Bldg. 50, D-558B
Denver, Colorado, 80225
and
National Technical Information Service
Springfield, Virginia, 22161

1,4 Hydrologist and Statistician, Bureau of Land Management, BLM Service Center, Denver, Colorado.
2 Hydrologist, Salt Lake City, Utah.
3 Hydrologist, Federal Interagency Sedimentation Project, Minneapolis, Minnesota.

A Runoff and Soil-Loss Monitoring Technique Using Paired Plots

Abstract

Differences in annual runoff and soil loss caused by livestock grazing on arid rangelands can be measured directly from large plots. A low-cost monitoring technique is described which uses rectangular plots, collection tanks, and cumulative mechanical stage-height counters. Annual runoff and soil loss are measured on paired grazed and ungrazed plots. The plots are replicated and the pairing provides a control. Thus the statistical validity of any differences between grazed and ungrazed plots can be assessed. The plots are easy to construct, and can be maintained with as few as one to two visits per year. The system is presently being tested at four separate locations.

Table of Contents

List of Figures

List of Tables

INTRODUCTION

This technical note describes the construction and instrumentation of runoff plots being tested to measure surface runoff and soil loss. Appropriate sampling designs and data analysis methods are also described. While the plots are designed to measure annual runoff and soil loss differences between grazed and ungrazed plots, they are easily adapted to measuring storm-period runoff and soil loss differences. Both grazed and ungrazed plots are located in close proximity to each other so that they have the same slope, aspect, vegetation cover, soil, and precipitation characteristics. The plots are a low-cost, low-maintenance method of monitoring upland rangeland hydrologic condition. Sampling controls and replication allow differences in runoff and sediment yield between grazed and ungrazed plots to be attributed to livestock grazing and allow a level of statistical significance to be attached to the difference. The plot size and measured variables are suitable for validating common runoff and soil-loss models, and thus provide information which can be extrapolated to other areas with similar hydrologic and range-site characteristics.

BACKGROUND

Instream runoff and sediment transport rates are highly variable and are influenced by many factors in addition to changes in land use and watershed condition. Most arid watersheds--even small ones--are hydrologically complex. This is due to large spatial and temporal variations in watershed conditions. Often ungrazed areas such as bedrock rims, gullies, or channels are important source areas for runoff and sediment. Contributions to streams of runoff and sediment from grazed upland areas may be masked by processes in ungrazed areas or channels. Suspended sediment transport, for example, may vary as much as an order of magnitude at a single stream location for a given runoff rate (Beschta, 1985). Thus, instream sediment transport may not be a sensitive indicator of changes in watershed conditions.

Alternatives to traditional instream sampling for direct rangeland watershed monitoring include retention basin studies (Burkham, 1966; Lusby, 1979), simulated rainfall studies (Lusby and Lichty, 1983), erosion transect studies (Blaney and Warrington, 1983), erosion net studies, and erosion condition assessments (Clark, 1974). Small retention basin studies are similar in concept to the plot technique described here, but are less amenable to the design principles of control and replication. Rainfall simulation studies using plots large enough for soil-loss assessments can be carefully designed and controlled, but are labor-intensive and expensive. Also, data from simulated rainfall studies may not be representative of natural runoff and erosion rates because simulated storms generally have little resemblance to natural storms, and temporal variations in infiltration and soil erodibility are not usually sampled. Erosion transect studies and erosion net studies provide soil-loss data, but not runoff data. However, both of these techniques are amenable to replication and control, and are easy to install and maintain. Erosion condition assessments provide relative ratings (without physical units) and are best suited to inventory-type studies.

CONCEPT

Runoff plots equipped with retention tanks have been successfully used to measure long-term runoff and erosion rates. In fact, a 0.01-ac. plot, 72.2 ft. long was the standard runoff unit used to develop soil-loss parameters for the Universal Soil Loss Equation (Wischmeier and Smith, 1978). The plot-retention tank technique of measuring runoff and erosion volumes is extremely accurate, amenable to replication (e.g., several plots per rangesite) and control (locating plots in exclosures), and inexpensive to install and maintain. In addition, data collected can be compared using standard statistical techniques or analyzed using the Universal Soil Loss Equation (USLE), the SCS Curve Number rainfall-runoff technique, or other common runoff or erosion models.

The main disadvantages to using upland runoff plots for directly monitoring rangeland hydrologic condition are (1) the low number of measurable events, (2) equipment failures, (3) improper site selection or plot installation, and (4) difficulties interpreting upslope processes in terms of off-site effects. The plot technique is most applicable when upland soil loss and surface runoff are the issues being addressed by management. Additional considerations in developing rangeland watershed monitoring programs are discussed in Bureau of Land Management Technical Note 369 (Jackson, et al., 1985).

METHODS

Plot Construction

The plots are constructed of low cost and readily available materials, and are easily installed. Cost of materials per plot is about $125, plus $160 for the recording instrument. A list of materials used in plot installation is shown in Table 1. Time required to install the four plots is approximately 10 person-days.

Each plot is 50 ft. long by 10 ft. wide. Side and upper borders are wood planks set about 3 in. into the soil and supported by wooden surveyor stakes (Figure 1). The lower border is a standard metal rain gutter set in the soil with its upper edge at ground level (Figure 2). The gutter is installed at an angle to the slope and with a slight drop to insure movement of sediments through the gutter. A length of angled roof edging is placed in the soil above the gutter and attached so that it overhangs the gutter edge, providing a stable runoff surface into the gutter. The gutter is covered with hardware cloth to prevent rodent nesting. The disturbed area above the gutter is treated with Celltite, a liquid soil sealer which hardens when sprayed on the soil. Figure 2 shows a finished lower border.

Table 1. Material List for Runoff Plots

44	1 in. x 6 in. x 10 ft. treated boards
2	bundles 18 in. surveyor stakes
3	lbs 8 penny galvanized nails
4	10 ft. metal rain gutters
12	10 ft. metal corrugated downspouts
4	10 ft. type AA angled roof edging
4	gutter end caps
4	gutter connecting sleeves
4	gutter corners
2	tubes latex caulk
	12 ft. x 36 in. wide 1/2 in. mesh hardware cloth
	baling wire
	twine
	fencing materials
	Celltite soil sealer
4	mechanical float counters
4	100-200 gal. stock water tanks

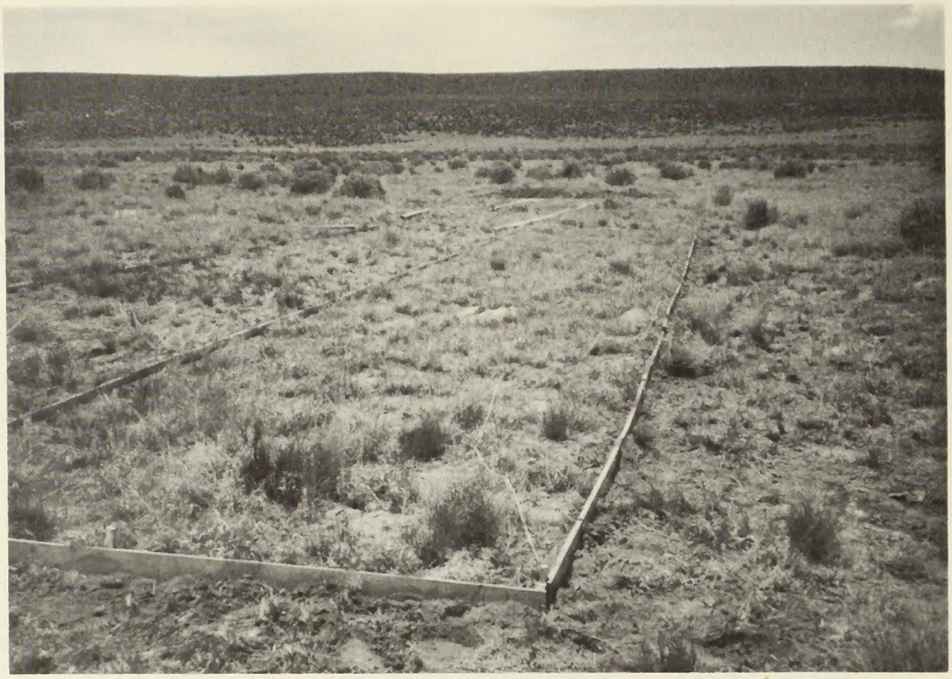


Figure 1. Photograph of plot borders.

Figure 2. Photograph of lower plot border.

All water and sediment collected in the gutter is transported to a collection trough via a downspout. Figure 3 shows a 30-ft. length of downspout ending at a collection trough set in the ground with its upper edge slightly above ground level. Depending on the slope of the terrain, the downspout length can be varied so that the trough rests on the ground surface or slightly below. This makes installation and maintenance easier. In any case, the downspout should be set so that a constant slope is maintained to the trough to prevent sediment deposition.

The collection tank is a 100 or 200 gal. oval stock watering trough. Water level in the tank is recorded by a mechanical float counter, described below, which will cumulatively measure increases in stage. Decreasing water level due to evaporation will not affect the readings. The counter is designed to be read yearly. The readings are converted to a depth, then multiplied by the area of the tank to calculate an annual runoff amount after precipitation has been subtracted. Sediment yield will also be measured at this time.

Instrumentation

There are many ways to measure runoff and sediment delivered to the retention tanks. In fact, for detailed storm period data, traditional methods of stage-height recording and automatic sediment sampling should be employed. However, this system is capable of collecting annual runoff and soil-loss data with as few as 1-2 maintenance visits per year. In arid areas, the retention tank (or basin) concept traps all inflowing waters and sediment. If the water evaporates during dry periods, sediment delivery (or, in this case, soil loss) can be measured directly by collecting and weighing the accumulated sediment. A delivery rate in units of mass over time is determined by dividing by the length of time, in years, since the last cleaning and weighing of sediment in the tank.

Total runoff is more difficult to measure, because of evaporation losses. To solve this problem, a cumulative mechanical water-level recorder that keeps track of the total delivery of runoff to the retention tank was designed for this project. The recorder, designed to be maintenance-free, is being tested on the plots constructed for this project.

The cumulative water-level recorder, available from the Federal Interagency Sediment Project, consists of an open-ended belt with a float attached to one end and a weight to the other end (Figure 4). The belt hangs from a pulley mounted on a horizontal shaft (Figure 5). A mechanical rotary counter is attached to one end of the shaft and a roller clutch is located in a support block at the other end of the shaft. A roller clutch looks like a roller bearing and acts like one for one direction of shaft rotation. When the shaft is rotated in the reverse direction, however, the roller clutch locks onto the shaft, preventing rotation. A second roller clutch is located in the bore of the pulley.

The float and counterweight are enclosed within an open 55-gal. barrel turned upside down. The pulley, shaft, and counter are enclosed in a box mounted on top of the barrel (Figure 5).

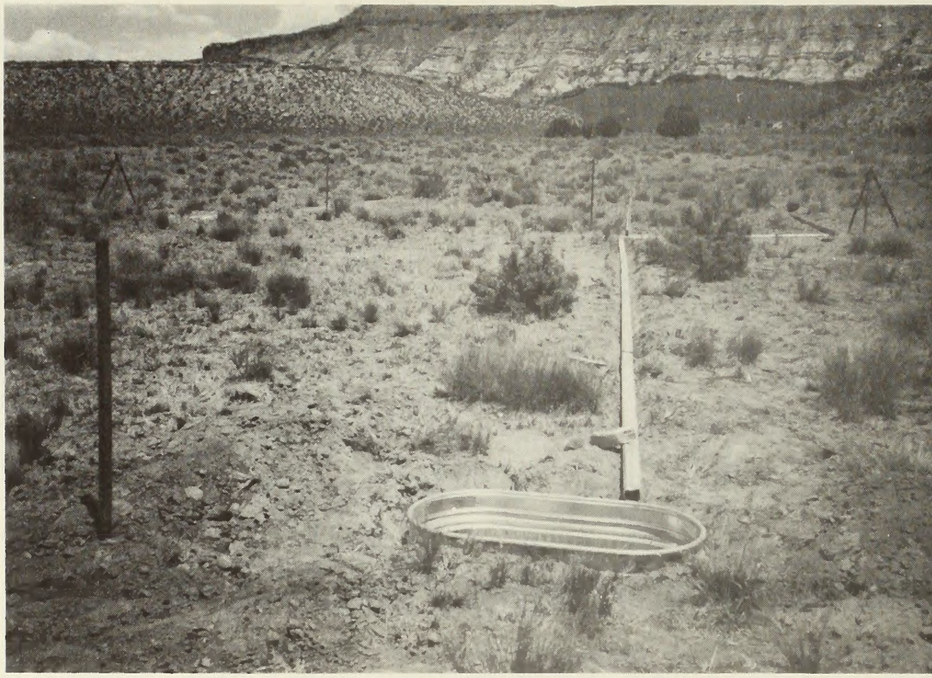


Figure 3. Photograph of Plot Downspout and Collection Tank.

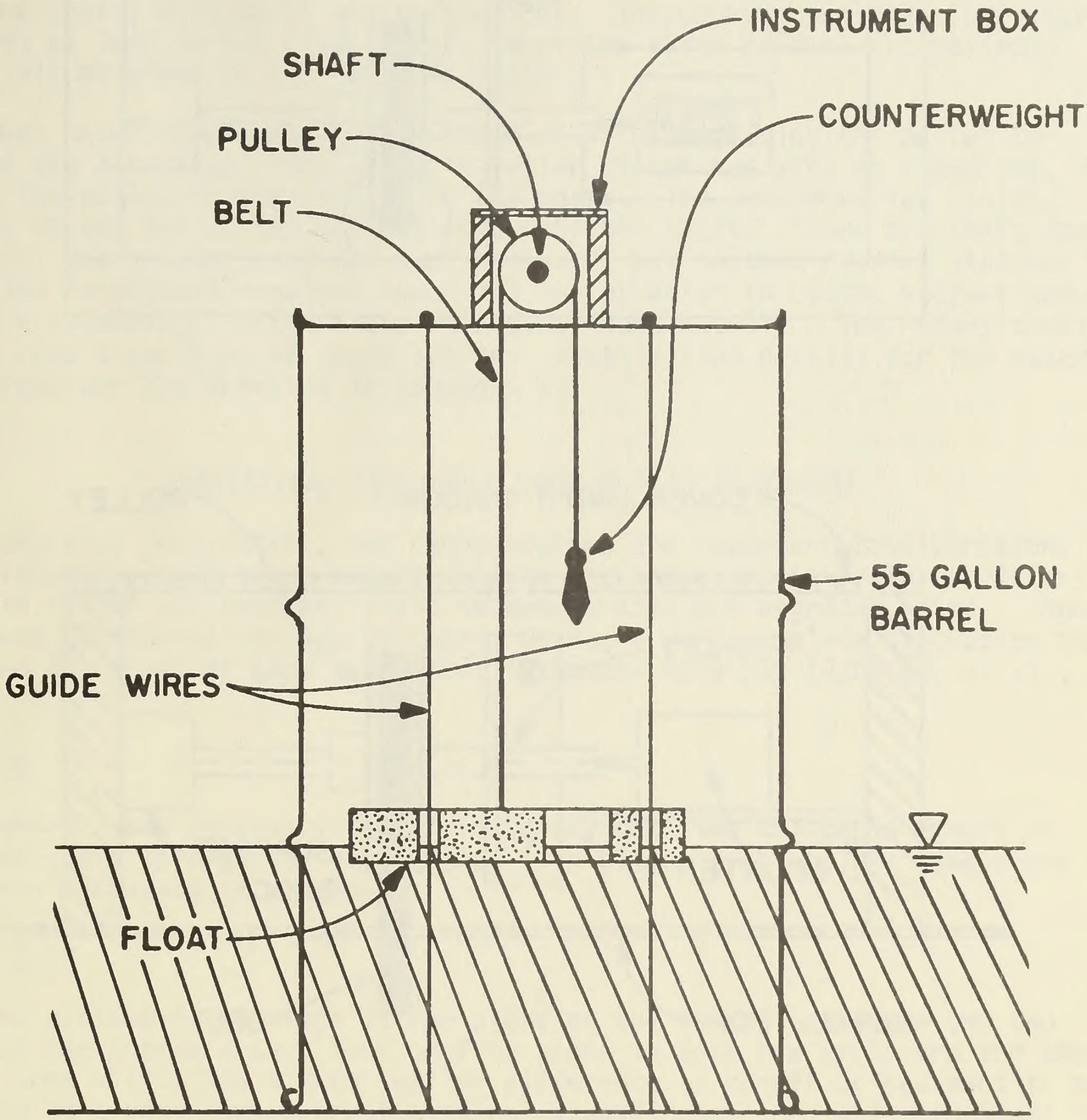


Figure 4. Cross-section View of Cumulative Stage Counter.

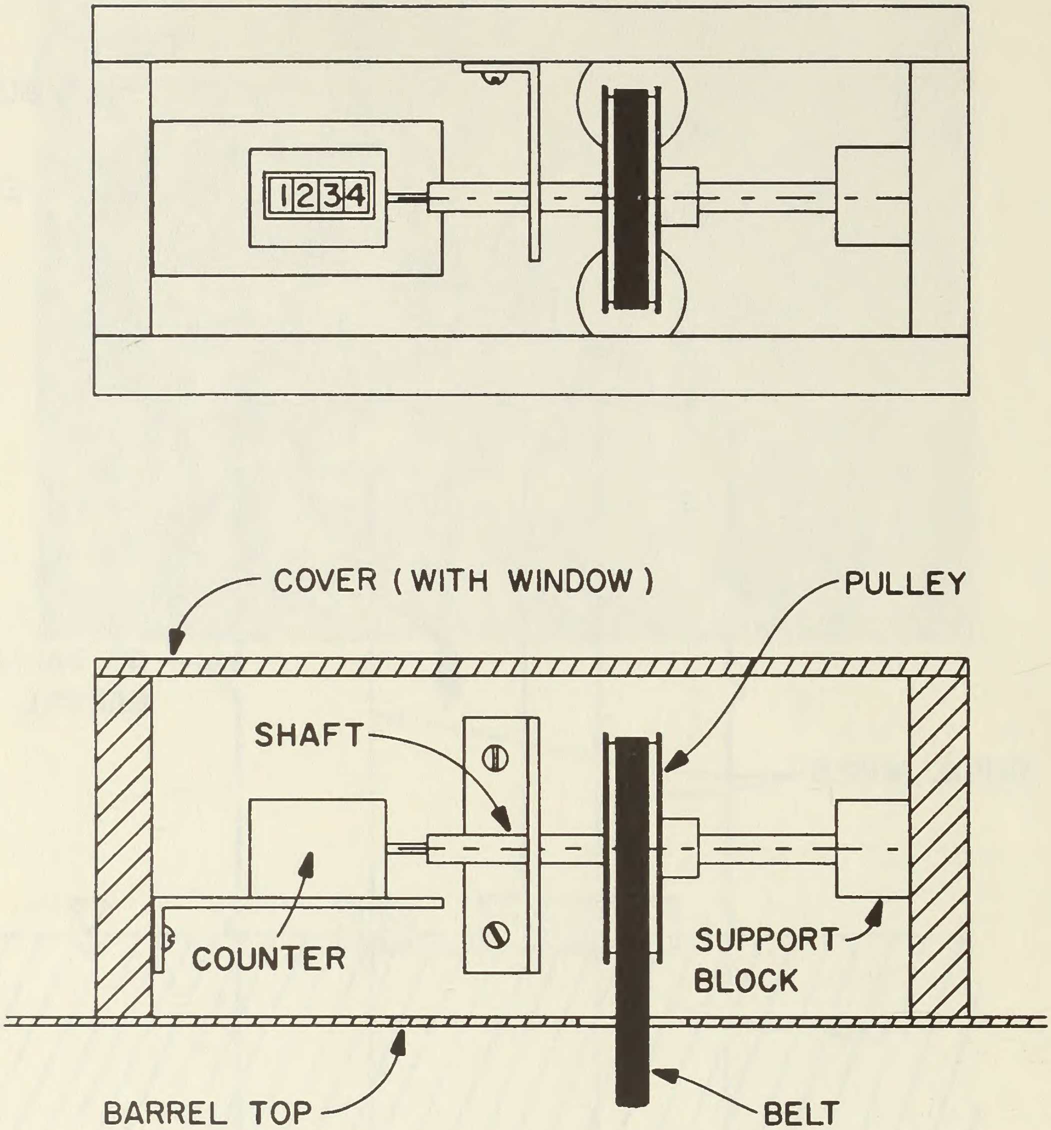


Figure 5. Top View of Cumulative Stage Counter.

As water enters the reservoir, the float is buoyed up off the retention tank floor. The counterweight at the other end of the belt pulls the belt across the pulley causing it to rotate. The pulley's roller clutch locks onto the shaft, turning it and the counter. The counter registers the shaft rotation as long as the float rises. When the water reaches its maximum level, all movement in the recorder ceases.

When water losses occur, the float will fall, causing the pulley to reverse its direction. The pulley's roller clutch now acts as a bearing, and allows the pulley to turn freely on the shaft. The second roller clutch, located at one end of the shaft, locks onto the shaft. Since the shaft does not turn, the counter does not turn backward, but instead remains stationary. The instrument requires about 1/3 in. of water to become buoyant enough to start recording. After that, it records continuously. The rotary counter can be read accurately to about 1/4 in. Installation details for the water level recorder are provided in Appendix I.

STATISTICAL CONSIDERATIONS IN PLOT PLACEMENT

Controls, replication, and randomization are important considerations in plot placement. All three considerations are necessary to evaluate differences in runoff and sediment yield between grazed and ungrazed areas. Though all three considerations are discussed below, a more complete discussion can be found in Bureau of Land Management Technical Note 369 (Jackson, et al., 1985).

Controls

Controls are necessary to attribute any detected change in runoff or sediment yield to grazing, rather than to a climatic change, or some other condition unrelated to grazing.

Replication

The minimum replication is two plots on the fenced exclosure and two plots on the grazed area. Four or five plots in both the exclosure and the grazed area will allow a much smaller difference in runoff or sediment to be detected at a given level of statistical significance than will two plots in each area.

It is not acceptable to establish one plot and measure it year after year. The years are not replications; but are repeated observations on the same plot. Statistics books refer to these as repeated measures (Winer, 1971). If only one plot is established, statistical methods cannot be used in the data analysis.

Randomization

Randomly placed plots will avoid bias. All potential plot locations should have an equal chance of selection. Following is an example which randomly locates three plots on an 8-ac. exclosure.

Randomization process: Example

Only areas at least 50 ft. from the exclosure fence with grasses (no trees or shrubs), slopes of 3-4%, no gullies, and the same soil will be included. The north and south portions of the exclosure have many small gullies which reduces potential plot locations by one-half to one-third.

The 8-ac. exclosure and grid system for this example are shown in Figure 6. The 50-ft. perimeter and the trees in the central portion have been excluded. Cutting the grid density in half for the north and south portions gives those areas less than half the chance of selection of the central areas, which is in proportion to the lower number of suitable plot locations in the north and south areas.

Final plot locations are selected by numbering all the intersections within the boundaries and randomly selecting a number between 1 and 43 (the number of plot locations) for each of the three desired plots. Find the selected grid locations in the field, then walk north and locate the plot in the first suitable location within 10 ft. to either the right or left. The map doesn't have to be perfect. The object is to try to give all suitable plot locations an equal chance of selection.

ANALYSIS OF COMMON SAMPLING DESIGNS FOR RUNOFF PLOTS

Design A. This design has only one plot and thus no control or replication, and should not be used. Let's assume you are not responsible for the design, but are responsible for evaluating 20 consecutive years of data collected from one plot.

Possible analyses: Regression can be used to quantify a change over time, but the significance levels of the slope (B) and the r^2 values are overestimated. However, the computed slope, B, is a valid estimate of the yearly change over time. This overestimate of r^2 and the significance level of B is caused by lack of independence between the yearly values, which violates the assumptions of the regression, and thus invalidates the significance levels of the results. Thus, if the slope is non significant, there is definitely no significant linear trend over time.

In a report, simply make a statement of the facts, such as "over the 20 years, runoff on the plot decreased from 8.6 ft^3 to 4.3 ft^3, averaging .2 ft^3 per year." Don't, however, quote significance levels or r^2 values, since they are incorrect.

Design B. This design has two or more plots on an area of interest, but has no corresponding control. The design will allow probability statements to be attached to a change over time, or confidence limits to be placed on sediment yield or runoff for any given year or group of years. However, because a control area was not measured, it may be impossible to sell the idea that a management action caused a change over time.

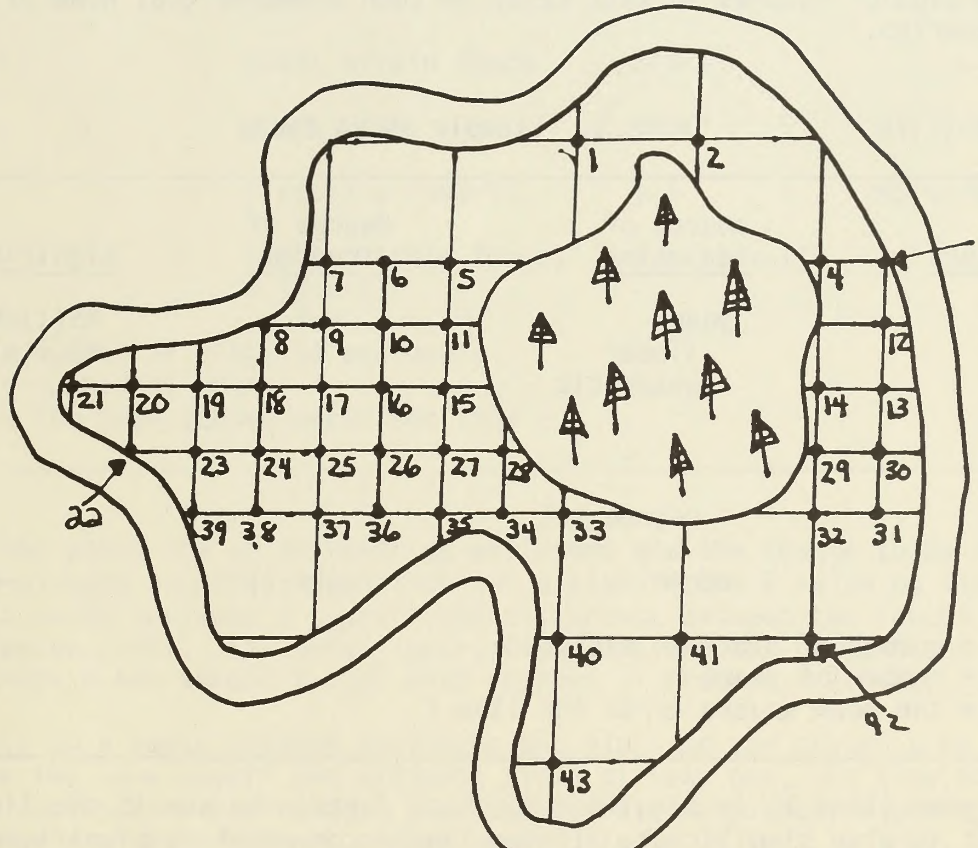


Figure 6. Eight-acre Exclosure and Grid System for Randomization Example.

Analyses: A change over time can be tested using a t-test or ANOVA. The t-test is simple, but not very powerful since the test will have only p-1 degrees of freedom, where p is the number of plots. For each plot, it is possible to quantify differences in annual soil loss or runoff between, say, the first year and the last year, or perhaps the sum of the first three years and the sum of the last three years. The t-test can be used to see if the differences are significantly different from zero. A repeat measure ANOVA, with an orthogonal decomposition of the year sum of squares into linear, quadratic, etc. components, is slightly more powerful (Table 2). The orthogonal decomposition is merely an algebraic method of breaking down an equation (sum of squares in this case) in such a manner that none of the pieces overlap.

Table 2. Example ANOVA Table

line number	source of variation	degree of freedom	significance test
1	year	y-1	MS(1)/MS(2)
	linear	1	MS(lin)/MS(2)
	quadratic	1	
	.	.	
	.	.	
	.	.	
	degree y-1	1	
2	error	y(p-1)	----

where p = number of plots in exclosure
y = number of years
MS(i) = the mean square error for line i

If year (line 1) is significant, check further to see if the linear component is also significant. If the linear component is significant, do a regression to quantitate the change per year, but use the significance level from the ANOVA rather than the regression as explained under "Possible Analyses." In the regression, years will be the independent variable, and runoff or sediment the dependent variable.

Design C. This is the recommended design. It has one exclosure with two or more plots within the exclosure and two or more plots outside the exclosure. Statistical methods can assess differences between the grazed and exclosure areas, as well as any changes over time. The control area allows management to take credit for any detected changes or differences.

Analyses: Two or more plots are nested within the exclosure and two or more plots are nested "outside the exclosure." See Sokal and Rohlf (1969) for more information on nested ANOVA design (Table 3).

Table 3. Nested ANOVA Table

line number	source of variation	degree of freedom	significance test
1	fence	1	MS(1)/MS(2)
2	plots within fence	2(p-1)	---
3	years	y-1	MS(3)/MS(5)
4	(fence) x (years)	y-1	MS(4)/MS(5)
5	(plots within fence) x (years)	2(p-1)(y-1)	---

Where p = number of plots in exclosure
y = number of years
MS(i)= the mean square error for line i

1. If the plots are on an existing exclosure and the change to be detected has already occurred, then look for a significant F value on line 1. This would indicate a significant difference between the fenced and unfenced plots. For only 1 year, lines 3-5 are not present and the test becomes a two sample t-test with degrees of freedom = 2(p-1).

2. Plots on a newly created exclosure and plots on the grazed area should have the same runoff and sediment yield at year one, the time at which the exclosure was created. Over the years, improvement might be expected on the exclosure but not on the grazed area. If this is true, line 4, the interaction between fence and year, will be significant. If the interaction is significant, the difference in runoff and sediment yield between the fenced and unfenced plots over time should be further investigated by analyzing the fenced and unfenced plots separately.

   These separate analyses are done via one-way repeated measure ANOVAs (Table 4) (Winer, 1971).

Table 4. One-way Repeated Measure ANOVA Table

line number	source of variation	degree of freedom	significance test
1	years	y-1	MS(1)/MS(2)
	linear	1	MS(lin)/MS(2)
2	plots within years	(y-1)(p-1)	- - -
3	between plots	p-1	- - -

Where y = number of years
p = number of plots
MS(i)= mean square error for line i

The mean square for years can be broken down into linear, quadratic, etc. terms up to degree y-1. See page 12 "Analyses," for an explanation. If there is a constant change over time, the linear component will be significant and a regression can be done to compute the slope of the line. The slope of the line is the increase or decrease in sediment or runoff per year. However, the regression overestimates the significance of the slope and the r^2 values, so don't make decisions which rely on them.

Design D. This design has two or more exclosures with one plot per exclosure, plus two or more grazed plots. It answers the same questions as Design C and has the same precision. Design D is more expensive than Design C to install since separate exclosures must be built for half the plots.

Analysis: Same as Design C.

IMPLEMENTATION

Plots should be located in the range site of interest to management. Unless an existing exclosure can be utilized for the control plots, a new exclosure will be required. Also, information on runoff and soil loss will be most useful in conjunction with corresponding monitoring information on rangeland vegetation. Thus it may be desirable to coordinate runoff plot locations with vegetation monitoring sites. Once the homogeneous site of interest is selected, individual plots should be sited randomly as described previously.

Of the plots constructed for this project, four each are located on:
1) Glaciated plains east of Havre, Montana,
2) Big sagebrush rangeland northwest of Elko, Nevada,
3) Fine, alluvial rangeland south of Hurricane, Utah, and
4) Silty salt-desert rangeland south of Naturita, Colorado.

All plots were constructed in the summer of 1984. The exclosure for the Hurricane plots had been in place for 3 yrs. at the time the plots were constructed. All other control plots were fenced at the time of construction. Detailed descriptions of each plot-monitoring site were prepared at the time of construction and are available from the local Bureau of Land Management Office. Data will be analyzed as described for sampling Design C above.

To date, runoff events have occurred on all 16 plots. While the plots and instruments have, in general, performed as planned, problems have been identified and some minor modifications in construction may be required. Possible improvements to be considered include a solid PVC-type drain spout, use of fabric in combination with soil sealant at the lower plot border, frequent (e.g., annual) applications of soil sealant, larger (e.g., 200 gal.) retention tanks in higher rainfall areas, better screening of tanks to keep out small animals, improved leveling of the float-counter, and improved sealing of plot borders in active (shrink/swell; freeze/thaw) soils. In addition, a lid will be required on retention tanks located in areas of blowing snow. When it is necessary to set tanks deep in the ground, additional screening from blowing soil is required, and cleaning sediment from the tanks is more difficult. Recommendations for modifications or improvements will be made after additional analysis of field performance.

CONCLUSIONS

Replicated pairs of runoff plots can be used to monitor directly changes in upland runoff and soil loss caused by livestock grazing. The plots allow a statistical significance to be placed on annual difference in runoff and soil loss between grazed and ungrazed plots. The plots are easy and inexpensive to construct, and, when instrumented with a cumulative stage counter, may be maintained with as few as one to two visits per year. Optional instrumentation would permit storm-period data to be collected. The plot design and cumulative stage counters developed for this project are currently being tested at four separate field locations.

ACKNOWLEDGMENTS

Ron Hooper, BLM-Cedar City, Utah, District Office; Dan Tippy, BLM-Havre, Montana, Resource Area Office; Dennis Murphy and Bill Ypsilantis, BLM-Montrose, Colorado, District Office; and Karl Gebhardt, BLM-Idaho State Office, helped coordinate field installation of the plots. Numerous BLM field office personnel helped in plot construction. The Federal Interagency Sediment Project at St. Anthony Falls Hydraulic Laboratory, Hennepin Island and Third Ave. S. E., Minneapolis, Minnesota 55414, helped design and fabricate the cumulative stage counters.

LITERATURE CITED

Beschta, R. L. 1985. Conceptual Model of Sediment Transport in Streams. IN Thorne, CR., ed. Proceeding of the International Workshop on Problems of Sediment Transport in Gravel-Bed Rivers. Aug. 12-17. Colorado State University, Pinghre Park, Colorado.

Blaney, D. G. and G. E. Warrington. 1983. Estimating Soil Erosion Using an Erosion Bridge. USDA Forest Service WSDG-TP-00008, 55pp.

Burkham, D. E. 1966. Hydrology of Cornfield Wash Area and Effects of Land-Treatment Practices. Sandoval County, New Mexico, 1951-60. USGS Water Supply Paper 1831. 87pp.

Clark, R. 1974. Erosion Conditions Classification System. USDI Bureau of Land Management Technical Note 346. BLM Service Center, Denver, Colorado, 47pp.

Jackson, W. L., S. Hudson, K. Gebhardt, 1985. Considerations in Rangeland Watershed Monitoring. USDI Bureau of Land Mgt. Tech. Note 369. BLM Service Center, Denver, Colorado, 27pp.

Lusby, G. C. 1979. Effects of Grazing on Runoff and Sediment Yield from Desert Rangeland at Badger Wash in Western Colorado, 1953-73. USGS Water Supply Paper 1532-I. 134pp.

Lusby, G. C. and R. W. Lichty. 1983. Use of Rainfall-Simulator Data in Precipitation-Runoff Modeling Studies. USGS Water-Resources Investigations Report 83-4159, Denver, Colorado, 59pp.

Ponce, S. L. 1981. Water Quality Monitoring Programs. USDA Technical Paper TP-00002. USDA Forest Service, Watershed Systems Development Group. Fort Collings, Colorado. 66pp.

Sokal, R. R. and Rohlf, F. J. 1969. Biometry, the Principles and Practice of Statistics in Biological Research. W. H. Freeman and Company, San Francisco. 776pp.

Winer, B. J. 1971. Statistical Principles in Experimental Design, 2nd ed. New York, McGraw-Hill. 907pp.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA Handbook No. 537. 58pp.

Appendix I

Instructions For Assembly of the Cumulative Water-Level Recorder

Appendix I

INSTRUCTIONS FOR ASSEMBLY OF THE CUMULATIVE WATER-LEVEL RECORDER

The cumulative water-level recorder is shipped in the following parts and subassemblies:

1) 55-gal. barrel
2) recording instrument
3) float, belt, and counterweight
4) anchor rod
5) stainless steel wire
6) Fiberglas filter material
7) bag of fasteners

Much of the assembly can be done in the shop prior to field installation. The recorder must, however, be protected while transporting it to the field when pre-assembled.

Assemble the recorder as follows:

1) Connect the instrument to the 55-gal. barrel. First be sure that the instrument sits reasonably flat on top of the barrel. Align the instrument so that the ends of the pulley are directly above the two large holes and that the two mounting brackets are aligned with the matching holes in the barrel./1 Apply caulk or silicone sealant to the bottom of the instrument box, reposition it on the barrel, and secure it with the #8-32 x 1/2 machine screws, lock washers, and nuts. Holes in the barrel may have burrs and sharp edges; appropriate caution should be used.

2) From outside of the barrel, pass two lengths of straightened stainless steel wire into the two inner holes on the barrel head. These holes (14 in. apart) are located on opposite sides of the instrument. Pass the wire through the barrel until it emerges from the open end of the barrel.

3) In a similar manner, pass a length of string or cord through the large hole at the take-up end of the pulley. This is the upper of the two large holes when viewed as if reading the counter.

4) Tie the string to the counterweight and orient the float so that the belt is aligned with the hole that the string passes through and that the two 1/2 in. holes in the float are aligned with the holes the wires pass through./2 Feed the wires through the matching holes in the float. Push the float into the barrel while holding onto the wires. Pull the counterweight and belt through the hole under the pulley.

5) Push one cotter pin into the hole at one end of the anchor rod. Push the rod through the matching holes at the open end of the barrel. Secure the rod in place by installing the second cotter pin in the rod end protruding from the barrel.

6) Insert the wires in the matching holes in the anchor rod. Wrap each wire around the rod and twist the free ends to the straight portion of wire that emerges from the rod. Make this tie as small and tight as possible. Nip-off the wire ends.

7) On the barrel head, locate the outer holes adjacent to the holes from which the wires emerge. Slip a washer onto each self-tapping screw and screw halfway into the outer holes. Pull each wire, one at a time, so that it is taut. Do not pull hard enough to bend the anchor rod. Wrap each wire around the shank of the adjacent screw and secure by tightening the screw to the barrel head. Do not strip the self-tapped thread. /3

8) Apply caulk or sealant over all holes and screw heads outside of the instrument box. This includes the inside diameter of the anchor rod. Caulk the outer edge of the instrument box, if desired. The barrel should be watertight except for the open end and the inside of the instrument box.

This completes the shop assembly.

FIELD INSTALLATION

The barrel should be located where it will be level and where the water surface will be the least disturbed. Cut 70 in. of fiberglass insulation. Fold the insulation in half along its length. Disposable gloves may be advisable when handling fiberglass. Keep fiber particles away from eyes and skin. Place the barrel in mounted position. Tuck the insulation under the lip of the barrel for the entire circumference. Be sure that no insulation interferes with the float. There should be no gaps in the insulation or areas where insulation is not fully compressed. Also, the barrel must be level. Make any needed adjustments to the fiberglass. The barrel can be secured in place by cross supports across the top of the retention tank, or by bolting to the bottom of the tank.

The insulation acts as a filter, keeping sediment and debris outside of the barrel. The tightly compressed insulation also is necessary to dampen fluctuations in water level. Without this dampening, slosh and wave motion will be recorded. A delay in the recording of a rising water level is not detrimental.

CALIBRATION

The recorder may be calibrated in the shop or in the field. A field check is more desirable, but may not be practical where water isn't readily available.

One revolution of the pulley is equal to about 7 in. of rise in water level. One revolution also registers as 10 counts on the counter. The counter, therefore, records about 3/4 in. increase in stage per count. Interpolating between counts should give results to the closest quarter in. Further precision in readout is unnecessary due to the magnitude of inherent errors in the recorder.

The vinyl covered fiber belt may become more supple over time. This would primarily be due to exposure to elevated temperatures. It may be advisable to recalibrate the recorder after this occurs.

For additional information, contact the Federal Interagency Sedimentation Project at FTS 787-3352 or (612) 349-3352.

/1 Stack flat washers under one bracket to level the instrument (if necessary).

/2 The bottom side of the float has a 1-in. wide channel, the top does not. The arrow on the bottom side of the float should point toward the "X" marked on the inside of the barrel. This will position the belt below the proper hole in the barrel head.

/3 Remove the string from the sinker. Gently pull the float toward the instrument. If necessary, twist the belt so that the length between the float and your hand is flat (untwisted). Feed the sinker through the second large hole beneath the pulley. The belt should be lowered onto the pulley so that the belt remains untwisted.

/4 The bolt should pass through a flat washer, the reservoir, and a second flat washer. Tighten down a nut onto the bolt. Hold this bolt in position with a wrench; then tighten a second nut onto the bolt using a second wrench. This will lock the two nuts together.

/5 Use two wrenches. One wrench must be used to hold the lowermost nut in place.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1986--676-003 / 40614

STATISTICS

TABLE OF CONTENTS

I. Randomization

1. Reduces bias (human)
2. Purpose is to give each potential site an equal chance of selection
3. Do before "treatment" is applied, if possible
4. Possible methods
   - grid systems
   - other

II. Replication and controls

1. Allow detected changes to be attributed to management actions
2. Allow use of statistical methods to assess the significance of differences
3. Note difference between replications, observations per cell, and observations over time
4. Replication reduces variance

III. Assumptions for Parametric Statistical Tests

1. Observations are independent
2. Distribution of the population is known
3. The variances of the population being compared are equal or of known ratio

Additional requirements for most test (ANOVA)

a. Data collected in a random manner
b. Error variation of data (Regression)
   a. Independent of means
   b. Normally distributed
   c. Homogeneous
c. Variance components are addative

IV. Steps in a study

1. Conduct literature review
2. Write study plan
   a. Objective
   b. Hypothesis
   c. Design
   d. Test statistic and level of significance
3. Peer review
4. Establish study
5. Collect data
6. Test hypotheses
7. Make inferences
8. Document
9. Review by peers
10. Publish information if applicable

From: Byron Thomas, Soil Scientist
Oregon State Office

V. Common "Experimental" designs

1. Completely random
2. Repeated measure
3. Nested
4. Randomized block
5. Split plot

Statistics

I. Introduction

What is statistics? Statistics is the technology of the scientific method. It is the making of decisions in the face of uncertainty. It is a branch of applied mathematics, based on probability theory, that deals with the collecting and interpreting of data. Data are collected from "populations" in an attempt to make "inferences" about those populations, usually about the mean (μ) and variance (σ^2) of the populations.

II. Estimating the mean (μ) and variance (σ^2) of a population.

1) If a "population" of numbers, caddis fly lengths for example, is finite and small, we can compute the value of the mean directly, by the formula

$$\mu = \Sigma x/n$$

where n is the number of caddis flies in the population of interest and Σx is the sum of the lengths of those n flies. If the population is not finite or imagined to be very large, we draw a "random sample" from the population and estimate the mean by

$$\bar{x} = \Sigma x/n,$$

where n is now the size of the sample and Σx is the sum of the measurements in that sample. $\bar{x}$ is an estimate of the true mean μ.

2) To estimate the variance, σ^2 (roughly speaking the measure of variation among the numbers in a population of numbers), we use

$$s^2 = \Sigma(x-\bar{x})^2/(n-1).$$

s^2 is an estimate of the true population variance, σ^2. s^2 is called the "sample variance" and $\bar{x}$ is called the "sample mean." An equivalent formula for the sample variance is

$$s^2 = (\Sigma x^2-(\Sigma x)^2/n)/(n-1),$$

which, for hand calculations, is a superior formulation. With the ready availability of electronic computing machinery these days, however, it matters little which formula is used.

3) Consider the following example - Z is a set of 6 caddis fly lengths randomly drawn from a stream.

$$Z = \{2,3,5,2,4,5\}.$$

$$\bar{x} = \Sigma x/n = (2+3+5+2+4+5)/6 = 3.5$$

$$s^2 = (\Sigma x^2 - (\Sigma x)^2/n)/(n-1)$$

$$= ((2^2+3^2+5^2+2^2+4^2+5^2)-(2+3+5+2+4+5)^2/6)$$

$$/(6-1) = (83-73.5)/5 = 1.9.$$

The square root of the sample variance is called "the sample standard deviation."

$$\text{STD DEV} = \sqrt{\text{variance}} = \sqrt{s^2} = s.$$

For our example,

$$s = \sqrt{s^2} = \sqrt{1.9} \doteq 1.38$$

is an estimate of the true population standard deviation, σ.
Standard error of the mean = s.e.= $S_{\bar{x}} = S/\sqrt{n}$

III. Hypothesis testing

1) Is the mean length of a caddis fly 3 centimeters? Suppose such a question were of interest to you. Let's say someone has assured you that the mean length of a caddis fly in a certain stream is 3 centimeters, but from your own experience you are sure the mean length is much longer. Here is how you would go about deciding who is right: To test the "null hypothesis" H_0 that $\mu = 3$ against the alternative H_A that $\mu > 3$ draw a random sample of n caddis flies from the stream, measure their lengths and compute the value of the "student-t" statistic

$$t = \frac{\bar{x} - 3}{s/\sqrt{n}},$$

where $\bar{x}$ and s are the sample mean and sample variance discussed in the last section.

2) If the computed value of t exceeds the "tabulated value" of t, t(.05,6-1) = 2.015, (from the student-t table in the appendix of any statistics book) you "reject" the null hypothesis $H_0:\mu=3$ and accept the alternative $H_A:\mu > 3$. If, on the other hand, the computed value of the t-statistic from the data does not exceed 2.015, your conclusion is: these data do not show that the null hypothesis, $\mu = 3$, should be rejected. This does not necessarily mean that you must accept the null hypothesis, it means that you should "reserve judgment" until more data are collected. In practice, few of us can afford the luxury of reserving judgment and we are usually obliged to accept H_0 when it is not rejected.

1 tail

3) Let's execute the test $H_0:\mu=3$ against $H_A:\mu>3$ using the data of article II:

Recall $\overline{x} = 3.5$, $s \doteq 1.38$ and $n = 6$, so

$$t = \frac{\overline{x}-\mu_0}{s/\sqrt{n}} = \frac{3.5 - 3}{1.38/\sqrt{6}} \doteq .89$$

Since $t = .89<2.015$, we fail to reject H_0 and conclude that maybe $\mu=3$ is correct for this stream.

Notice that the conclusion tends to be somewhat non-committal. You really don't want to ascend the pulpit and beat a drum when your data fails to reject a null hypothesis. You really never have grounds for a strong positive statement about conclusions unless the data has rejected the null hypothesis. Even then, when you reject the null hypothesis, there is a chance that you are wrong - that is, you may conclude that the null hypothesis should be rejected when in fact it is true. However, the chances of your committing such an error (formally it's called a type I error) is carefully controlled by what is called the "significance level" of the test. For the test just executed the significance level was

$$\alpha = 5\% = .05;$$

it was the number .05 in the expression $t(.05,6-1)$.

That other number (6-1) in the expression $t(.05,6-1)$ is called the "degree of freedom" of the t-statistic, abbreviated "df" and determined by the sample size used in estimating s.

$$df = n-1$$

for the case when a single sample is used to compute the student-t. Both the degree of freedom, df = 6-1,and the significance level, $\alpha = .05$, were used in locating the tabulated critical value 2.015 in the t-table.

IV. Comparing two population means.

1) Suppose you wanted to compare the caddis flies in two different streams (or the turbidity or the dissolved oxygen or any measureable characteristic). To test $H_0:\mu_1 = \mu_2$ against $H_A:\mu_1 \neq \mu_2$ use the student-t statistic

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\dfrac{(n_1-1)\, s_1^2 + (n_2-1)\, s_2^2}{n_1+n_2-1}\left(\dfrac{1}{n_1}+\dfrac{1}{n_2}\right)}}$$

and reject H_0 if the computed value of t is greater than t(.025, df) or less than -t(.05 , df), where

$$df = n_1+n_2-2$$

is the degree of freedom for this student-t.

2) Consider the following example:

Suppose $\bar{x}_1=3.5$, $s_1^2=1.9$, $n_1=6$ and $\bar{x}_2=4.8$, $s_2^2=2.0$, $n_2=10$.

$$t = (3.5-4.8)/((((6-1)1.9+(10-1)2.0)(1/6+1/10))/(6+10-2))^{1/2}$$

$$= -1.3/(((9.5+18.0)(8/30))/14)^{1/2}$$

$$= -1.3/((27.5)(.267)/14)^{1/2}$$

$$= -1.3/(7.333/14)^{1/2}$$

$$= -1.3/\sqrt{.524} = -1.796.$$

2 tail → Comparing this with the tabulated t-values, t(.05 ,14) = 2.145 and -t(.05 ,14) = -2.145, we fail to reject H_0 and conclude that $\bar{x}_1=3.5$ and $\bar{x}_2=4.8$ are not significantly different from one another.

This test presupposes that $\bar{x}_1$ and $\bar{x}_2$ are calculated from "independent" random samples. When measurements are not from independent samples, a "paired-difference" t-test may be appropriate.

V. The paired-difference test for comparing two means.

1) Suppose you are making measurements on turbidity (or some other characteristic) at 8 specific locations on a stream during the summer, and plan to compare them with 8 similar measurements to be made the following winter. Note that winter and summer measurements made at the same location will not be independent but are "naturally" paired by location.

2) If the summer mean is μ_1 and the winter mean is μ_2, we may test $H_0:\mu_1 = \mu_2$ against $H_A:\mu_1 \neq \mu_2$ using the student-t statistic

2 tail →

$$t = \bar{d}/(s/\sqrt{n})$$

where

$$\bar{d} = \Sigma(x_1-x_2)/n$$

is the average of the "differences" of the pairs of measurements made at each of n locations. The s in the formula is, just as before, the sample standard deviation of these differences,

$$s = \sqrt{(\Sigma(d-\bar{d})^2/(n-1)} .$$

3) Suppose the 16 measurements at the 8 locations were (2,3) (5,4) (1,7), (3,6), (2,4) (5,8), (1,3), (3,5).

$$\bar{d} = ((2-3)+(5-4)+(1-7)+(3-6)+(2-4)+(5-8)+(1-3)+(3-5))/8$$

$$= (-1+1-6-3-2-3-2-2)/8$$

$$= -18/8 = -2.25.$$

$$s^2 = ((\Sigma d^2-(\Sigma d)^2/8)(8-1)$$

$$= ((-1)^2+1^2+(-6)^2+(-3)^2+(-2)^2+(-3)^2+(-2)^2+(-2)^2$$

$$-(-18)^2/8)/7 = (68-324/8)7$$

$$= 27.5/7 = 3.929.$$

$$s = \sqrt{3.929} = 1.982.$$

The computed value of t is thus

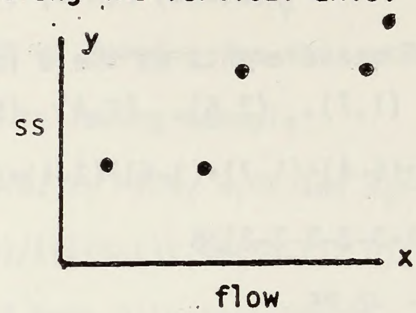
$$t = -2.25/(1.982/\sqrt{8}) = -3.211.$$

2tail → We reject the null hypothesis, $\mu_1=\mu_2$, if this computed value of t is larger than t(.05 ,n-1) or smaller than -t(.05 ,n-1). From a t-table we discover that t(.05 ,8-1) = 2.365. Since t=-3.211 < -2.365 we reject the null hypothesis and conclude that the mean turbidity (or whatever is being measured) for summer is different from that during the winter. The jargon of statistics might have you say, "there is evidence at the 5% level of significance that the hypothesis of equal means should be rejected." There is a 5% chance that you are wrong when you say this.

VI Regression Analysis

1) What is regression analysis? The term "regression analysis" dates back to a study done by Sir Francis Galton (a cousin of Charles Darwin) on the relationship between a man's height and the adult height of his sons. In modern applications it is used whenever a relationship between two or more variables is suspected. Consider for example the variation in suspended solids with stream flow during a hydrologic event. If x = stream flow in millions of gallons per day and y = suspended solids in milligrams per liter we might collect data in the form of ordered pairs (x,y). The data can be plotted in what

is called a "scatter diagram" measuring x along the horizontal axis and y along the vertical axis.



If the scatter diagram exhibits a "linear tendency" you might conjecture a linear relationship

$$y = mx + b$$

between x and y and attempt to estimate the parameters m (slope) and b (y-intercept). The equation $y = mx + b$, with suitable estimates of m and b, is called "the estimated regression line" and can be used for prediction both "within" and "beyond" the data. The process of fitting a straight line to the data in a scatter diagram is called regression analysis.

2) How are the regression parameters m and b estimated? The technique is called the "method of least squares" and the results are:

$$m = \frac{\Sigma xy - \Sigma x \Sigma y/n}{\Sigma x^2 - (\Sigma x)^2/n}$$

and

$$b = \bar{y} - m\bar{x}.$$

Note that m must be calculated first, then b (using m). Let's try an example with contrived data to keep the calculations simple.

3) Suppose the collected data were (1,1), (2,3), (3,3), and (5,4). You should plot these points in a rough scatter diagram before we begin.

The denominator, $\Sigma x^2 - (\Sigma x)^2/n$, is algebraically equivalent to $\Sigma(x-\bar{x})^2$ and is denoted by the abbreviation SSx (meaning sum of squares for x),

$$SSx = \Sigma x^2 - (\Sigma x)^2/n.$$

Similarly,

$$SSxy = \Sigma xy - \Sigma x \Sigma y/n,$$

so m can be written

$$m = \frac{SSxy}{SSx}.$$

Let's do SSx first.

$$SS_x = (1^2+2^2+3^2+5^2)-(1+2+3+5)^2/4$$

$$= 39-11^2/4=39-30.25=8.75.$$

Then

$$SSxy = (1\cdot 1+2\cdot 3+3\cdot 3+5\cdot 4)-(1+2+3+5)(1+3+3+4)/4$$

$$= (1+6+9+20)-(11)(11)/4$$

$$= 36-30.25 = 5.75.$$

Thus the slope of the regression line is

$$m = \frac{SSxy}{SSx} = \frac{5.75}{8.75} = .66.$$

The intercept is given by

$$b = \bar{y}-m\bar{x} = (1+3+3+4)/4-.66(1+2+3+5)/4$$

$$= (11)/4-.66(11)/4$$

$$= 2.75-1.82 = .93.$$

The equation of the estimated regression line is

$$y = .66x +.93.$$

To predict what the suspended solids concentration, y, will be when the flow reaches x = 7 MGD, set

$$y = .66(7)+.93$$

to get $y = 5.55$ mg/l.

This "reaching beyond the data" is called "extrapolation." To predict y when x = 4, set

$$y = .66(4)+.93$$

$$y = 3.57\text{mg/l}.$$

This is called "interpolation."

4) The estimated regression line is of no use as a predictor if the slope, m, is zero. In the example, m turned out to be m = .66 and, of course, .66 is different from zero. The question is though, is the difference between .66 and 0 statistically significant. There is a t-test which can be used to test the slope of a regression line, but a roughly equivalent test is to test the "correlation coefficient" r, which measures the strength of the linear relationship between x and y.

VII. The analysis of variance--one way classification. (The completely randomized design)

1) We saw in the student-t statistic a way to compare the means of two populations. Is it possible to compare three or more populations simultaneously? The answer is yes. The technique is called "the analysis of variance" anova. Here's how it works.

2) Given k random samples (not necessarily of equal sample size) from k separate populations, we can test the null hypothesis $H_0:\mu_1 = \mu_2 = \ldots = \mu_k$, that all the means are equal against the alternative H_A that not all the means are equal using the Fisher F-statistic.

$$F = MST/MSE,$$

rejecting the null hypothesis if this computed F exceeds the tabulated value, $F(.05, df_1, df_2)$. The F-statistic is a ratio of two chi-square statistics, each divided by their respective degrees of freedom. Consequently the tabulated F's have two separate degrees of freedom, df_1, and df_2, associated with them.

3) MST stands for "mean square for treatments." MSE stands for "mean square error." They are computed by the following formulas:

$$MST = SST/(k-1)$$

$$SST = \Sigma(\frac{T^2}{n}) - (\Sigma x)^2/N$$

where $T_1, T_2, \ldots, T_k$ are the sums (totals) of the observations in each of the k samples. n is the number of observations in the sample with sum T. Σx is the sum of all the observations in all the samples and N is the total number of all observations.

MSE = SSE/(N-k) = (SSTOTAL-SST)/(N-k)

where

SSTOTAL = $\Sigma x^2 - (\Sigma x)^2/N$.

These formulas may appear formidable, but they are quite easy to apply as our numerical example will show.

4) Suppose the following data were collected on the phosphorus content of the leaves of three species of trees:

The species are labeled A, B and C.

A: 3,4,6,5,5

B: 6,7,9,8

C: 6,8,7

The population totals are

$T_1 = 3+4+6+5+5 = 23$ $\quad n_1 = 5$

$T_2 = 6+7+9+8 = 30$ $\quad n_2 = 4$

$T_3 = 6+8+7 = 21$ $\quad n_3 = 3$.

$$(\Sigma x)^2/N = (23+30+21)^2/(5+4+3)$$

$$= 74^2/12 = 456.333.$$

$$\text{SSTOTAL} = \Sigma x^2 - (\Sigma x)^2/N$$

$$= (3^2+4^2+6^2+5^2+5^2+6^2+7^2+9^2+8^2+6^2+8^2+7^2)$$

$$-456.333$$

$$= 490-456.333 = 33.667.$$

$$\text{SST} = \Sigma(T^2/n) - (\Sigma x)^2/N$$

$$= \frac{T_1^2}{n_1} + \frac{T_2^2}{n_2} + \frac{T_3^2}{n_3} - 456.333$$

$$= \frac{23^2}{5} + \frac{30^2}{4} + \frac{21^2}{3} - 456.333$$

$$= 477.800-456.333 = 21.467.$$

$SSE = SSTOTAL - SST = 33.667 - 21.467 = 12.200.$

$MST = SST/(k-1) = 21.467/(3-1) = 10.733.$

$MSE = SSE/(N-k) = 12.200/(12-3) = 1.355.$

Finally

$F = MST/MSE = 10.733/1.355 = 7.918$ ·

Now $df_1 = k-1 = 3-1 = 2$,

and $df_2 = N-k = 12-3 = 9$,

so, $F(.05,df_1,df_2) = F(.05,2,9) = 4.26$.

Comparing F = 7.198 with 4.26 we reject the null hypothesis and conclude that not all the means are equal, but...maybe two of the means are equal. Having discovered that there are significant differences among the sample means, how do we discover exactly which differences are significant? There are several methods available. A test due to Tukey can be used when the k sample sizes are all equal. The Duncan multiple range test also requires equal sample sizes. Yet another method due to Scheffe' uses a series of "contrasts." None of these methods will be discussed here. The student is referred to the literature. R. Lowell Wines' book has a particularly good discussion. It is generally safe to assume that the difference between the largest and smallest of the k means is significant without further testing.

VIII. Covariance Analysis

1) Suppose you are interested in the dissolved oxygen (y, the response variable) in a stream at three different locations. Simply run an analysis of variance, right? No, that won't do, because the effect of temperature would mask differences in location. The effect of temperature (x, the covariate) can be "removed" by combining regression analysis and analysis of variance.

2) This analysis takes into account the effect of the covariate, x, on the response variable, y. Basically, a regression is done, $y = mX + b$, to correct the response, y, for the effect of x. This new, corrected response value is used in the anova. However, all this is done simultaneously, so that the significance of the regression (covariate) as well as the "treatment" are tested.

IX. Variance stabilizing transformations

Case (i): $\sigma_{ij}^2 = c^2\mu_{ij}$. In this case the cell variances tend to be functions of the cell means: the larger the mean, the larger the variance. This kind of relationship exists when the within-cell distribution is Poisson in form. For this case, a square-root transformation will tend to make the variances more homogeneous. This transformation has the form

$$X'_{ijk} = \sqrt{X_{ijk}},$$

where X is the original scale and X' is the transformed scale. If X is a frequency, i.e., number of errors, number of positive responses, and if X is numerically small in some cases (say less than 10), then a more appropriate transformation is

$$X'_{ijk} = \sqrt{X_{ijk}} + \sqrt{X_{ijk} + 1}.$$

The following transformation is also used for frequency data in which some of the entries are numerically small:

$$X'_{ijk} = \sqrt{X_{ijk} + \tfrac{1}{2}}.$$

Either of the last two transformations is suitable for the stated purpose.

Case (ii): $\sigma_{ij}^2 = \mu_{ij}(1 - \mu_{ij})$. This case occurs in practice when the basic observations have a binomial distribution. For example, if the basic observations are proportions, variances and means will be related in the manner indicated. The following transformation is effective in stabilizing the variances,

$$X'_{ijk} = 2 \arcsin \sqrt{X_{ijk}},$$

where X_{ijk} is a proportion. In many cases only a single proportion appears in a cell. Tables are available for this transformation. Numerically, X'_{ijk} is an angle measured in radians. For proportions between .001 and .999, X'_{ijk} assumes values between .0633 and 3.0783. The notation $\sin^{-1}$ (read inverse sine) is equivalent to the notation arcsin. For values of X close to zero or close to unity, the following transformation is recommended:

$$X'_{ijk} = 2 \arcsin \sqrt{X_{ijk} \pm [1/(2n)]},$$

where n is the number of observations on which X is based. The plus sign is used for X_{ijk} close to zero; the minus sign is used for X_{ijk} close to unity.

Case (iii): $\sigma_{ij}^2 = k^2\mu_{ij}^2$. In this case the logarithmic transformation will stabilize the variances.

$$X'_{ijk} = \log X_{ijk}.$$

To avoid values of X close to zero, an alternative transformation

$$X'_{ijk} = \log (X_{ijk} + 1)$$

is often used when some of the measurements are equal to or close to zero. The logarithmic transformation is particularly effective in normalizing distributions which have positive skewness. Such distributions occur in psychological research when the criterion is in terms of a time scale, i.e., number of seconds required to complete a task.

From: Winer, B.J. 1971 Statistical Principles in Experimental Design
McGraw-Hill, New York

Values of t (Steel and Torrie 1960).

df	Probability of a larger value of *t*, sign ignored — Two tailed								
	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.001
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	.718	.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291
	0.25	0.2	0.15	0.1	0.05	0.025	0.01	0.005	0.0005
df	Probability of a larger value of *t*, sign considered — One tailed								

Source: This table is abridged from Table III of Fisher and Yates, *Statistical Tables for Biological, Agricultural, and Medical Research*, published by Oliver and Boyd Ltd., Edinburgh, 1949, by permission of the authors and publishers.

Percentage Points of the F Distribution

$\alpha = 0.05$

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9
1	161	200	216	225	230	234	237	239	241
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4
3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
29	4.18	2.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88

Percentage Points of the F Distribution (*cont.*)

$\alpha = 0.05$

10	12	15	20	24	30	40	60	120	∞
242	244	246	248	249	250	251	252	253	254
19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.5
8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.00	2.97	2.93
3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
2.98	2.91	2.84	2.77	2.74	2.70	2.66	2.62	2.58	2.54
2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
2.27	2.20	2.13	2.05	2.00	1.96	1.91	1.86	1.81	1.76
2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

EXERCISE 1

Soil bulk densities randomly selected by your supervisor from an unknown soil.

i	X_i
1	0.99
2	1.08
3	0.94
4	1.17
5	1.10
6	1.14
7	0.98
8	1.12
9	1.05
10	1.08

n =

MEAN = $\bar{X}$

VARIANCE = S^2 =

STANDARD DEVIATION = S =

STANDARD ERROR = $S_{\bar{x}} = S/\sqrt{n}$ =

COEFFICIENT OF VARIATION = CV = $S*100/\bar{X}$ =

t(.05)(n-1)
(2 tailed) =

t(.10)(n-1)
(2 tailed) =

1. Enter the data set -- use DATA-ONE
   Name the date set BULKD.DAT
   DATA-ONE will provide $\bar{X}$ and S.

2. Fill in the blanks above
   Get out of EPISTAT (CTRL and BREAK)
   In BASIC enter commands such as the following:

```
PRINT SQR(4.00);2.0/SQR(10)
```

3. Use HISTOGRM to plot the data.

EXERCISE 2

You think that the soil in Exercise 1 is an ABC. The ABC soil has an average bulk density of 1.14. Is the mean of the bulk densities in Exercise 1 significantly different from 1.11 at the $\alpha = 0.05$ level? At the $\alpha = 0.10$ level?

Ho:
Ha:
$t(0.05)(n-1) =$
$t(.10)(n-1) =$
$S/\sqrt{n} =$
$|\bar{x}-1.11| =$
If $\frac{|\bar{x}-1.14|}{s/\sqrt{n}} > t(\alpha)(n-1)$ Reject Ho

Conclusion:

Your boss thinks that the soil is an XYZ. The average bulk density of an XYZ soil is 1.05. Is the mean of the bulk densities in Exercise 1 significantly different from 1.05 at the $\alpha = 0.05$ level of significance?

Ho:
Ha:
$t(.05)(n-1) =$
$S/\sqrt{n} =$
$|\bar{x}-1.05| =$

If $\frac{|\bar{x}-1.05|}{S/\sqrt{n}} > t(\alpha)(n-1)$ Reject Ho

Conclusion:

EXERCISE 3

Well, you are upset. You are sure that the bulk density of that unknown soil is higher than the 1.07 your boss' random sample showed. You diplomatically ask your boss a few questions about her randomization and selection techniques, and discover that her sample selection was flawed. (You've been to the 7000.1 course and have a knowledge about that sort of thing.)

So...you decide that another random sample needs to be done. Your boss asks that you take two samples at each site, so that they can be sent to two separate labs, since she thinks one reports values a bit too high. O.K. ... You randomize, select 10 sites, take two samples at each site, send the samples to the labs, and get the following results back.

Results

Point no.	Lab A	Lab B
1	1.10	1.15
2	1.12	1.19
3	1.02	1.12
4	1.15	1.20
5	1.18	1.22
6	1.16	1.18
7	1.19	1.15
8	1.00	1.17
9	1.10	1.17
10	1.08	1.11

1. Is the mean bulk density from Lab B higher than the mean bulk density from Lab A at the $\alpha = 0.05$ level?

Use the program: T-TEST
Use the data file: EX3.DAT
Is it paired or unpaired?
Is it one or two tailed?

Ho:
Ha:
t(.05)(n-1) =
Conclusion:

2. Is the mean bulk density from Lab A different from the original mean (from Exercise 1) at the $\alpha = 0.05$ level?

Use the program: T-TEST Use the data file: EX3.DAT
Is it paired or unpaired? Is it one or two tailed?

Ho:
Ha:
t(.05)(2n-2) =
Conclusion:

3. Is the mean from Lab A significantly different from 1.14, the mean bulk density of the ABC soil?

Ho:
Ha:
t(.05)(n-1) =
If $\frac{|\bar{x}-1.14|}{S/\sqrt{n}} > t(.05)(n-1)$ Reject Ho

Conclusion:

EXERCISE 4

You have run ERHYM for several years on an area, and you feel that ERHYM is well validated for that area. You think that there is a relationship between soil moisture at the end of April and the peak production. If this relationship is good enough, you think you can use it to predict subsequent years' peak production by measuring the soil moisture at the end of April. So...you run ERHYM for 15 years (continuous mode) and obtain the following yield indices and soil moistures. They are in the file EX4.DAT

Year	Yield Index	Soil Moisture
1960	.22	1.30
1961	.14	.85
1962	.47	3.10
1963	.46	4.60
1964	.18	2.80
1965	.18	2.40
1966	.46	5.75
1967	.51	4.70
1968	.35	4.05
1969	.48	5.25
1970	.37	2.75
1971	.28	3.90
1972	.24	1.30
1973	.11	2.10
1974	.06	.90

1. Use DATA-ONE to list the data file. Note the variable names and sample numbers.

2. Use LNREGRES to transform the yield index to pounds per acre. The potential production is 750 pounds/acre. Name the new data file EX41.DAT Again, note your sample names and numbers.

3. Use SCATRGRM to plot the data. (y-axis = yield, x-axis = soil moisture). Read the SCATRGRM portion of the manual to step through this part. Add the regression line. Print the plot. (Take a break, the plot will take 5-10 minutes.)

4. Use LNREGRES to find the equation of the regression line, y=mx+b. If the April 30, 1986 soil moisture is 3.0 inches, what is your best guess at the peak production for 1986?

5. Use CORRELAT to compute Pearson's Correlation coefficient. This is r. What you want is r^2, the percent of the overall variability in production explained by the April 30 soil moisture.

6. Is the relationship "good enough"? If so, how could you use this equation in evaluating monitoring data?

EXERCISE 5

Your district has a riparian demonstration project initiated three years ago. Three streams were selected for the project. Two were fenced for a mile, the third was left unfenced. (Your statistician said you better have a control). At the time the fences were put in, four cross sections were surveyed on each stream. These cross sections were at 0.2, 0.4, 0.6, and 0.8 miles inside the fence on Willow and Granite Creeks, and the same distances from a fixed stake on Birch Creek. These same cross sections were re-surveyed in 1986, under the same runoff conditions. The following ratios of width to average depth were obtained. All this is in the data file EX5.DAT.

Ratio of Width to Depth

	1983			1986			1983 - 1986		
	Willow	Granite	Birch	Willow	Granite	Birch	Willow	Granite	Birch
transect	W1983	G1983	B1983	W1983	G1983	B1983	WDIF	GDIF	BDIF
.2	15.3	27.3	18.6	13.1	12.0	19.4	2.2	15.3	-0.8
.4	18.7	20.8	13.1	8.6	15.2	15.0	10.1	5.6	-1.9
.6	23.8	15.9	15.8	15.2	8.6	16.3	8.6	7.3	-0.5
.8	13.9	25.7	20.4	7.5	13.1	16.8	6.4	12.6	3.6

1. Questions:

    a. Were all the streams the same in 1983?

    b. Were all the streams the same in 1986?

    c. Were the differences between 1983 and 1986 the same for all streams?

    d. Did the unfenced stream change from 1983 to 1986?

    e. Did the fenced streams change between 1983 and 1986?

How to statistically test the above questions.

a. Run one-way ANOVA with samples 2, 3, 4.

b. Run one-way ANOVA with samples 5, 6, 7.

c. Run one-way ANOVA with samples 8, 9, 10.

d. Run T-TEST with samples 4 and 7. Yes, they are paired, but how many tails does it have?

e. Scenario A:

Run two separate paired t-tests, one with samples 2 and 5, and one with samples 3 and 6. But when multiple t-tests are done, the significance of the individual tests decreases.

Scenario B:

A better, and certainly more powerful if Willow and Granite Creeks are no different both before and after follows: Do a paired t-test with both Willow and Granite Creeks combined, so that d.f. = 7.

2. Should the study have been designed differently? Did you really need Birch Creek in the study? Or should you have had two controls? Could the analysis have been simplified with a different design? What other designs might have been used?

Answers to Exercises

1. $n=10$, $\bar{X}=1.07$, $S^2=0.006$, $S=0.07$, $S_{\bar{X}}=0.02$, CV=7%, t(0.5)(9)=2.262, t(.10)(9)=1.833

2. $Ho: \bar{X}-1.14=0$, $Ha: \bar{X}-1.14 \neq 0$, t(.05)(9)=2.262, t(.10)(9)=1.833, $S/\sqrt{n}=0.02$, $|\bar{X}-1.14|=.04$, $|\bar{X}-1.14|/(S/\sqrt{n})=2.97 > 2.262$ and 1.833, Conclusion: Reject Ho at both .05 and .10

3. 1. yes, paired, one-tailed, $Ho: \bar{X}_A-\bar{X}_B=0$, $Ha: \bar{X}_A-\bar{X}_B < 0$, t(.05)(9)=1.833

   2. no, unpaired, two-tailed, $Ho: \bar{X}_A-\bar{X}_O=0$; $Ha: \bar{X}_A-\bar{X}_O \neq 0$, t(.05)(18)=2.101, Conclusion: Calculated t=1.45 and $1.45 < 2.101$ thus fail to reject Ho.

   3. no, $Ho: \bar{X}-1.14=0$, $Ha: \bar{X}-1.14 \neq 0$, t(.05)(9)=2.262, $|1.11-1.14|/(.063944/\sqrt{10})=.99$, Conclusion: $.99 < 2.262$ thus fail to reject Ho.

4. 4. y=59.2X+45.0, y=59.2*3.00+45.0=222.6 pound/acre for 1986
   5. r=.83, $r^2=.70$
   6. the regression equation is significant at $\alpha=.0001$

5. 2. a. Calculated F = 1.81 Tabled F 2, 9, .05 = 4.26 no differences
      b. Calculated F = 4.62 Tabled F 2, 9, .05 = 4.26 differences
      c. Calculated F = 8.24 Tabled F 2, 9, .05 = 4.26 differences
      d. Calculated t = 0.08, two-tailed, t(.05)(3) = 3.182 no change
      e. A. samples 2 and 5 t = 3.97 t(.05)(3) = 3.182 changed
         samples 3 and 6 t = 4.51, t(.05)(3) = 3.182 changed
         B. samples 2 and 3 vs. samples 5 and 6 t = 5.82, df = 7, t(.05)(7) = 2.365, changed

I. Statistics Packages for Micro Computers

Commercial

MINITAB
Minitab Project
Statistics Department
215 Pond Laboratory
Pennsylvania State Univ.
University Park, PA 16802
(814) 865-1595
about $1000

STATPAK
Northwest Analytical, Inc.
520 N.W. Davis Street
Portland, Oregon
(503) 224-7727
about $400

SPSS
SPSS, Inc.
444 North Michigan
Chicago, Illinois 60611
(312) 329-3500
about $800 for basic; more for advanced and graphics

Public Domain

EPISTAT
available from
Division of Resources (D-470)
Bureau of Land Management
Building 50, Denver Federal Center
P.O. Box 25047
Denver, Colorado 80225-0047
FTS 776-0170
(303 236-0170

SPAK
Send a blank diskette to
Kimbark McDonough
Computer Cartography Lab
North Carolina State University
Box 8007
Raleigh, NC 27695-8007

II. Statistical Packages Available on the Honeywell DPS-8

Statpack
- Activate it by typing STPK
- Interactive and easy to use
- Manual available from D-200, DFC
- Can use data files or interactively enter data
- Limited to 15 variables and 250 cases

SPSS (Statistical Package for the Social Sciences)
- Example file in A363/SPSSCC
- Operates in BATCH mode
- User guide is excellent
- Number of cases is unlimited; variables limited to 500
- Does all but the unusual statistical procedures

SPSSX
- Newer, expanded version of SPSS
- Example file in A363/SPSSXCC
- Operates in BATCH mode
- Number of cases is unlimited; variables limited to 500
- Allows unusual, complicated analyses

BMDP
- Example file in A363/BMDPCC
- Operates in BATCH mode
- Number of cases is unlimited; variables limited to 500
- Allows unusual, complicated analyses

For assistance in running any of these statistical packages, call either

Shirley Hudson, Statistician	or	Mike Garratt, Statistician
FTS 776-0152		FTS 776-0096
(303) 236-0152		(303) 236-0096

Randomized Complete Block

- block = replication

- have units in blocks as uniform as possible so that observed differences will be due to treatment

- variation between blocks is maximized, while variation within blocks is minimized

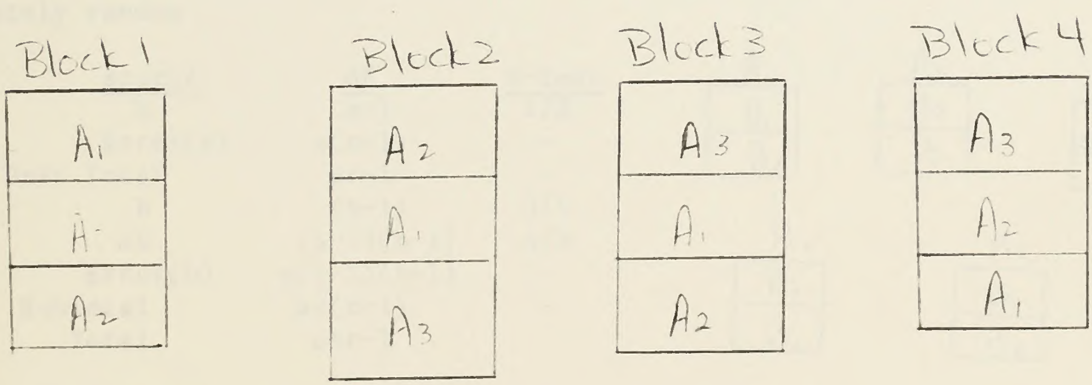
- each treatment occurs the same number of times in each block

- if the effect of blocks is significant, the precision of the experiment has been increased over that of the completely randomized design

Line	Source of Variation	df	F-test
1	Blocks	r-1	1/3
2	Treatments	t-1	2/3
3	Error	(r-1)(t-1)	
	Total	rt-1	

more than one (S) observation per treatment

Line	Source of Variation	df	F-test
1	Blocks	r-1	1/3
2	Treatments	t-1	2/3
3	error	(r-1)(t-1)	
4	Sampling error	rt(s-1)	
	Total	rts-1	



r = 4

t = 3

S = 1

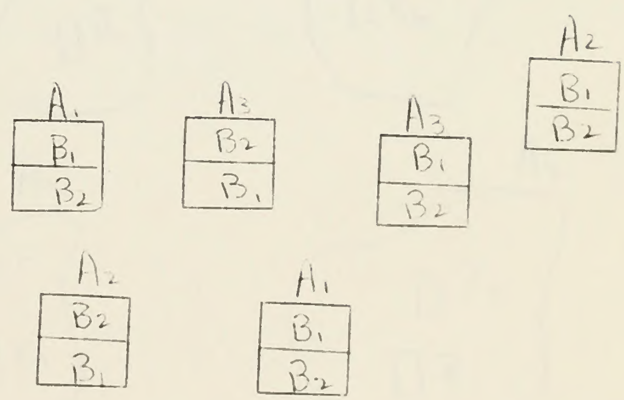
Split Plot Designs

- whole plots or units to which levels of one or more factors are applied are divided into subplots or subunits to which levels of one or more additional factors are applied.
- frequently used for factorial experiments.
- may incorporate either completely random or randomized complete block.
- each whole plot becomes a block for the subunit treatment.
- can be split in either time or space.
- two stage randomization, first randomize levels of A over whole plots, then levels of B over subunits.
- gives increased precision for subunit comparisons, but at a cost of lower precision for whole unit comparisons.
- assumes blocks do not interact with factor B.
- each level of B occurs only once in each whole plot. Additional observations on B become sampling error.
- if there are no replications, the effect of A cannot be tested.

r = number of reps or blocks
a = levels of A (whole units)
b = levels of B (subunits)

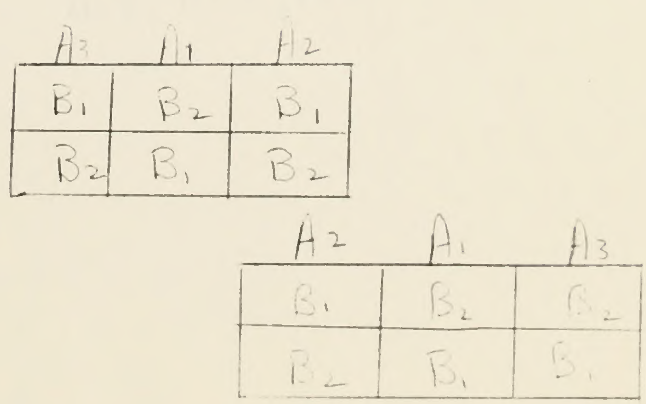
Completely random

line	source	df	F-test
1	A	a-1	1/2
2	Error(a)	a(r-1)	-
Whole Unit Total		ar-1	-
3	B	(b-1)	3/5
4	AB	(a-1)(b-1)	4/5
5	Error(b)	a(r-1)(b-1)	-
	Subtotal	ar(b-1)	-
	Total	abr-1	



Randomized complete blocks

line	source	df	F-test
1	Blocks	r-1	1/3
2	A	a-1	2/3
3	Error(a)	a(r-1)	-
Whole Unit Total		ar-1	-
4	B	b-1	4/6
5	AB	(a-1)(b-1)	5/6
6	Error(b)	a(r-1)(b-1)	-
	Subtotal	ar(b-1)	-
	Total	abr-1	-

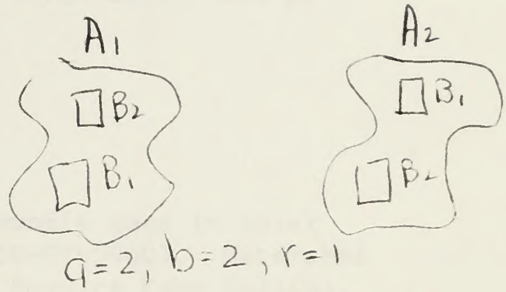


Nested Designs

- Factor B is nested under factor A.
- Interaction between A and B can never be evaluated
- To increase precision of A, increase levels of B
- Replicate entire experiment to test for differences between levels of B
- Years don't affect the precision for tests of either A or B

No reps

line	source	df	F-test
1	A	a-1	1/2
2	B (within A)	a(b-1)	



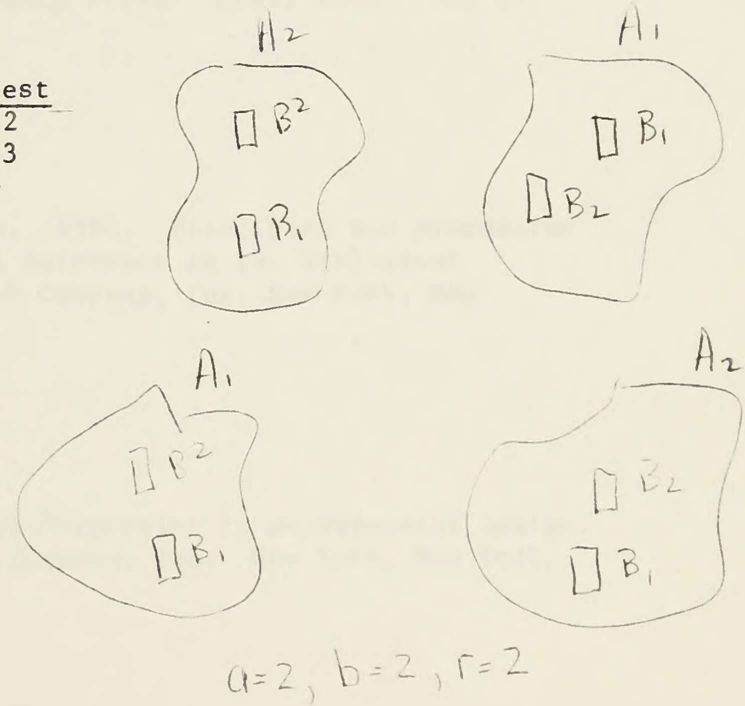
No reps, several years

line	source	df	F-test
1	A	a-1	1/2
2	B (within A)	a(b-1)	-
3	years	y-1	3/5
4	A x years	(a-1)(y-1)	3/5
5	B (within A) x years	a(b-1)(y-1)	-

same as above, but measure over several years

reps

line	source	df	F-test
1	A	a-1	1/2
2	B (within A)	a(b-1)	2/3
3	Error (AB)	ab(r-1)	-



References

Blaney, D., S. Ponce and G. Warrington. 1984. Statistical methods commonly used in soil data analysis. USDG Report WSDG-TP-00011. Watershed Systems Development Group, USDA Forest Service Fort Collins, Colorado 80524-8597. 223 p.

Ponce, S.L. 1980. Statistical methods commonly used in water quality data analysis. WSDG Report WSDG-TP-00001. Watershed Systems Development Group, USDA Forest Service Fort Collins, Colorado 80524. 136 p.

Snedecor, G.W., and W.G. Cochran. 1956. Statistical methods. 5th ed. Iowa State University Press. Ames, Iowa. 534 p.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill Book Company, Inc. New York, New York. 481 p.

Winer, B.J. 1971. Statistical Principles in experimental design. 2nd ed. McGraw-Hill Book Company, Inc. New York, New York. 907 p.

REPLICATION IN GRAZING STUDIES - WHY BOTHER?

John W. Walker and Edgar W. Richardson

ABSTRACT: Random sampling of experimental units from a larger population of interest, random assignment of grazing treatments to experimental units and replication are the components of experimental design that allow the results of grazing trials to be unambiguously attributed to the imposed treatments and inferred to a larger population. An experimental unit is the unit of material to which one application of a treatment is applied. In grazing management research the experimental unit consists of the pasture and herd to which a grazing system is applied as a whole. The sources of variation associated with the analysis of grazing systems research are presented. The implication of these sources of variation on the interpretation and extension of results are discussed. We recommend that when presenting the results from non-replicated grazing experiments scientists should clearly state the limitations on the interpretation and extension of their data.

INTRODUCTION

A well designed grazing experiment should compare grazing management systems in such a way that any differences observed in the responses being measured can be unambiguously attributed to the effect of the different management systems and not to any other source of variation. The study should also allow the researcher to infer that the differences observed under controlled conditions would also be seen in some larger population of which the experimental units are a representative sample. Such a study would allow one to conclude that livestock producers and other scientists could obtain similar results using similar techniques. In our opinion, the manner in which grazing systems research often is conducted does not permit either an unambiguous assessment of the cause of the observed differences nor the statistical inference of the observed effects to a population larger than the particular set of pastures and herds used in the study.

Early literature pertaining to experimental design of grazing studies recognized the importance of proper replication (Peterson and Lucas 1960, Hilmon et al. 1962). More recently, after another 20 years of experience with the replication vs. resource constraints dilemma, some authors have been more supportive of the usefulness of non-replicated studies (Dahl 1982). Also, as discussed later, non-replicated studies have become quite common. Non-replicated experiments are also common in field studies in other biological disciplines (Connell 1974, Eberhardt 1976). Hurlbert (1984) considered ecological studies in general and noted that the "most common type of controlled experiment in field ecology involves a single replicate per treatment. This is neither surprising nor bad. Replication is impossible when very large scale systems are studied".

In this paper we hope to relate some of the basic concepts of experimental design to grazing systems research and to suggest compromises that may yield more sound results in spite of the logistical difficulties inherent in such research. Our purpose is not to criticize any particular study or non-replicated experiments in general. Rather the objectives are to clarify what the experimental unit is in grazing systems research, to understand why replication is important and to suggest appropriate reporting and analysis procedures for non-replicated experiments.

Paper presented at the Symposium on Statistical Analysis and Modeling of Grazing Systems Responses, Orlando, FLA. February 10, 1986

John W. Walker, Department of Range Science, Edgar W. Richardson, Department of Statistics, Texas A&M University, College Station, TX.

Report is published with the approval of the Director, Texas Agricultural Experiment Station as TA 21057.

EXPERIMENTAL UNITS IN GRAZING SYSTEMS RESEARCH

Steel and Torrie (1980) state that an "experimental unit or experimental plot is the unit of material to which one application of a treatment is applied". In experiments in which the treatments being applied are grazing management systems (GMSs) the experimental unit or plot consists of a piece of land (a pasture) and a group of animals (a herd). In some GMSs pastures and/or herds are divided into paddocks and subherds, respectively, but the management system is not applied to individual paddocks nor to individual subherds nor to individual animals. It is applied to the pasture+herd unit as a whole and it is at this level that values to compare GMSs should be calculated.

Pasture+herd units will always perform somewhat differently even though they may seem to be quite similar. Two pastures matched as closely as possible with respect to size, species composition and forage production and stocked with the same number of phenotypically and genotypically matched animals will not perform exactly the same even if they are both grazed under the same management system. The change in their performance over time also will not be exactly the same. Variability such as this is inherent to all experimental material, especially biological systems. It is controlled for in three ways: random assignment of treatments to experimental units, random sampling of experimental units from the population for which recommendations are desired, and replication.

Random assignment of GMSs to pasture+herd units ensures that the differences in performance inherent to these units does not systematically bias the evaluation of the management systems. This seems to be well understood and commonly practiced.

Random sampling of experimental units from the population of producers' pasture+herd units in the region for which recommendations are desired is not practiced. No small set of pasture+herd units can exactly represent a population of such units spread over a large geographic area but random sampling would guarantee that a sample was (statistically) representative. Grazing system experiments are, however, usually carried out on federal or state experiment stations. This is logistically necessary but the pastures and livestock on these stations are often less variable than those found in the area as a whole. This is good for experimental work in that the experimental error will be relatively less but by the same token the applicability of the resulting recommendations is also less. Cornfield and Tukey (1956) point out that non-statistical inference of the results of such research to a broader population can be justified based on the scientist's knowledge of the research topic. This issue is, however, beyond the scope of the present paper. The reader is referred to Morton and Ridgeman (1977) for further discussion.

REPLICATION IN GRAZING MANAGEMENT STUDIES

Any time a treatment is applied to more than one experimental unit that treatment is said to be replicated. As mentioned above, a pasture and a herd together make up the unit to which a GMS is applied. Within a pasture+herd unit, measurements are usually recorded for individual animals, subherds, paddocks or quadrats randomly placed within a paddock. These units (individual animals, subherds, paddocks and quadrats) are sampling units used to collect the measurements which are then used to compute an average value for the pasture+herd unit. This one value is the response for the entire unit. Variation between the sampled values represents sampling error, not experimental error, since all of the animals, subherds, quadrats and paddocks within a single pasture+herd unit were subjected to the same application of a GMS. This sampling error tells us nothing about the variability of the responses we can expect when the same GMS is applied to other pasture+herd units either on the experiment station or elsewhere.

Experimental Error

The variability in the responses of different pasture+herd units grazed under the same management system is the experimental error. Steel and Torrie (1980) state that this "variation comes from two main sources. First, there is the inherent variability that exists in the experimental material to which the treatments are applied. Second, there is the variation which results from any lack in uniformity in the physical conduct of the experiment". "Lack in uniformity" in the application of a GMS to several pasture+herd units is due in part to limitations of time and personnel. Movement of animals through a rotational system is usually done one unit at a time. Equipment breakdowns or adverse weather can delay the application of management practices such as feeding, moving or treating animals or mowing or fertilizing pastures. Lack of uniformity in the implementation of a GMS on several pasture+herd units tends to increase the experimental error but it also makes for a more realistic assessment of the variability

to be expected among producers using the system.

The other source of experimental error, variability inherent to pasture+herd units, was discussed earlier. This variability can be observed directly when several units are grazed under the same management system. When each pasture+herd unit is grazed under a different system it is impossible to observe the inherent unit-to-unit variability directly. The units vary in their responses, but it is not clear whether this is because they are different pastures and herds or because they were grazed under different management systems. It is certain, however, that the inherent variability of the units is not "turned off" simply because different grazing systems are used. It is expressed but is confounded with the grazing system effect.

Testing For Grazing System Effects

In order to unambiguously test for a grazing system effect we need estimates of two quantities which differ only with respect to this effect, if it exists, and which do not differ at all if it does not exist. By ruling out unlikely occurrences, we can then say that a significant difference between the two estimates indicates that there is a grazing system effect. The treatment mean square and the experimental error provide us with two such estimators.

Consider, for example, an experiment comparing a continuous grazing system and a short duration grazing system. Suppose that there are three pasture+herd units (40 animals per herd) grazed under each system and assume for the moment that measurements are taken only once (at the end of the first year, for example). If the assignment of pasture+herd units to grazing systems is completely randomized then the model for analyzing an animal characteristic such as average daily gain is:

$$X_{ijk} = \mu + G_i + P(G)_{j(i)} + A(GP)_{k(ij)}$$

where:

X_{ijk} = average daily gain

μ = overall mean

G_i = i-th treatment effect, i = 1,2

$P(G)_{j(i)}$ = effect due to being in the j-th pasture+herd under treatment i, i = 1,2. j = 1, 2, 3

$A(GP)_{k(ij)}$ = k-th animal effect in the j-th pasture+herd under treatment i, i = 1,2. j = 1,2,3. k = 1, ..., 40.

The true overall mean μ and the treatment effects G1 and G2 are fixed (but unknown) values. The pasture+herd effect is random with mean value zero and variance σ_p^2. The animal effect is also random with mean zero and variance σ_A^2. The expected mean squares are shown in table 1.

Comparing the expected mean squares for G and P(G) we see that the variation caused by the different grazing systems [i.e., (3)(40) $(G_1^2+G_2^2)$] is the only term in G that is not in P(G). Thus, a significant result of an F-test of the G mean square using the P(G) mean square as the error term must be due to this grazing system term, i.e., a significant difference between treatment means can be unambiguously attributed to the difference between grazing systems.

Suppose now that the experiment has no replicaton. There are still two treatments and 40 animals per pasture+herd unit but only two units. One unit is randomly assigned to one grazing system and the other unit is assigned to the other. The only change in the model given above is that the subscript j now takes only the single value 1. The expected mean squares are shown in table 2.

With only one pasture+herd unit per treatment we have no way of calculating the P(G) mean square which estimates $\sigma_A^2 + 40\,\sigma_p^2$. The term $40\,\sigma_p^2$

Table 1. -- Expected mean squares for a completely randomized design with 3 pastures per treatment.

Source		df	Expected Mean Square (EMS)
G	2-1	= 1	$\sigma_A^2+40\sigma_p^2+(3)(40)(\frac{1}{2-1})(G_1^2+G_2^2)$
P(G)	(2)(3-1)	= 4	$\sigma_A^2+40\sigma_p^2$
A(GP)	(2)(3)(40-1)	= 234	σ_A^2
		239	

Table 2. -- Expected mean squares for a non-replicated experiment.

Source			df	Expected Mean Squares (EMS)
G	2-1	=	1	$\sigma_A^2+40\sigma_p^2+(1)(40)(\frac{1}{2-1})(G_1^2+G_2^2)$
P(G)	(2)(1-1)	=	0	
A(GP)	(2)(1)(40-1)	=	78	σ_A^2
			79	

is still present in the treatment EMS reminding us that we expect some difference between randomly chosen pasture+herd units even if they are treated exactly alike.

A significant F-ratio of the G mean square to the A(GP) mean square is a valid test telling us that the variation observed between treatments is greater than the average variation of animals within treatments. However, it does not allow us to determine the cause of the greater variation in the treatment mean square. This is indicated by examining the expected mean squares for G and A(GP). The EMS for G contains 2 terms [(i.e., $40\sigma_p^2$ and $40(G_1^2+G_2^2)$] in addition to the component σ_A^2 which is common to both G and A(GP). Thus we can not unambigously determine whether the significant F-test is due to the grazing system effect, $G_1^2+G_2^2$, or to variability of the pasture+herd units, σ_p^2, or to some combination of the two effects.

Years as Replicates

It is sometimes suggested that observations can be taken on pastures over the course of several years and then years can be used as replicates, thus avoiding the need for true replication. One problem with this approach is the correlation that exists between observations taken on the same pasture over years. For present purposes, we are willing to assume that this correlation is negligible. (However, see Gill (1977).) An objection that is more relevant to the present discussion is the fact that this approach also does not provide a valid test of the treatment effect when each grazing system is applied to only one pasture+herd unit (Petersen and Lucas, 1960). In order to see this, let us assume that we have four years of data from the replicated experiment discussed above. The model is:

$$X_{ijkl} = \mu + G_i + P(G)_{j(i)} + Y_k + GY_{ik} + P(G)*Y_{j(i)k} + A(GPY)_{l(ijk)}$$

where:

Y_k = effect of the k-th year, k = 1, 2, 3, 4

GY_{ik} = the interaction of years and

$P(G)*Y_{j(i)k}$ = the interaction of years and pasture+herd variability within treatments

$A(GPY)_{l(ijk)}$ = the variability among animals within the jth pasture under the ith treatment during the kth year

and all other terms are as before. Also as before, the true overall mean μ and the treatment effects G1 and G2 are fixed but unknown values. All of the other effects are random with mean values zero. Their variances are:

Random Effect	Variance
P(G)	σ_p^2
Y	σ_Y^2
GY	σ_{GY}^2
P(G)*Y	σ_{GPY}^2
A(GPY)	σ_A^2

The expected mean squares are shown in table 3.

There is no obvious error term for testing the grazing system effect $480(G_1^2+G_2^2)$. However, if we add the EMSs for P(G) and GY and then subtract the EMS for P(G)*Y the result is:

$$\sigma_A^2+40\sigma_{GPY}^2+(3)(40)\sigma_{GY}^2+(4)(40)\sigma_p^2.$$

The only difference between this expression and the EMS for G is the grazing system

Table 3. -- Expected mean squares for a completely randomized design with 3 pastures per treatment conducted over 4 years.

Source		df	Expected Mean Squares (EMS)
G	2-1	= 1	$\sigma_A^2+40\sigma_{GPY}^2+(3)(40)\sigma_{GY}^2+(4)(40)\sigma_p^2+(3)(4)(40)(\frac{1}{2-1})(G_1^2+G_2^2)$
P(G)	(2)(3-1)	= 4	$\sigma_A^2+40\sigma_{GPY}^2+(4)(40)\sigma_p^2$
Y	4-1	= 3	$\sigma_A^2+40\sigma_{GPY}^2 \quad +(2)(3)(40)\sigma_Y^2$
GY	(2-1)(4-1)	= 3	$\sigma_A^2+40\sigma_{GPY}^2+(3)(40)\sigma_{GY}^2$
P(G)*Y	(2)(3-1)(4-1)	= 12	$\sigma_A^2+40\sigma_{GPY}^2$
A(GPY)	(2)(3)(4)(40-1)	= 936	σ_A^2
		959	

effect. Thus, if we add the mean squares for P(G) and GY and then subtract the mean square for P(G)*Y the result can be used as the error term in a pseudo F-test of G. This test will be an unambiguous test of the grazing system effect $480(G_1^2+G_2^2)$. See Hicks (1973) for the method and the adjusted degrees of freedom.

If there was only one pasture+herd unit per grazing system then the expected mean squares are as shown in table 4.

Since we do not have a P(G) nor a P(G)*Y mean square there is no pseudo F-test as above. A significant F-ratio of the G mean square to the GY mean square is a valid test. However, as before it does not tell us unambiguously whether the larger G mean square is due to the variability of the pasture+herd units (i.e., $160\sigma_p^2$) or to the grazing system effect $160(G_1^2+G_2^2)$.

DISCUSSION

When a grazing study is designed biological relevance and statistical validity are considered. Range scientists generally understand the biological implications of an experimental design better than the statistical implications. Therefore, more concern is often given to designing the biological aspect of an experiment than the statistical aspect. This is justified since if the biological model does not mimic the biological system to which experimental results are to be extended, then statistical validity is meaningless. The design of the grazing study determines which of the conclusions derived from the data must be accepted on faith and which are unambiguously supported by statistical theory. In discussing a non-replicated yield trial comparing two treatments Fisher (1951) stated that

Table 4. -- Expected mean squares for a non-replicated experiment conducted over 4 years.

Source		df	Expected Mean Square (EMS)
G	2-1	= 1	$\sigma_A^2+40\sigma_{GPY}^2+(1)(40)\sigma_{GY}^2+(4)(40)\sigma_p^2+(1)(4)(40)(\frac{1}{2-1})(G_1^2+G_2^2)$
P(G)	(2)(1-1)	= 0	
Y	4-1	= 3	$\sigma_A^2+40\sigma_{GPY}^2 \quad +(2)(1)(40)\sigma_Y^2$
GY	(2-1)(4-1)	= 3	$\sigma_A^2+40\sigma_{GPY}^2+(1)(40)\sigma_{GY}^2$
P(G)*Y	(2)(1-1)(4-1)	= 0	
A(GPY)	(2)(1)(4)(40-1)	= 312	σ_A^2
		319	

"If ... the difference in yield appeared large to the experimenters they might argue that so large a difference could not reasonably be ascribed to a difference in soil fertility, since it was contrary to their experience that neighbouring plots treated alike should differ so greatly. To enforce this argument they would in fact have to claim that their past experience had already furnished a basis for the estimation of error, which could be applied with confidence to the circumstances of the experiment under discussion. Even if this claim could be granted the experiment would carry with it the serious disadvantage that it would no longer be self-contained, but would depend for its interpretation from experience previously gathered. It could no longer be expected to carry conviction to others lacking this supplementary experience."

Although replication is required in order to arrive at unambiguous conclusions regarding teatment effects, 95% of the grazing studies published in the Journal of Range Management since 1980 were not replicated. These studies were analyzed using the sampling error as if it were experimental error and, with a few exceptions, the results of the analyses and p-values were reported as if the cause of the observed differences could be unambiguously attributed to the treatments imposed and inference could be made to a larger population. We hope that it is obvious from the previous discussion that such inferences are not statistically valid.

Two of the reasons why replication is so rare in grazing systems research appear to be 1) a misunderstanding of what replication is, and 2) logistical limitations. It is not surprising that there is confusion concerning experimental units and replication in grazing systems research. Most statistics texts treat the subject of experimental units superficially. Furthermore, the experimental units of examples used in most statistics texts are more similar to a subsample, at least in the physical sense, than to the experimental unit in grazing research. Literature that has addressed sources of variation and control of this variation in grazing research has generally investigated the problem at the level of the subsample (e.g. Matches 1969, Holechek and Vavra 1983). Although sampling error is an important issue, greater attention given sampling error compared to experimental error may have confused some persons as to the correct error term for testing treatment effects. Finally, there appears to be some confusion between replication and duplication. Duplication of experimental units in grazing research is impossible since no two pastures or herds perform exactly alike. However, replication does not imply duplication. It is because we cannot duplicate that we must replicate in order to obtain unambiguous results.

Resource limitations usually are more important than any other factor in determining an experimental design. Statisticians live in a world where all samples are infinite or nearly so; the world of the range scientist is finite and usually enclosed by a barb wire fence. Because of this restriciton resources should be allocated in an optimal manner. The location of fences and existing pastures is sometimes a barrier to optimal experimental design. With the recent improvement of relatively low cost electrical fences attitudes that restrict grazing research to existing pastures should be questioned.

The optimal size of a pasture+herd unit for grazing research is primarily a biological question. The size will vary depending on the hypothesis under consideration. We believe that in grazing systems investigations on rangelands the size of the pasture+herd unit is either explicitly or implicitly a part of the hypothesis. For example, if increased production from some grazing systems may be related to greater efficiency of harvest that is at least in part related to livestock distribution (Heitschmidt and Walker 1983) then pasture+herd units must be of sufficient size to create distribution problems that may be ameliorated by one grazing system compared to another. However, if the question involves a specific process that is to be studied at a high level of resolution (e.g., the effect of grazing pressure on organic matter intake) then the size of the pasture+herd unit should be determined by the minimum amount of land and animals necessary to estimate parameters at a desired level of precision. Estimates of variances and consequent sample sizes have been made for various production parameters (Johnson and Laycock 1962, Matches, 1969) diet quality and composition (Obioha et al. 1972, Holechek and Vavra 1983) and forage intake (Cordova et al. 1978). The smallest pasture+herd unit that will provide an adequate biological model and the desired level of precision for estimating response variables is the optimal size for an experimental unit in grazing studies. In general, as many of these experimental units as are feasible should be established.

In discussing the analysis and presentation of the results of non-replicated studies, Hurlbert (1984) suggested that only means, standard deviations and sample sizes be presented and commented that "if we know the precise details of [a non-replicated experiment], we most likely could find grounds for subjectively appraising whether there was a treatment effect and, if so, how great a one. Common sense, biological knowledge, and intuition should be applied to that task; inferential statistics should not be used". We take a slightly less conservative approach. We are convinced that scientists will (correctly) continue to use inferential statistics as a subjective tool in evaluating their non-replicated experiments. We agree with Dahl (1982) that non-replicated studies yield "much useful information on animal response to grazing management" and that in such trials "replication in time (over two or more years) has provided good insight ... to treatment response". We do recommend, however, that non-replicated studies be labeled as such and that the limitations of any inference (statistical or otherwise) be clearly stated.

Other approaches should also be considered. If it is decided that replication is impossible and yet a non-replicated experiment is deemed preferable to no experiment at all then approximate methods of obtaining an estimate of the true experimental error should be investigated. Petersen and Lucas (1960) studied this issue but they considered only small improved pastures. Using data from previous grazing studies they estimated the experimental error to be expected in future trials and were thus able to determine the number of replicates needed in future experiments. The application of their method to production-scale units on rangelands should be investigated. Another possibility is to combine the data from separate non-replicated studies done at several locations. Cochran and Cox (1957) discuss this approach.

CONCLUSIONS

We hope that this paper has accomplished three things. First, we hope the reader understands that an experimental unit is the physical entity to which a treatment is independently applied. In grazing systems research the experimental unit is all of the land and livestock to which a grazing system is applied. Second, experimental units must be replicated if we are to design grazing experiments in such a way that they will produce unambiguous results which can be of use to the rest of the world. Despite the fact that replication is difficult in grazing systems research the non-replicated experiment should be considered the design of last resort. Third, when logistic and economic constraints prevent us from replicating our treatments let us not report our results as if we had.

LITERATURE CITED

Cochran, W.G. and G.M. Cox. 1957. Experimental Designs, 2nd Edition. Wiley, New York.

Connell, J.H. 1974. Field Experiments in Marine Ecology. In: R. Mariscal (Ed.). Experimental Marine Biology. Academic Press, New York, N.Y.

Cordova, F.J., J.D. Wallace and R.D. Pieper. 1978. Forage intake by grazing livestock: A review. J. Range Manage. 31:430-438.

Cornfield, J., and J.W. Tukey. 1956. Average values of mean squares in factorials. Ann. of Math. Stat. 27:907-949.

Dahl, B.E. 1982. Animal response to grazing management: Measurement of diet, nutrition, animal performance and statistical analysis. In: Briske, D.D. and M.M. Kothmann (Eds.). Proc. Natl. Conf. Grazing Manage. Tech. Texas A&M Univ. College Station.

Eberhardt, L.L. 1976. Quantitataive ecology and impact assessment. J. of Env. Man. 4:27-70.

Fisher, R.A. 1951. The Design of Experiments, Sixth Edition. Oliver and Boyd, London.

Gill, J.L. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. The Iowa State Univ. Press, Ames.

Heitschmidt, R.K. and J.W. Walker. 1983. Short duration grazing and the Savory Grazing Method in perspective. Rangelands 5:147-150.

Hilmon, J.B., J.L. Clutter, and D.R. Cable. 1962. Design and conduct of grazing experiments: Layout of experimental units. p. 124-131. In: Range Research Methods. USDA Misc. Pub. 940.

Holechek, J.L., and M. Vavra. 1983. Fistula sample numbers required to determine cattle diets on forest and grassland range. J. Range Manage. 36:323-326.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Mono. 54:187-211.

Johnson, W.M. and W.A. Laycock. 1962. Design and conduct of grazing experiments: Kind, number, and selection of livestock for grazing studies, and animal measurements most suited for evaluating results. p. 137-142 In: Range Research Methods. USDA Misc. Publ. 940.

Morton, J.R. and Ridgman. 1977. Problems in the statistical design and analysis of feeding trials. Proc. Nutr. Soc. 36: 173-177.

Matches, A.G. 1969. Pasture Research Methods. P. I-1 - I-32. In: Proceedings of the National Conference on Forage Quality Evaluation and Utilization. Lincoln, Nebraska.

Obioha, F.C., D.C. Clanton, L.R. Rittenhouse, and C.L. Streeter. Source of variation in chemical composition of forage ingested by eshophageal fistulated cattle. J. Range Manage. 23:133-136.

Peterson, R.G. and H.L. Lucas. 1960. Experimental errors in grazing trials. Proc. 8th Int. Grassl. Cong. 8:747-750.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics. Second Edition. McGraw-Hill, New York.

THE USE OF REPEATED MEASUREMENT DESIGNS IN FIELD STUDIES

Richard M. Engeman, Debra Easi Palmquist and Lyman L. McDonald

ABSTRACT: The use of repeated measurement designs is illustrated for the comparison of grazing systems over a period of years. Additional examples are given to illustrate the potential use of these designs in a wide variety of field studies.

INTRODUCTION

Studies in range science frequently measure each member of a group(s) of experimental units under differing "treatment" conditions, including time. For example, the effects of grazing systems on pastures might be compared over time. A number of pastures (experimental units) would be assigned to each grazing system. Then each pasture in each grazing system would be measured (subsampled) at the same designated points in time. Thus, ignoring the measurement problems for the present, we are faced with two levels of experimental units, the larger experimental units (pastures) which are "split" into smaller units (time intervals). Because each of the larger units in a grazing system is repeatedly measured under differing experimental conditions (time), these experiments are frequently referred to as repeated measures experiments. The factor over which the experimental units are measured does not have to be time; however, time most frequently is the factor with repeated measures.

A second complicating aspect of field studies and particularly studies of grazing systems is the difficulty of measuring the attribute(s) of interest on pastures, the larger experimental units. Subsampling of pastures by use of macroplots, transects, quadrats or even individual plants requires careful attention to obtain both efficient design and correct analysis. This problem is addressed indirectly throughout the paper and in more detail in the discussion section.

Paper presented at the Symposium on Statistical Analysis and Modelling of Grazing Systems, Orlando, Florida, February 10-13, 1985.

Richard M. Engeman is Statistician, Denver Wildlife Research Center, USFWS, Denver Federal Center, Denver, Colorado; Debra Easi Palmquist is Statistician, University of Nevada, Reno, and USDA/ARS, Mountain States Area, Reno, Nevada, and Lyman L. McDonald is Professor of Statistics and Zoology, University of Wyoming, Laramie, Wyoming, on sabbatical leave at the Denver Wildlife Research Center, USFWS, Denver Federal Center, Denver, Colorado.

In repeated measures studies, the repeated measures on an experimental unit are likely to be more closely related with each other than to those of the other experimental units. This relationship must be accounted for during data analysis. In addition to the usual univariate analysis of variance (ANOVA) assumptions of normality of data, homogeneity of variances and the independence of the experimental units, it is also required that the covariance structure have compound symmetry. Compound symmetry exists when the variance is constant over all observations and the correlation between any two observations in time is also a constant. Thus, the covariance matrix between observations appears as:

$$\sigma^2 \begin{bmatrix} 1 & \rho & \rho & \cdot & \cdot & \cdot & \rho \\ \rho & 1 & \rho & \cdot & \cdot & \cdot & \rho \\ \rho & \rho & 1 & \cdot & \cdot & \cdot & \rho \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \rho & \rho & \rho & \cdot & \cdot & \cdot & 1 \end{bmatrix} .$$

The purpose of this paper is to give an introduction to the design, analysis and proper inferences for repeated measures experiments. The most common designs will be described along with their analyses, assuming compound symmetry holds. Problems with assumptions, alternate analyses, and more complicated designs will be briefly discussed and referenced. Two general references for additional information on repeated measures designs are Winer (1971) and Milliken and Johnson (1984).

SINGLE FACTOR EXPERIMENTS

As a first example, consider a single factor repeated measures experiment which arose as a

subset of a large study designed to evaluate a specific rest-rotation grazing system (unpublished data courtesy of R. E. Eckert, Jr., USDA/ARS, Mountain States Area, Reno, Nevada). Coverage by a specific species, Poa sandbergii (POSA), on a specific macroplot is selected to illustrate the basic principles of repeated measures experiments. Five permanent quadrats were systematically located in the macroplot with a random starting point for the first quadrat. Percent cover by POSA was measured using standard techniques before the start of the study and at the end of three cycles of the grazing system, giving rise to these data:

Quadrat	Beginning	End
1	3.7	0.7
2	3.1	0.8
3	5.6	0.7
4	4.4	2.5
5	3.7	1.2 .

Statistical (inductive) inferences can only be made to the specific macroplot. There were n = 5 large experimental units (quadrats) each "split" into k = 2 smaller units (time intervals). These data were analyzed after applying the variance stabilizing transformation, arcsin $\sqrt{\%\ \text{cover}/100}$, and assuming that the quadrats are far enough apart to be statistically independent. The form of the appropriate analysis of variance (ANOVA) table for testing the null hypotheses of no effect due to time is given below:

Source of variation	Degrees of freedom (df)
Between quadrats	n-1 = 4
Within quadrats	n(k-1) = 5
Treatments (Time)	k-1 = 1
Residual	(n-1)(k-1) = 4
Total	nk-1 = 9 .

In the jargon of ANOVA, the "within quadrats" term is separated into the effect due to time and a residual error (equivalent to the quadrat x time interaction). This form for the ANOVA table serves to remind the user of the repeated measurements over time on the same experimental units. Also the degrees of freedom column gives an approximate check that the correct analysis has been provided by a computer program. The F-statistic with 1 and 4 degrees of freedom is F = 33.04 and is significant at the P = .01 level, leading to the inference that coverage by POSA changed on the macroplot during the course of the study. Note that, in this simplest example of a repeated measurements design with k = 2 time periods, the F-statistic is equal to the square of the "paired t-statistic" for testing the hypothesis of no change in the cover by POSA over time. Possible reasons for the observed change would be the result of further deductive (subjective) arguments which are beyond the scope of the present paper.

In the second example, the fruiting phenology of squaw currant (Ribes cereum) was studied in a homogeneous area under a given grazing system. Ten plants (n = 10) were randomly selected and, beginning with the onset of berry production, counts of berries on each of the 10 plants were made weekly (on the same day of the week) for k = 8 weeks. The abbreviated ANOVA table is given by:

Source	df
Between plants	n-1 = 9
Within plants	n(k-1) = 70
Times	(k-1) = 7
Residual	(n-1)(k-1) = 63
Total	nk-1 = 79 .

The F-statistic with 7 and 63 df is used to test the hypothesis of no change in mean berry count over time during the 8-week period.

As a third example, consider a study of the food habits of mule deer (Odocoileus hemionus) in a particular habitat. Fifty (= n) pellet groups were randomly selected from the area at a given point in time and the proportions of k = 5 food sources were measured for each pellet group. The large units, pellet groups, were "split" into five correlated proportions, which illustrates the case where repeated measurements are measured on a factor other than time. In this example, the proportion of a sixth food source was dropped from the analysis to avoid a linear dependency in these data. The abbreviated ANOVA table for testing the hypothesis of equal proportions from each of the food sources is as follows:

Source	df
Between pellet groups	n-1 = 49
Within pellet groups	n(k-1) = 200
Food sources	(k-1) = 4
Residual	(n-1)(k-1) = 196
Total	nk-1 = 249 .

The analytical form of the single factor repeated measures experiment is identical to other forms of ANOVA. If the words "pellet groups" in the above table were changed to "blocks," then the table would be identical to that for analysis of a randomized complete block design. Simultaneous multiple comparison procedures can be applied to compare the levels of the treatment factor (e.g., time or food sources) when a significant difference is indicated by the overall F-test in the ANOVA (Winer, 1971).

The relatively simple analysis for the single factor repeated measures experiment also has nonparametric analogs. For ranked data, Friedman's test for a two-way layout is appropriate. This test is described in many statistics books, including Winer (1971). A thorough description is found in Hollander and Wolfe (1973). Cochran's Q (Winer, 1971) provides a test where the measurements yield dichotomous data (that is, each measurement on each unit can be written as 0 or 1).

TWO FACTOR EXPERIMENTS WITH REPEATED MEASURES

Consider an extension of the first example in the single factor experiments. Suppose it is of interest to compare the effect of the rest-rotation grazing system on coverage by POSA in p = 4 "macroplots" selected to represent 4 different vegetation types (study areas) within the pasture. Five (= n) permanent quadrats (i.e., experimental units) were randomly located in each macroplot, and coverage by POSA was measured on each unit every third year for 9 years. This yielded q = 3 cover values for each unit.

As before, the lines for "between units" and "within units" in the abbreviated ANOVA table are included for the reader to see their relative contributions, but are not necessary for presenting analytical results. A thorough description of this model is found in Chapter 7 of Winer (1971), whose notation is used below:

Source	df
Between units (transects)	np-1 = 19
A (macroplots)	p-1 = 3
Units in A	p(n-1) = 16
Within units (transects)	np(q-1) = 40
B (times)	q-1 = 2
BA	(q-1)(p-1) = 6
B x Units in A	p(n-1)(q-1) = 32
Total	npq-1 = 59 .

The mean squared residual Units-in-Macroplots is the divisor for the F-test comparing the effects of different Macroplots (A) while the Times x Units-in-Macroplots is the appropriate divisor for F-tests comparing the effects of Time (B) and for the existence of a Time-by-Macroplot (BA) interaction.

Statistical inferences are limited to the four fixed macroplots (study areas) selected by the experimenter. If the pasture is stratified into four homogeneous vegetation types and macroplots are randomly sampled from each stratum, then inferences from strata comparisons apply only to that pasture. More general inferences could validly be made if a set of pastures were randomly selected for study.

For the second example, consider a study of the effects of competition by naturally occurring brush on a given grass species. Sixteen plots were randomly selected and sectioned off in the study area. Into each of these plots, two plants of the grass species were planted so that they were surrounded by a ring of naturally occurring brush. In n = 8 of the plots, this outside ring of brush was removed. Factor A is referred to as "competition," with p = 2 levels, control (no brush removal) and treatment (brush removal). Live basal area covered by the plants was measured each year for q = 6 years, factor B. Since measurements of the same plants in the same plots were taken over time, assume that a repeated-measures analysis is appropriate. Because the primary experimental unit is a plot with two plants, the analysis is conducted on the average cover of the plants in each plot. Recording cover values for the individual plants does not change the appropriate analysis indicated below (see the discussion section):

Source	df
Between plots	np-1 = 15
A (competition)	p-1 = 1
Plots in A	p(n-1) = 14
Within plots	np(q-1) = 80
B (times)	q-1 = 5
A x B	(p-1)(q-1) = 5
B x plots in A	p(n-1)(q-1) = 70
Total	npq-1 = 95 .

As a third example consider a study to compare the acceptance of bait by Columbian ground squirrels (Spermophilus columbianus) for three levels of an anticoagulant toxicant (factor A). Because the toxicant may induce illness or produce an aversive

response in the animals, one would expect they might eat less through time and therefore may not receive a lethal dose. Thus, measurement of consumption over time (factor B) is of interest. The experimental design for this study consisted of randomly assigning n = 10 animals to each of the p = 3 treatment groups: control bait (no toxicant), 50 ppm toxicant, and 100 ppm toxicant. The animals were in individual cages and the amount of bait consumed was measured for each ground squirrel on q = 3 consecutive days.

Thus, time (days) was the factor for which repeated measures were taken. For simplicity's sake, the animals are assumed to be assigned to treatment groups according to weight class and to be of the same sex, thus avoiding the effects of sex and weight on consumption. The source of variation and degrees of freedom columns from the ANOVA table for analyzing data from this experiment are shown below:

Source	df
Between animals	np-1 = 29
Toxicant (A)	p-1 = 2
Animals in A	p(n-1) = 27
Within animals	np(q-1) = 60
Days (B)	q-1 = 2
AB	(q-1)(p-1) = 4
B x Animals in A	p(n-1)(q-1) = 54
Total	npq-1 = 89 .

If all observations were independent, i.e., if different experimental animals were used across all levels of B in addition to A, then the Animals-in-A and B x Animals-in-A terms in the above table would be combined into one term, Animals in BA. This is the usual two-factor factorial ANOVA. This model would have npq different experimental units whereas the two factor repeated measures model has np units, each measured q times.

It is also interesting to note that if the Units-in-A are considered plots and the units can be divided such that the levels of B can be randomly assigned to the divisions of the unit, then the design is the traditional split plot design. In repeated measures designs the levels of B (e.g., the levels of time) cannot be randomly assigned to each of the units. The analysis of a split plot experiment will frequently apply to the data from a repeated measures experiment. However, it is possible that the error structure from a repeated measures experiment does not fit the assumptions of split plot analysis. Milliken and Johnson (1984) provide a discussion of this point in their chapter 26.

THREE FACTOR EXPERIMENTS WITH REPEATED MEASUREMENTS

The first example is a generalization of the study of grazing systems where repeated observations are made over time. Four pastures were available and p = 2 grazing systems (factor A) were each randomly assigned to n = 2 pastures. The pastures were stratified into q = 5 homogeneous vegetation types (factor B) and 25 randomly located permanent subsampling units were obtained in each stratum of each pasture. An attribute of interest (e.g., cover by a certain grass species) was measured on each unit at r = 3 times (factor C): years, 3, 6 and 9 of the study.

The example is more realistic than before and is becoming more complex. There are four sizes of experimental units: pastures, vegetation types within pastures, time periods, and subsampling units (transects, quadrats, plants, etc.). The subsampling units can be eliminated from consideration (without altering the ANOVA results on the effects of interest) by averaging (totaling) the response over the 25 values obtained in each of the npqr = 60 cases on the other factors. The appropriate ANOVA can then be obtained by an analysis of these means.

Because the vegetation types cannot be randomly assigned to sections of a pasture as in a split-plot design, the vegetation types are considered "repeated observations" on a pasture. This yields one factor, grazing systems, randomly assigned to the primary experimental units (pastures) and repeated observations on two factors (vegetation type and time). Also, considering vegetation types as repeated measures is similar to the consideration of proportions of food sources as repeated measures in the mule deer food habits example. The abbreviated ANOVA table has four residual error terms for testing the various hypotheses of interest:

Source	df
Between pastures	np-1 = 3
Grazing Systems (A)	(p-1) = 1
Pastures in A	p(n-1) = 2
Within pastures	np(qr-1) = 56
Vegetation types (B)	(q-1) = 4
AB	(p-1)(q-1) = 4
B x pastures in A	p(n-1)(q-1) = 8
Times (C)	(r-1) = 2
AC	(p-1)(r-1) = 2
C x pastures in A	p(n-1)(r-1) = 4
BC	(q-1)(r-1) = 8
ABC	(p-1)(q-1)(r-1) = 8
BC x pastures in A	p(n-1)(q-1)(r-1) = 16
Total	npqr-1 = 59 .

Pastures-in-A is the error term for the F-test comparing main effects of Grazing Systems (A). Similarly, B x Pastures-in-A is the error term for the F-tests for B and AB effects, C x Pastures-in-A is the error term for the F-tests for C and AC effects, and BC x Pastures-in-A is the error term for the F-tests for BC and ABC effects.

These data are balanced in the above example. This may not be the case in practice if: some of the vegetation types do not exist in some of the pastures, or if the response (e.g., cover) is not measured on all pastures in the same years. Such variations will greatly increase the complexity of the analysis, and in fact an appropriate statistical analysis may not exist. The experimenter is encouraged to consider if an appropriate analysis exists before conducting an experiment. A problem of less serious consequence arises if some of the permanent subsampling units (e.g., quadrats) are lost or destroyed. In this case, if data from remaining units are averaged and included in the analysis as before, an acceptable approximation should result.

Note that if there were only n = 1 replication of each grazing system, we have n-1 = 0 and therefore 0 degrees of freedom for the error terms in the above ANOVA table and no statistical comparisons are possible. In the above discussion it is assumed that each of the vegetation types within each pasture is "randomly subsampled" by appropriate units (macroplots, transects, quadrats, plants, etc.). The assumption of random sampling can usually be relaxed to allow systematic sampling with random starting rules if there is uniform coverage over the vegetation type and the subunits are "far enough apart" to be considered statistically independent. In some studies it may not be practical to randomly sample the vegetation types. In this case representative "macroplots" are often subjectively selected in each vegetation type within each pasture, then the macroplots are subsampled by appropriate methods. Exactly the same analysis as given above can be conducted for this case; however, the statistical inferences are limited to the selected macroplots! Inferences concerning the effects of nonreplicated grazing systems or extrapolation beyond subjectively selected macroplots are deductive (subjective) and are the sole responsibility of the experimenter.

The words "vegetation types" are intended to be generic. Specific applications might be made to community types, range sites, soil types, disturbed sites vs. undisturbed sites, etc. Also, the same analysis would apply to other attributes of interest such as plant density (number per unit area), frequency of occurrence, biomass per unit area, etc.

For the second example, consider an expansion of the squaw currant study. The fruiting phenology was studied for p = 2 habitat types (A), rocky outcrops versus open meadow. Also, the fruiting phenology was compared over q = 2 consecutive years (B). Ten plants (n = 10) were randomly selected from each habitat type at the start of the study. At the initiation of berry production in each year, berry counts were made on a weekly basis for r = 8 weeks (C). The source of variation and degrees of freedom columns for the ANOVA table are as follows:

Source	df
Between plants	np-1 = 19
Habitats (A)	p-1 = 1
Plants in A	p(n-1) = 18
Within plants	np(qr-1) = 300
Years (B)	q-1 = 1
AB	(p-1)(q-1) = 1
B x plants in A	p(n-1)(q-1) = 18
Weeks (C)	(r-1) = 7
AC	(p-1)(r-1) = 7
C x plants in A	p(n-1)(r-1) = 126
BC	(q-1)(r-1) = 7
ABC	(p-1)(q-1)(r-1) = 7
BC x plants in A	p(n-1)(q-1)(r-1) = 126
Total	npqr-1 = 319 .

This design is also a three-factor repeated measures with repeated observations on two factors (Years and Weeks). The appropriate F-tests are formed as in the previous example.

In the third example, consider an extension of the mule deer food habits study where

repeated observations were taken on only one factor, namely the r = 5 proportions of food sources for a given pellet group. It was of interest to compare food habits of mule deer and domestic sheep (Ovis aries) (i.e., p = 2 species) during a summer grazing period for q = 3 years.

During each summer of each of the 3 years, n = 50 fresh pellet groups (units) were randomly collected from the study area from each species and the proportional contribution of the same five food sources given earlier was measured. Note that summer periods do not involve "repeated measurements" on the same pellet groups. New samples of pellet groups were randomly selected for each period and only the r = 5 proportions were "repeated" on each group. Thus, summer periods are a typical fixed effects term in the model for ANOVA.

The source of variation and degree of freedom columns for the ANOVA table would appear as follows:

Source	df
Between pellet groups	npq-1 = 299
Species (A)	p-1 = 1
Periods (B)	q-1 = 2
AB	(p-1)(q-1) = 2
Groups in AB	pq(n-1) = 294
Within pellet groups	npq(r-1) = 1200
Food sources (C)	r-1 = 4
AC	(p-1)(r-1) = 4
BC	(q-1)(r-1) = 8
ABC	(p-1)(q-1)(r-1) = 8
C x groups in AB	pq(n-1)(r-1) = 1176
Total	npqr-1 = 1499 .

The Species, Period, and Species x Period effects are tested using Pellet Groups-in-Species x Period as the error term in the three F-tests. Similarly, the main effects of the food sources and its interactions are tested using the Food Source x Pellet Groups in Species x Period term as the error term in those F-tests.

Note that if there were n different independent experimental units in each of the pqr treatment combinations of ABC, then this model would become the usual three factor factorial model with only one error term.

As the number of factors increase, the models become progressively more complicated. A four factor repeated measures design can have repeated observations on one, two, or three factors and the corresponding ANOVA tables contain two, four, or eight error terms, respectively. For example, assume several species of grass are of interest in the study of grazing systems. These resulting data might be analyzed under a four factor design with grazing systems, the first factor, randomly assigned to pastures and "repeated observations" on three factors: vegetation types, grass species, and time. For more on complicated designs and unbalanced cases see Winer (1971) or Milliken and Johnson (1984).

OTHER ANALYTICAL CONSIDERATIONS

To this point, the discussion has been concerned with the standard repeated measures designs with balanced data and the usual hypothesis tests where the compound symmetry assumption is not questioned. In this section we briefly discuss other analytical considerations. Detailed discussions of these topics are beyond the scope of this paper, but the reader should be aware of them. We direct the reader to sources of further information.

Frequently, the number of experimental units varies among the groups of a multi-factor repeated measures design. This could be due to many unintentional causes such as death of a subject (unit) or unequal availability of experimental material. An unbalanced design could be intentional to reflect the proportion of the number of units in each strata of their general population. Depending on the reason for the unbalanced structure of the data, there are alternate methods of calculating the sums of squares (e.g., least squares vs. unweighted analyses) for the ANOVA table. Winer (1971) presents a section on unequal group sizes in chapter 7 where the unweighted and least squares approaches are discussed and compared. Milliken and Johnson (1984) also go into detail for the unbalanced case in their chapter 28. There, they discuss approaching the problem using a general linear model procedure in a computer package.

A topic of interest to the investigator is often the comparison of means within an effect. These could be specific a priori comparisons of interest or a general search for the particular means causing an effect to be "significant." Many times when the repeated factor is time, the investigator will want to look for the most appropriate model of trend among the time points for the measured variable. Methods for determining the most appropriate trend model are

discussed in chapters 4 and 7 of Winer (1971) and chapter 26 of Milliken and Johnson (1984). Multiple comparisons on the means in significant effects are also discussed in these chapters. Milliken and Johnson (1984) also go into detail for testing trends and multiple comparisons in the unbalanced case in chapter 28.

A potential problem faced by investigators using repeated measures designs is that, in addition to the usual ANOVA assumptions, the assumption that the covariance structure has a compound symmetry form may not hold. Box (1950, 1954) suggested a test for the hypothesis that compound symmetry holds and developed a conservative test to apply when compound symmetry is rejected. This test may be unnecessarily conservative but performs well with a further complicated adjustment on the degrees of freedom (Collier et al., 1967). Greenhouse and Geisser (1959) suggest a three step approach to analyzing data where compound symmetry may not hold. This algorithm, described in chapter 27 of Milliken and Johnson (1984) is briefly:

1. Test using the usual degrees of freedom. If this test is nonsignificant, stop because the adjusted degrees of freedom tests are more conservative and will also be nonsignificant,

2. If the usual test is significant, apply Box's conservative test. If that test is also significant, stop because it is the most conservative test and further adjustment will also result in significance,

3. If the usual F-test is significant, but Box's conservative test is not, then the complicated adjustment to the degrees of freedom should be performed.

Milliken and Johnson (1984) also describe how this three step procedure can be applied to tests on trends and multiple comparisons.

When time is the repeated factor in a repeated measures design, the observational errors can frequently be related through time by an auto-regressive covariance structure. The covariance structure with a first-order autoregressive process and t-time points, in contrast to compound symmetry, appears as

$$\sigma^2/(1-\rho^2)\begin{bmatrix} 1 & \rho & \rho^2 & \cdots & \rho^{t-1} \\ \rho & 1 & \rho & \cdots & \rho^{t-2} \\ \rho^2 & \rho & 1 & \cdots & \rho^{t-3} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \rho^{t-1} & \rho^{t-2} & \rho^{t-3} & \cdots & 1 \end{bmatrix}.$$

Although the complicated adjustment to the F-test discussed above is still effective in this case, special methods for handling this covariance structure that are more powerful are described in chapter 27 of Milliken and Johnson (1984).

Finally, if one is unwilling to assume the compound symmetry covariance structure nor apply the adjustments to the F-tests, then one can take a multivariate approach to data analyses. The "multiple variables" are the repeated measurements made on each unit. The multivariate approach is the most general, but is less powerful if compound symmetry really exists. A good discussion of the multivariate approach to repeated measures experiments can be found in chapter 31 of Milliken and Johnson (1984).

DISCUSSION AND SAMPLING CONSIDERATIONS IN GRAZING STUDIES

The sampling design in a particular study dictates the type of analyses that can be performed and the extent to which inferences can be made. Often the inferences are not as broad as intended, or the correct analyses may not have as much power (degrees of freedom) as appears on the surface. Using examples, each of these problems is illustrated and discussed.

Consider a study to compare the effect of two grazing systems on cover by grasses. Two "similar" pastures are selected and assigned at random to the grazing systems. Within each pasture 10 quadrats are randomly selected and each quadrat is measured in July of each of 5 years. This can be analyzed as a two factor repeated measures design with the following ANOVA table.

Source	df	
Between quadrats	19	
Pasture (grazing system)		1
Quadrats in pasture		18
Within quadrats	80	
Years		4
Years x pasture		4
Years x quadrats in pasture		72
Total	99	

$$\sigma^2 \begin{bmatrix} 1 & \rho & \rho^2 & \cdots & \rho^{t-1} \\ \rho & 1 & \rho & \cdots & \rho^{t-2} \\ \rho^2 & \rho & 1 & \cdots & \rho^{t-3} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \rho^{t-1} & \rho^{t-2} & \rho^{t-3} & \cdots & 1 \end{bmatrix}$$

Although the conservative adjustment to the F-test discussed above is still effective in this case, special methods for modeling this covariance structure that are more powerful are described in chapter 11 of Milliken and Johnson (1984).

Finally, if one is unwilling to assume the compound symmetry covariance structure nor apply the adjustments to the F-tests, then one can take a multivariate approach to data analysis. The "multiple variables" are the repeated measurements made on each unit. The multivariate approach is the most general, but is less powerful if compound symmetry really exists. A good discussion of the multivariate approach to repeated measures experiments can be found in chapter 32 of Milliken and Johnson (1984).

ANALYSIS AND SAMPLING CONSIDERATIONS IN SAMPLING DESIGNS

The sampling design in a particular study dictates the type of analyses that can be performed and the level to which inferences can be made. Often the inferences are not as broad as intended, or the correct analysis may not have as much power (degrees of freedom) as appears on the surface. Using examples, some of these problems are illustrated and discussed.

Consider a study to compare the effect of two grazing systems on cover by grasses. Ten "similar" pastures are selected and assigned at random to the grazing systems. Within each pasture a quadrat is set randomly located and cover in it is measured for data of each of 5 years. This can be analyzed as a two factor repeated measures design with the following ANOVA table:

Source	df
Between subjects	19
Factor A (grazing system)	1
Subjects in factor	18
Within subjects	80
Time	4
Time x Factor	4
Time x Subjects in Factor	72
Total	99

discussion in chapters 5 and 7 of Winer (1971) and chapter 26 of Milliken and Johnson (1984). Multiple comparisons on the means in significant effects are also discussed in these chapters. Milliken and Johnson (1984) also go into detail for testing trends and multiple comparisons in the unbalanced case in chapter 28.

A potential problem faced by investigators using repeated measures designs is that, in addition to the usual ANOVA assumptions, the assumption that the covariance structure has a compound symmetry form may not hold. Box (1950, 1954) suggested a test for the hypothesis that compound symmetry holds and developed a conservative test to apply when compound symmetry is rejected. This test may be unnecessarily conservative and performs well with a further complicated adjustment to the degrees of freedom (Collier et al. 1967). Greenhouse and Geisser (1959) suggest a three step approach to analyzing data where compound symmetry may not hold. This algorithm, described in chapter 27 of Milliken and Johnson (1984), is briefly:

1. Test using the usual degrees of freedom. If this test is non-significant, stop because the critical values of the two tests in a conservative test can only also be non-significant.

2. If the usual test is significant, apply Box's conservative test. If that test is also significant, stop because it is the most conservative test and further adjustment will also result in significance.

3. If the usual F-test is significant, but Box's conservative test is not, then the complicated adjustment to the degrees of freedom should be performed.

Milliken and Johnson (1984) also discuss how they would deal with structures that can be analyzed in terms of trends and multiple comparisons.

When time is the repeated factor in a repeated measures design, the observational errors are frequently be related through time by an autoregressive covariance structure. The covariance structure with a first-order autoregressive process and 5 time points, in contrast to compound symmetry, appears as

Assume that the analysis indicates a difference between pastures. A desired inference is that the different grazing systems result in a difference in grass cover. However, only one pasture per grazing system was used. Therefore, any differences between the grazing systems cannot be distinguished from any inherent pretreatment differences that may exist between the pastures. Multiple pastures in each treatment are needed before statistical inferences from the analyses could imply a general effect to pastures from the treatment. Although an adequate sample may be available for comparing the two pastures, the only valid statistical inference is to the two specific pastures and not beyond.

Next consider a study where inferences are not the problem, but the appropriate error term and associated degrees of freedom are. Three levels of intensity of grazing by horses (Equus caballus) are to be studied by taking a measure of plant cover. Two pastures are randomly assigned to each level of grazing intensity. Twenty quadrats are randomly placed within each pasture. These quadrats are measured each month from April through September. Again this is a two factor repeated measures design, but with an extra level of nesting, i.e., quadrats in pastures. The ANOVA table could appear as

Source	df
Treatments	2
Pastures in treatments	3
Quadrats in pastures	114
Months	5
Months x treatments	10
Months x pastures in treatments	15
Months x quadrats in pastures	570
Total	719

The appropriate error term for the F-test on Treatment effect is Pastures-in-Treatments and the appropriate error term for the F-test on Months and Months x Treatments interaction is Months x Pastures-in-Treatments. The F-test for Treatment has two degrees of freedom in the numerator and three in the denominator. The F-tests for Months and Months x Treatments have 5 and 10 degrees of freedom in the numerator, respectively, and 15 in the denominator. The 114 degrees of freedom for Quadrats-in-Pastures and the 570 degrees of freedom for Months x Quadrats-in-Pastures do not increase the power of tests on the effects of interest. The tests on these effects would be numerically identical if the 20 values from each quadrat in each month were averaged and the usual two factor repeated measures analysis applied to this data set of 36 means (versus 720 individual values). If enough pastures are available, then the experimental effort might be more efficiently applied to more pastures with fewer quadrats per pasture. This would increase the power (number of degrees of freedom) for the tests of interest. Even if more pastures are not available, but the ones used are reasonably homogeneous, then the study might be done more economically with fewer quadrats per pasture. Subsampling the primary experimental units and thus collecting "more data" does not necessarily increase the sensitivity of the tests. If subsamples are to be taken, then the number needed is only enough to arrive at a representative measurement for the primary sample (i.e., reduce the measurement error to an acceptable level). Further subsampling is unlikely to benefit the analyses.

LITERATURE CITED

Box, G.E.P. 1950. Problems in the analysis of growth and wear curves. Biometrics 6: 362-389.

Box, G.E.P. 1954. Some theorems on quadratic forms applied in the study of analysis of variance problems. The Annals of Mathematical Statistics 25: 290-302.

Collier, R. O., Jr., Baker, F. B., Mandeville, G. K. and Hayes, T. F. 1967. Estimates of test size for several test procedures based on variance ratios in repeated measures experiments. Psychometrika 32: 339-353.

Greenhouse, S. W. and Geisser, S. 1959. On methods in the analysis of profile data. Psychometrika 24: 95-112.

Hollander, M. and Wolfe, D. A. 1973. Nonparametric Statistical Methods, John Wiley and Sons, New York.

Milliken, G. A. and Johnson, D. E. 1984. Analysis of Messy Data, Lifetime Learning Publications, London.

Winer, B. J. 1971. Statistical Principles in Experimental Design, McGraw-Hill, New York.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
DENVER SERVICE CENTER

THE LIGHTER SIDE OF STATISTICS

MARCH 1985
REVISED FEBRUARY 1986

BY
KRIS ESHELMAN
SHIRLEY HUDSON
BOB MITCHELL
MIKE PELLANT
KAY THOMAS

THE LIGHTER SIDE OF STATISTICS

Statistical analysis is one of those processes that many field offices are using, are curious about, would like to use, or are trying to avoid. In all seriousness, statistics remind many people of the old saying "liars figure and figures lie." Believe it or not, statistics do have a place in BLM.

Principles of statistics are often used in private industry. Most people, if they are going to invest a large amount of time and scarce dollars, will not take a chance on something if they have a greater than 50 percent chance (odds) of being wrong. If they do take a chance at those odds, they are considered crazy. If they succeed, they are brillant and have a lot of luck.

The taxpayers' inventory and monitoring program is very similar to investing in private industry except taxpayers never want a large amount of time and money invested in something if there is a 50 percent or greater chance of being wrong. Since bureaucrats are never called brilliant and are usually thought of as crazy, we cannot operate with a 50 percent or greater chance of being wrong. So we have statistics, and thus mathematicians, statisticians, and biometricians to baffle and confuse everyone, and to calculate our chances of success and accuracy.

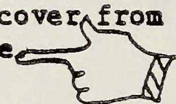
Statistics tell us the probability of success and let us know how confident we can feel about a value we have measured. The basic principles of statistics have made many casino operators rich men and have provided millions of dollars to Nevada's education system. (New Jersey does not count since it is not in the "real" West.) The "odds" are in favor of the casino at all times.

Now that we recognize the value of statistics, we can evaluate the reliability of the inventory and monitoring program, calculate how confident we are about the results of our work, and maybe avoid losing our hard-earned money next time we visit Reno, Las Vegas, or Panaca, Nevada.

The first objective of statistics is to place a range of values about a measured value (percent cover, production, etc.) and to state how confident we are (e.g., 80 percent or 90 percent) that the true value for that study sample is within that range. Statisticians call this calculating a confidence interval. The second objective is to pick a range of values around the mean, expressed as $\pm$ some percentage of the mean (statisticians say precision, and that $\pm$ is read plus or minus); pick a level of confidence; and then figure out how many samples we need to obtain that level of precision at that confidence. See, statistical language isn't completely confusing. The third objective is to evaluate the statistical significance of change that has occurred on a site or study over time.

Statistical terms that will be used are mean (average), precision, variance, standard deviation, coefficient of variation, and confidence interval. All you have to do is calculate them; I'll tell you how to use them. To make things easy, we are going to use a cookbook approach.

Now is a good time to get a pencil, a big eraser (or calculator with a $\sqrt{\ }$ key on it), a cup of coffee (to prevent sudden drowsiness) or another refreshment, and two aspirins if mathematics gives you headaches. Avoid alcoholic beverages! While you are up, grab an inventory or monitoring file and take out the data for one study. If you do not have a file handy, pull an example of density, frequency, production, or cover from Appendices 1, 2, 3, or 4. I will mark your spot while you are gone.



The first thing we have to determine is what type of study you have chosen to analyze. If it is cover, density, or production, you have to go to Part A; and if it is frequency, go to Part B. After you have mastered Parts A, B, and C (if you end up in C we are in trouble), you can use Part D to learn how to detect the statistical significance of any change.

Part A - Cover, Density, or Production

Please answer the following question: Did you (or somebody else) use more than one hoop, plot, or frame of uniform size to gather the cover, density, or production data; and are the data recorded plot by plot?

If your answer is no, then you are unable to continue further at least using Part A. Go to Section C for further instructions and suggestions. If your answer is yes, please continue.

Find Figure A_1 and take it out so you can use it. You should notice that there is a completed example on the right half of the page.

a. Pick a species (it is usually best to pick a key or dominant species) from your data and write the name in the appropriate blank. Fill in the attribute (i.e., density, production, etc.,) we are analyzing as well.

b. Count the number of hoops, plots, or frames that were sampled and enter the number in the space provided. Note the symbol in parenthesis (n) after the space; we will use this number later.

c. Enter the sample values (for the species you picked) in the vertical column (X) for each hoop, frame, etc. (plot 1, plot 2, etc.,).

d. Add up Column (X) and enter the answer in TOTAL (X)______.

e. Remember (n)(number of plots, frames, etc.)? Divide TOTAL (X) by (n). This number is the mean or average ($\bar{X}$) of your species for all plots. Fill in the ($\bar{X}$) blank and the ($\bar{X}$) column, all with the same value.

f. Subtract the ($\bar{X}$) column from the plot 1, plot 2, etc. values in the (X) column. Enter each answer in the two ($X - \bar{X}$) columns.

Species ______ State ______
Attribute ______ District ______
Date ______ Allotment ______
Study # ______

Number of plots, hoops, or frames ______ (n)

	(X)	-	$(\bar{X})$	=	$(X-\bar{X})$	x	$(X-\bar{X})$	=	$(X-\bar{X})^2$
Plot 1		-		=		x		=	
Plot 2		-		=		x		=	
Plot 3		-		=		x		=	
Plot 4		-		=		x		=	
Plot 5		-		=		x		=	
Plot 6		-		=		x		=	
Plot 7		-		=		x		=	
Plot 8		-		=		x		=	
Plot 9		-		=		x		=	
Plot 10		-		=		x		=	

TOTAL (X) ______ ÷ ______ (n) = ______ $(\bar{X})$ TOTAL A ______

______ (TOTAL A) ÷ ______ (n-1) = ______ (S^2)

$\sqrt{\_\_\_ (S^2)}$ = ______ (S) ______ (S) ÷ ______ $(\bar{X})$ = ______ (CV)

INTERCEPT (n) and CV:

90% Confidence ______ % (∓ mean) 80% Confidence ______ % (∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND DATA

@ 90% CONFIDENCE

(100%- ______ (% ∓mean)) x ______ mean, density, cover, (or production value) = lower limit ______

(100%+ ______ (% ∓mean)) x ______ mean, density, cover, (or production value) = upper limit ______

@ 80% CONFIDENCE

(100%- ______ (% ∓mean)) x ______ mean, density, cover, (or production value) = lower limit ______

(100%+ ______ (% ∓mean)) x ______ mean, density, cover, (or production value) = upper limit ______

Species ABSP State YA
Attribute Density District 0470
Date 2/29/84 Allotment 1007
Study # 2

Number of plots, hoops, or frames 6 (n)

	(X)	-	$(\bar{X})$	=	$(X-\bar{X})$	x	$(X-\bar{X})$	=	$(X-\bar{X})^2$
Plot 1	20	-	16	=	4	x	4	=	16
Plot 2	14	-	16	=	-2	x	-2	=	4
Plot 3	15	-	16	=	-1	x	-1	=	1
Plot 4	12	-	16	=	-4	x	-4	=	16
Plot 5	18	-	16	=	2	x	2	=	4
Plot 6	17	-	16	=	1	x	1	=	1
Plot 7		-		=		x		=	
Plot 8		-		=		x		=	
Plot 9		-		=		x		=	
Plot 10		-		=		x		=	

TOTAL (X) 96 ÷ 6 (n) = 16 $(\bar{X})$ TOTAL A 42

42 (TOTAL A) ÷ 5 (n-1) = 8.4 (S^2)

$\sqrt{8.4 (S^2)}$ = 2.9 (S) 2.9 (S) ÷ 16 $(\bar{X})$ = .18 (CV)

INTERCEPT (n) and CV:

90% Confidence 14 % (∓ mean) 80% Confidence 10 % (∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND DATA

@ 90% CONFIDENCE

(100%- 14 (% ∓mean)) x 16 mean, density, cover, (or production value) = lower limit 13.8

(100%+ 14 (% ∓mean)) x 16 mean, density, cover, (or production value) = upper limit 18.2

@ 80% CONFIDENCE

(100%- 10 (% ∓mean)) x 16 mean, density, cover, (or production value) = lower limit 14.4

(100%+ 10 (% ∓mean)) x 16 mean, density, cover, (or production value) = upper limit 17.6

Figure A1

g. Multiply one $(X - \overline{X})$ column times the other $(X - \overline{X})$ column. [We are actually squaring $(X - \overline{X})$]. Remember, a negative number times a negative number equals a positive number, so all of your answers will be positive. Enter each answer in the $(X - \overline{X})^2$ column.

h. Add up the $(X - \overline{X})^2$ column and enter the answer in TOTAL A.

i. Divide TOTAL A by (n - 1) (your number of plots less 1) and enter in the (S^2) spaces. S^2 is the variance of your data.

j. Use your calculator to find the square root of (S^2) and enter it in the (S) blanks. (S) is the standard deviation and means very little to most people, but statisticians include it in most formulae they use.

k. Divide (S) by your mean ($\overline{X}$) and enter this innocent looking value in the (CV) space. You have just calculated the coefficient of variation (CV) for the species named "whatever."

You have now completed all the calculations necessary to determine the precision at a given level of confidence for your inventory or monitoring study.

Remove Figures A_2 and A_3. Note that A_2 is titled 90 percent confidence and A_3 is titled 80 percent confidence. Select one of the confidence figures. For most purposes in BLM, 80 percent confidence is adequate. You will notice on the figure(s) that the number of samples (plots) (n) is on the bottom, and the Coefficient of Variation (CV) is on the left. Do not worry about the numbers on the right yet. If your (n) figure is five or less, consider using Appendices 5 and 6 (enlarged versions of Figures A_2 and A_3).

Find your (n) number on the figure. Now find your (CV) on the left-hand side. Where do these points intersect? Staying between the curved lines, follow the curve all the way over to the right-hand side. What is the number? This is the precision or plus or minus percent of the mean figure. For example, if your precision was 15 percent and you used the figure for 80 percent confidence, it means that you can be 80 percent confident that your data for species "whatever" is within $\pm$ 15 percent of the actual mean.

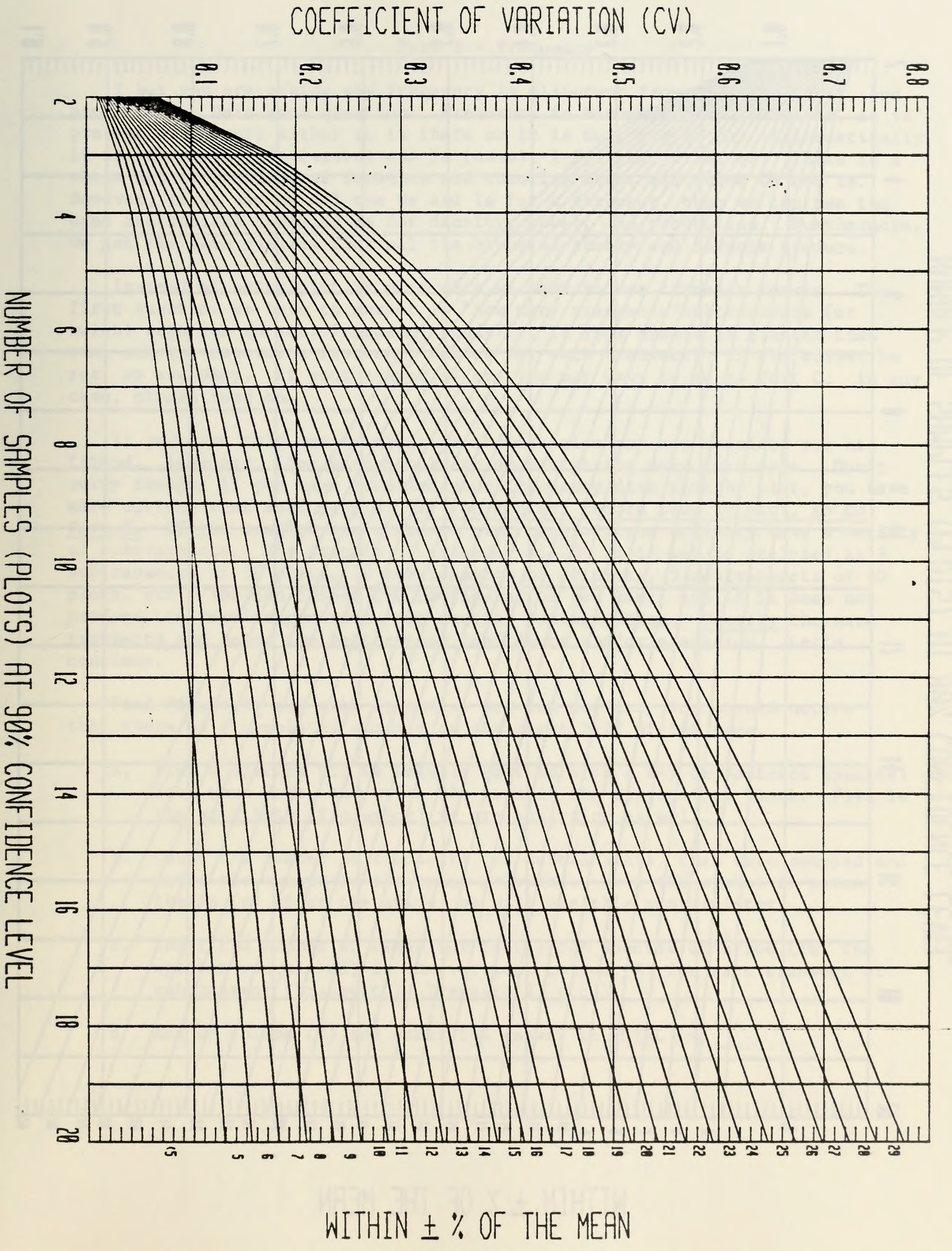
Enter your precision value in the appropriate confidence (80 percent or 90 percent) level blank (under the title INTERCEPT (n) and CV). Now select the appropriate formula (same confidence percent) and calculate the upper and lower limits for the Confidence Interval (CI). Be sure to convert the percent values to their decimal equivalents, i.e., in Figure A_1 for the 90 percent confidence, the 100% - 14% becomes 0.86 whereas the 100% + 14% becomes 1.14. A confidence interval tells you that the true population value lies somewhere between the upper and lower limits 80% (at the 80% confidence level) or 90% (at the 90% confidence level) of the time.

In the example shown in A_1 besides the confidence interval for the mean we could calculate the density of Agsp to be 72,600/acre (16 x 43,560 ÷ 9.6) and enter this value into the formula to arrive at the confidence interval for the population value. At the 90% confidence level the range would be from 62,436/ac to 82,764/ac. Now use the other confidence level figure to calculate the CI.

That wasn't so hard! What happens if the boss sends you out to do a study and he expects you to be 80 percent confident that your key species data are ± 20 percent of the mean ($\bar{X}$). While in the field, you sampled nine plots and calculated a coefficient of variation (CV) of .50. Using Figure A_3, you find that your precision (±% of the mean) is ± 23 percent. (In the world of statistics, smaller precision values are "better" and statisticians [and I will, too] refer to those smaller values as a "higher level" of precision. Logical, isn't it?) Since your precision is lower than the boss wants, you must collect more data. How much more? Quite simple! Using Figure A_3, find the intersection for CV = .50 and (n) = 9. Now using the same (CV) value, move to the right until you reach the 20 percent "band." Keep going to the right until you hit a vertical line or "tick" mark. Now go down to the number of samples. This is the total number of plots (11) you have to sample to be 80 percent confident your data for species X will be within ± 20 percent of the actual study mean. Now using your data, subtract 5 percent from your precision (±% of the mean) and figure out how many plots to sample at this new level. REMEMBER, STATISTICS ARE MORE MEANINGFUL ON A SPECIES BY SPECIES BASIS!

I would recommend you try the section on frequency next. Do not be surprised if all the instructions are basically the same. There is little difference in how we look at frequency, density, cover, and production. In frequency you use transect data whereas in density cover, etc., you use plot data.

Detecting change is found in Part D.



COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
NUMBER OF SAMPLES (PLOTS) AT 90% CONFIDENCE LEVEL
2
4
6
8
10
12
14
16
18
20
WITHIN ± % OF THE MEAN

Figure A_2

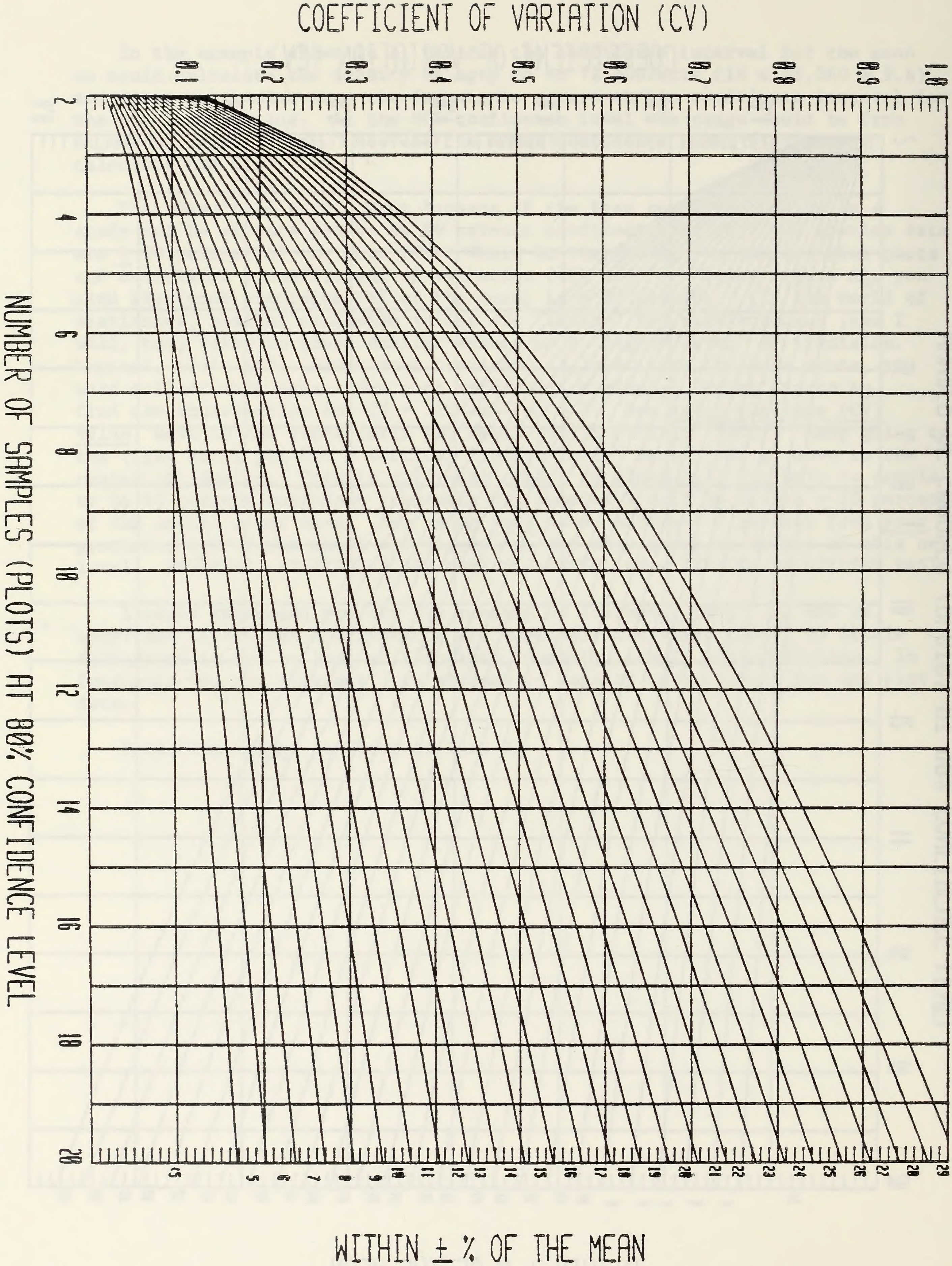

COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
NUMBER OF SAMPLES (PLOTS) AT 80% CONFIDENCE LEVEL
2
4
6
8
10
12
14
16
18
20
WITHIN ± % OF THE MEAN

Figure A_3

Part B - Frequency

I bet you are asking why frequency is different from density, cover, and production. Darn good question! Frequency is binomial data. That is, it is present or absent; either it is there or it is not; yes or no. Mathematically it is like having 0s (zeros) and 1s (ones); 1 for yes, 0 for no. There is a whole set of statistical formulas and theories about all these 0s and 1s. However, if we add up all the 0s and 1s for a transect, then we can use the same statistical formulas as for density, cover, and production. Furthermore, we get the same results that all the binomial theory and formula produce.

Instead of using plot by plot data we have to use transect totals. The first question we have to answer is "how many transects/subtransects (or belts) were run in your frequency study?". If your answer is greater than one, can you determine frequency values for each transect? If the answer is yes, we are okay. If your answer is no, you may have to go to Part C. In any case, please read on.

If you have only one transect, a statistician may not consider you his friend. Remember, they want people to do everything more than once. Don't worry though; if you have recorded your frequency data plot by plot, you have more options than most people. If you did not record plot by plot, go to Part C. If you sampled one transect plot by plot, you actually have a variety of subtransects. For example, 1 transect of 200 plots may be analyzed as 4 subtransects of 50 plots, 10 subtransects of 20 plots, 5 subtransects of 40 plots, etc. You can choose the configuration you want; and if it does not produce the results you want, try another configuration. Usually the more transects you have, the better your confidence and/or precision. Let's continue.

Find Figure B_1 and take it out so you can use it. You should notice that there is a completed example on the right half of the page.

a. Pick a species (it is usually best to pick a key or dominant species) from your data, and write the name in the appropriate blank. Fill in the attribute (frequency) we are analyzing as well.

b. Count the number of transects (or subtransects) that were sampled and enter the number in the space provided. Note the symbol in parenthesis (n) after the space; we will use this number later.

c. Enter the number of times (or plots) the species occurred (for the species you picked) in the vertical column (X) for each transect or subtransect (Transect 1, Transect 2, etc.).

d. Add up column (X) and enter the answer in TOTAL (X)____.

e. Remember (n) the number of transects (subtransects) etc.,? Divide TOTAL (X) by (n). This number is the mean or the average ($\overline{X}$) times your species occurred. Fill in the ($\overline{X}$) blank and the ($\overline{X}$) column, all with the same value.

f. Subtract ($\overline{X}$) from the Transect 1, Transect 2, etc., values in the (X) column. Enter each answer in the two ($X - \overline{X}$) columns.

g. Multiply one ($X - \overline{X}$) column times the other ($X - \overline{X}$) column. [We are actually squaring ($X - \overline{X}$)]. Remember, a negative number times a negative number equals a positive number, so all your answers will be positive. Enter the answer in the $(X - \overline{X})^2$ column.

h. Add up the $(X - \overline{X})^2$ column and enter the answer in TOTAL A.

i. Divide TOTAL A by (n-1) (your number of transects less 1) and enter in the (S^2) spaces. S^2 is the variance of your data.

j. Find the square root of (S^2) and enter it in the (S) blanks using your calcultor. (S) is the standard deviation and statisticians include it in most formulas they use.

k. Divide (S) by your mean ($\overline{X}$) and enter this innocent looking value in the (CV) space. You have just calculated the coefficient of variation for the species named "whatever."

You have now completed all the calculations necessary to determine the precision at a given level of confidence for your inventory or monitoring study.

Remove Figures B_2 and B_3. Note that B_2 is titled 90 percent confidence, and B_3 is titled 80 percent confidence. Select one of the confidence figures. For most purposes in BLM 80 percent confidence is adequate. You will notice on the figures that the number of transects/ subtransects (n) is on the bottom and coefficient of variation (CV) is on the left. Do not worry about the numbers on the right yet. If your (n) is five or less, consider using Appendices 7 and 8 (enlarged versions of Figures B_2 and B_3).

Find your (n) number on the figure. Now, find your (CV) on the left hand side. Where do these points intersect? Staying between the curved lines, follow the curve all the way over to the right-hand side. What is the number? This is the precision or plus or minus percent of the mean figure. For example, if your precision was 15 percent and you used the figure for 80 percent confidence, it means that you can be 80 percent confident that your data for species "whatever" is within $\pm$ 15 percent of the actual mean.

Enter your precision value in the appropriate confidence (80 percent or ninety percent) level blank (under the title INTERCEPT (n) and CV). Now using the correct formula (same confidence percent), calculate the upper and lower

Species ______ State ______
Attribute ______ District ______
Date ______ Allotment ______
Study # ______

Number of transects or subtransects ______ (n)

	(X)	-	($\bar{X}$)	=	(X-$\bar{X}$)	x	(X-$\bar{X}$)	=	(X-$\bar{X}$)^2
Transect 1		-		=		x		=	
Transect 2		-		=		x		=	
Transect 3		-		=		x		=	
Transect 4		-		=		x		=	
Transect 5		-		=		x		=	
Transect 6		-		=		x		=	
Transect 7		-		=		x		=	
Transect 8		-		=		x		=	
Transect 9		-		=		x		=	
Transect 10		-		=		x		=	

TOTAL (X) ______ ÷ ______ (n) = ______ ($\bar{X}$) TOTAL A ______

______ (TOTAL A) ÷ ______ (n-1) = ______ (S^2)

$\sqrt{\_\_\_\_ (S^2)}$ = ______ (S) ______ (S) ÷ ______ ($\bar{X}$) = ______ (CV)

INTERCEPT (n) and CV:

90% Confidence ______ % (∓ mean) 80% Confidence ______ % (∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND DATA

@ 90% CONFIDENCE

(100%- ______ (% ∓mean)) x ______ mean or (frequency value)= lower limit ______

(100%+ ______ (% ∓mean)) x ______ mean or (frequency value)= upper limit ______

@ 80% CONFIDENCE

(100%- ______ (% ∓mean)) x ______ mean or (frequency value)= lower limit ______

(100%+ ______ (% ∓mean)) x ______ mean or (frequency value)= upper limit ______

Species HIJa State YA
Attribute Frequency District 0470
Date 10/87/48 Allotment 9999
Study # A3

Number of transects or subtransects 10 (n) 20 plots per subtran.

	(X)	-	($\bar{X}$)	=	(X-$\bar{X}$)	x	(X-$\bar{X}$)	=	(X-$\bar{X}$)^2
Transect 1	16	-	14	=	2	x	2	=	4
Transect 2	13	-	14	=	-1	x	-1	=	1
Transect 3	15	-	14	=	1	x	1	=	1
Transect 4	12	-	14	=	-2	x	-2	=	4
Transect 5	8	-	14	=	-6	x	-6	=	36
Transect 6	15	-	14	=	1	x	1	=	1
Transect 7	16	-	14	=	2	x	2	=	4
Transect 8	20	-	14	=	6	x	6	=	36
Transect 9	10	-	14	=	-4	x	-4	=	16
Transect 10	15	-	14	=	1	x	1	=	1

TOTAL (X) 140 ÷ 10 (n) = 14 ($\bar{X}$) TOTAL A 104

104 (TOTAL A) ÷ 9 (n-1) = 11.6 (S^2)

$\sqrt{11.6 (S^2)}$ = 3.4 (S) 3.4 (S) ÷ 14 ($\bar{X}$) = .24 (CV)

INTERCEPT (n) and CV:

90% Confidence 13 % (∓ mean) 80% Confidence 10 % (∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND DATA

@ 90% CONFIDENCE

(100%- 13 (% ∓mean)) x 70 mean or (frequency value)= lower limit 61

(100%+ 13 (% ∓mean)) x 70 mean or (frequency value)= upper limit 79

@ 80% CONFIDENCE

(100%- 10 (% ∓mean)) x 70 mean or (frequency value)= lower limit 63

(100%+ 10 (% ∓mean)) x 70 mean or (frequency value)= upper limit 77

Figure B_1

limits for the confidence interval (CI). Be sure to convert the percent values in the formula to their decimal equivalents. For example, in Figure B_1, for 90% confidence, 100% - 13% becomes 0.87 whereas 100% + 13% becomes 1.13. The example in figure B_1 derived a frequency value for Hija by dividing the number of plots in which Hija occurred by the total plots sampled (140 ÷ 200 = .70 or 70%). A confidence interval tells you that the true population value lies somewhere between the upper and lower limits 80% (at the 80% confidence level) or 90% (at the 90% confidence level) of the time. Now use the other confidence level figure to calculate the CI.

That wasn't so hard! What happens if the boss sends you out to do a study and he expects you to be 80 percent confident that your key species data are ± 20 percent of the mean ($\bar{X}$)? While in the field you sampled 9 transects and calculated a coefficient of variation (CV) of .50. Using Figure B_3 you find that your precision (±% of the mean) is ± 23 percent. (In the world of statistics, smaller precision values are "better," and statisticians (and I will, too) refer to those smaller values as a "higher level" of precision. Logical, isn't it?) Since your precision is lower than the boss wants, you must collect more data. How much more? Quite simple! Using Figure B_3, find the intersection for CV = .50 and (n) = 9. Now using the same (CV) value, move to the right until you reach the 20 percent "band". Keep going to the right until you hit a vertical line or tick mark. Now go down to the number of transects/subtransects. This is the total number of subtransects (11) you have to sample to be 80 percent confident your data for species X will be within ± 20 percent of the actual study mean. Now using your data, subtract 5 percent from your precision (±% of the mean) and figure out how many transects to sample at this new level. REMEMBER, STATISTICS ARE ONLY GOOD ON A SPECIES BY SPECIES BASIS!

You have done so well you are hereby declared a member of the Royal Order of Befuddlers. If you haven't done so, I would recommend you try the section on cover, density, or production (Part A) next. Do not be surprised if all the instructions are basically the same. There is little difference in how we look at frequency, density, cover, and production. In frequency you use transect data whereas in cover, etc., you use plot data.

Detecting change is found in Part D.

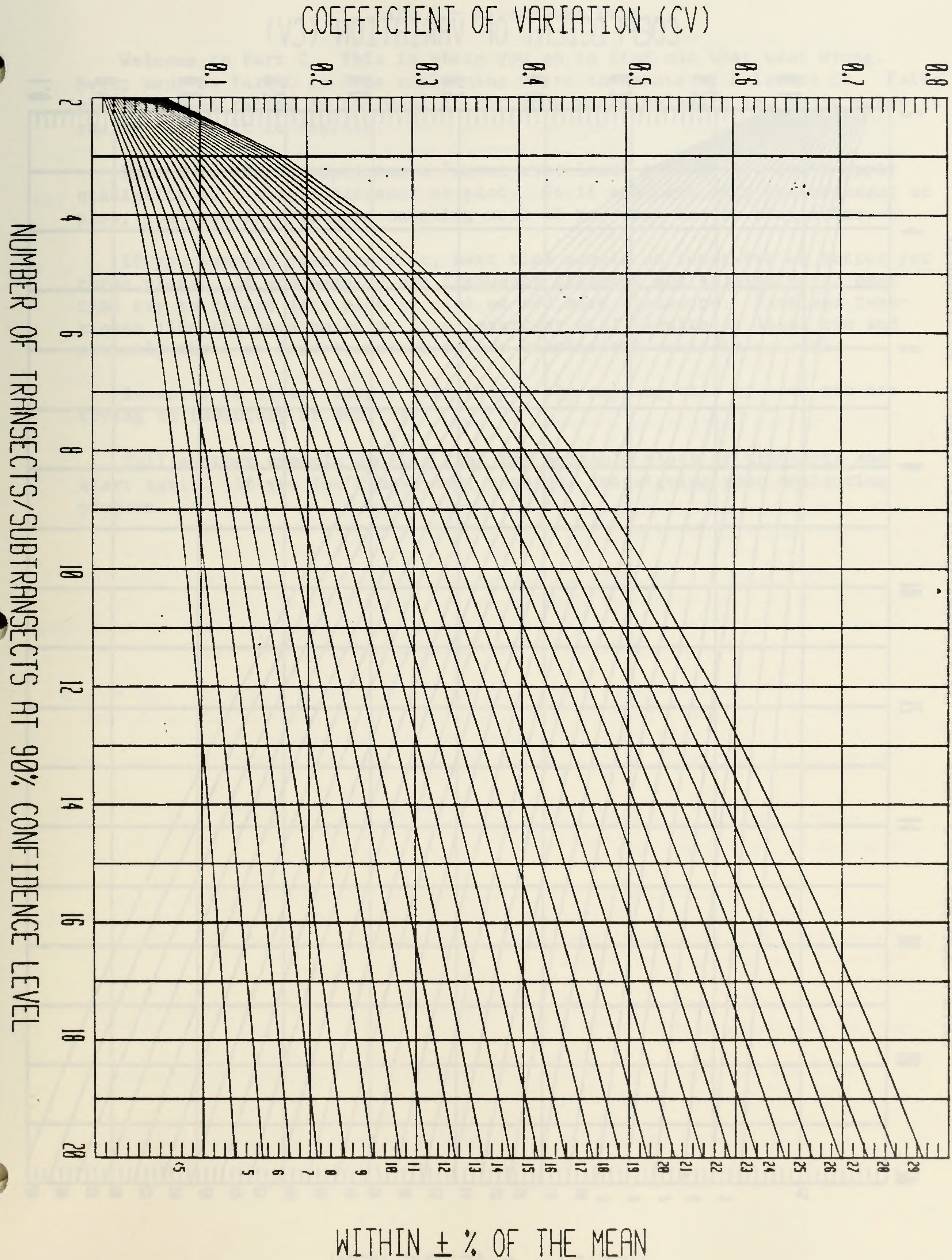

COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
NUMBER OF TRANSECTS/SUBTRANSECTS AT 90% CONFIDENCE LEVEL
2
4
6
8
10
12
14
16
18
20
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
WITHIN ± % OF THE MEAN

Figure B2

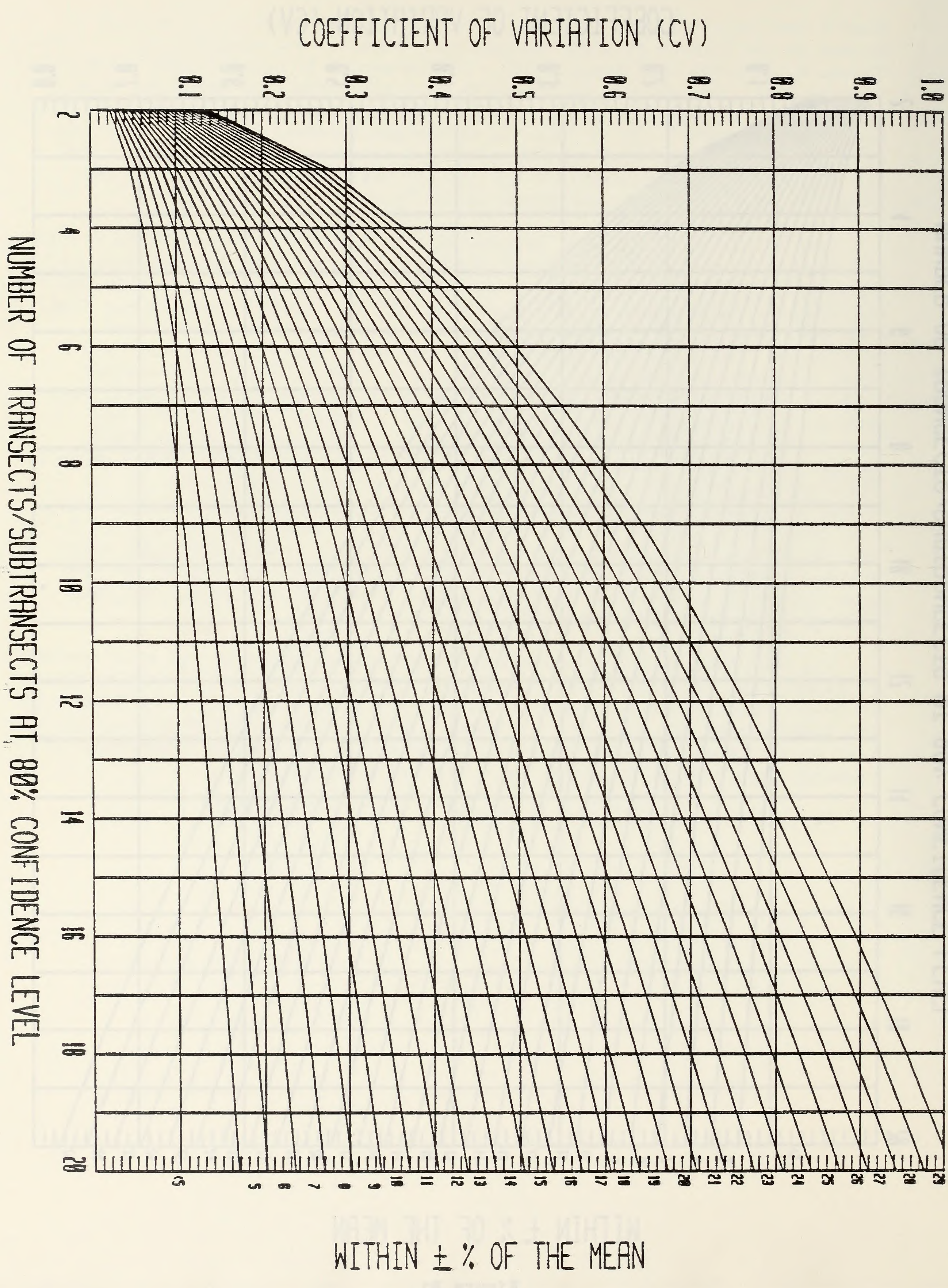

COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
NUMBER OF TRANSECTS/SUBTRANSECTS AT 80% CONFIDENCE LEVEL
2
4
6
8
10
12
14
16
18
20
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
WITHIN ± % OF THE MEAN

Figure B_3

Part C - Never-Ever Land

Welcome to Part C. This is where you go to find out what went wrong. Being sent to Part C is like explaining where the state of Delaware is. Folks who have been raised in the West do not know where Delaware is, so it makes it really difficult to explain.

Part C is the statistician's "never-ever land" because you can't apply statistics to a single transect or plot. So if you have only one transect or plot, you must do some more sampling work if you want to use statistics.

If you sampled just one plot, next time sample at least two or better yet three plots. If you sampled one frequency transect and tallied data, next time try to record data plot by plot or add more transects. Plotless techniques like the pace point or line intercept will require at least two and probably three or four transects to put statistical analysis to work.

Remember to always sample data within the mapping unit or area you are trying to inventory or monitor.

Pull another example or file that has multiple plots or transects and start again. If you don't have any, consider redesigning your monitoring program.

Part D - Detecting Change

Finally, we will use statistics to help us detect change over a period of time. Statistics can let us know our level of confidence and precision in stating that change has occurred. Unfortunately, there may be cases where change will be obvious, but the data collected do not statistically show it. Another thing to remember is that by the time statistics indicate change, rangeland may not respond to management. So "fine tune" (a nice verb for the TV generation, musicians, and auto mechanics) management as you go along.

Rule # 1 - In order to correctly state the statistical significance of a detected change, all studies must have been completed using the same ground rules and techniques each year. The number of plots or transects can vary, but it is never a good idea to do less than the baseline study.

Rule # 2 - Analysis of data must use the same analysis procedures each year; therefore, if you ever want to change analysis procedures, you must reanalyze all data using the same method.

Let's move on to more "productive range (ground)". You have already learned what the mean ($\bar{X}$) and variance (S^2) are. Now, we'll use the $\bar{X}$ and S^2 values from year 1 and year 2, as well as a value I'll have you look up in the t-table (Appendix 9) to detect change.

Find Figure D_1 and take it out so you can use it. As with Figures A_1, and B_1 there is a completed example on the right half of the page. The example has extra steps in the math computations. I just wanted to make sure you understand the order in which to multiply and add the values.

a. Fill in the blanks for n, $\bar{X}$, and S^2 for years 1 and 2. You should be able to copy them directly from forms A_1 or B_1. Notice that n, $\bar{X}$, and S^2 now have subscripts (a 1 indicates the earlier reading whereas a 2 indicates a subsequent or the latest reading) so that we can tell them apart.

b. Use the equation in line 1 to compute S^2, and enter it in the space provided. This is a new S^2 value. It is an average of S_1^2 and S_2^2, weighted by $(n_1-1)$and (n_2-1).

c. Use the equation in line 2 to compute S_d^2 (this confusing combination of letters and numbers is the variance of the difference between the earlier and later mean readings. Confused? . . . so am I!!. Put your value in the appropriate blank.

d. Use the equation in line 3 to compute the square root of S_d^2, and put it in the S_d blank.

e. Use the equation in line 4 to find df, the degrees of freedom you will use to look up the t-values in Appendix 9.

f. O.K. Using Appendix 9 and the df you have just calculated, fill in the blanks in line 5a with t-values. Now, multiply S_d (from line 3) by each of the t-values in line 5a and put the answers in line 5b.

g. Compute the difference between $\overline{X}_1$ and $\overline{X}_2$. Subtract the smaller from the larger so that diff (the difference) will be positive.

h. Finally, we're ready to see how confident we are that a change has occurred. Compare diff (from line 6) to the values in line 5b. If diff exceeds a value in line 5b, then you are 70% to 95% confident (depending on what the column heading is) that a change has occurred. Pick the largest value in line 5b which diff exceeds, and thus the corresponding confidence will be as high as possible.

O.K. We're through! Want a clue on how to set your objectives? You'll need $\overline{X}$, n, and S from a study you've already done.

a. First we'll have to look up a t-value in Appendix 9. Degrees of freedom will equal (2n)-2. Pick the t-value for the confidence level (e.g. 80% or 90%) you'll accept.

b. Compute the following: $t * S \div \sqrt{n}$

c. Add this value to $\overline{X}$ (your density, frequency, cover, etc. value). This is how large your subsequent $\overline{X}$ value must be to statistically exceed the first, original $\overline{X}$ at the confidence level you've selected. Remember this is only a target....an objective! If your variation for the first reading is different from the variation calculated for the second reading the figure may be a little off.

Year 1	Year 2
____ n_1	____ n_2
____ $\overline{X}_1$	____ $\overline{X}_2$
____ S^2	____ S^2

1. $[(n_1-1)S_1^2 + (n_2-1)S_2^2] \div (n_1+n_2-2) =$ ____ (S^2)

2. $(S^2 \div n_1) + (S^2 \div n_2) =$ ____ (S_d^2)

3. $\sqrt{S_d^2} =$ ____ (S_d)

4. $n_1 + n_2 - 2 =$ ____ (df)

5. t values from Appendix 9

Confidence Level	70%	80%	90%	95%
a. t value =	____	____	____	____
b. $S_d \times t$ =	____	____	____	____

6. $\overline{X}_1 - \overline{X}_2$ or $\overline{X}_2 - \overline{X}_1 =$ ____ (diff)
(diff must be zero or greater)

Conclusion:

Year 1	Year 2
10 n_1	10 n_2
14 $\overline{X}_1$	16 $\overline{X}_2$
11.6 S^2	10.0 S^2

1. $[(n_1-1)S_1^2 + (n_2-1)S_2^2] \div (n_1+n_2-2) =$ ____ (S^2)

$[(9) \times 11.6 + (9) \times 10.0] \div (10 + 10 - 2) =$

$[104.4 + 90.0] \div 18 = \underline{10.80}\ (S^2)$

2. $(S^2 \div n_1) + (S^2 \div n_2) =$ ____ (S_d^2)

$10.80 \div 10 + 10.80 \div 10 =$

$1.08 + 1.08 = \underline{2.16}\ (S_d^2)$

3. $\sqrt{S_d^2} = \sqrt{2.16} = \underline{1.47}\ (S_d)$

4. $n_1 + n_2 - 2 = \underline{18}$ (df)

5.

Confidence Level	70%	80%	90%	95%
a. t value =	1.07	1.33	1.73	2.10
b. $S_d \times t$ =	1.57	1.96	2.54	3.09

6. $\overline{X}_1 - \overline{X}_2$ or $\overline{X}_2 - \overline{X}_1 = \underline{2.0}$ (diff)
(diff must be zero or greater)

Conclusion: $\overline{X}_2$ (our second reading) is greater than $\overline{X}_1$ (our first reading) at the 80% confidence level because 2.0 ($\overline{X}_2 - \overline{X}_1$) is greater than 1.96, but less than 2.54 (the value needed in order to be 90% confident).

Figure D_1

Part E - Statistical Formulas

n = number of transects (frequency, line cover, point cover) or plots (plot cover, density, production)

X = species or sample values

$\overline{X}$ = mean or average — formula: $\overline{X} = \frac{\Sigma X}{n}$

S^2 = variance — formula: $S^2 = \frac{\Sigma (X - \overline{X})^2}{n-1}$

S = standard deviation — formula: $S = \sqrt{S^2}$

CV = coefficient of variation — formula: $CV = \frac{S}{\overline{X}}$

E = the precision or $\pm$ ___% of the mean. Note: in statistical calculations you always use the decimal equivalent i.e., $\pm$ 10% = $\pm$ .10

$t_{.90}$ = t value at the 90 % confidence level (or 10% chance to be wrong) level; (Note the decimal format) and where degrees of freedom = n-1. See Appendix 9 (t Table)

$t_{.95}$ = t value at 95% confidence (5% chance to be wrong)
$t_{.80}$ = t value at 80% confidence (20% chance to be wrong)

TO SOLVE FOR:

number (n) of required transects to reach a particular level of confidence and $\pm$% of the mean given t, CV, and E

$$n = \frac{t^2 * CV^2}{E^2}$$

$\pm$% of the mean (E) given t, CV, and n

$$E = t * CV * \sqrt{1/n}$$

coefficient of variation given n, E, and t

$$CV = \frac{\sqrt{n} * E}{t}$$

Note: t is shown without a particular level of confidence. The value of t must be obtained from the t table (Appendix 9).

ALLOTMENT: Plucked Goose
DATE: 9/31/84
OBSERVER: I. R. Quick
LOCATION: 1/4 mile W. of Dry Well #19
PARAMETER: Cover
TECHNIQUE: Daubenmire 6 class

% Cover (midpoint) By Plot

	1	2	3	4	5	6	7	8	9	10
Blackgrama	85.0	2.5	2.5	0.0	15.0	2.5	15.0	2.5	62.5	2.5
Western wheatgrass	62.5	2.5	15.0	15.0	37.5	2.5	2.5	15.0	87.5	2.5
Euphor(b)ia	2.5	15.0	0	0	2.5	15.0	0	0	2.5	15.0

ALLOTMENT: Cowtown
DATE: 10/07/84
OBSERVER: Down N. Out
LOCATION: 70 yards NW of truck
PARAMETER: Density
TECHNIQUE: 4 each 9.6 sq. ft. hoops

	Plot 1	Plot 2	Plot 3	Plot 4
Idaho Fescue	20	24	16	19
Phlox	5	7	3	6
Cheatgrass	70	60	65	69
Saguaro Cactus	1	0	0	0
Blue Spruce	1	0	0	0

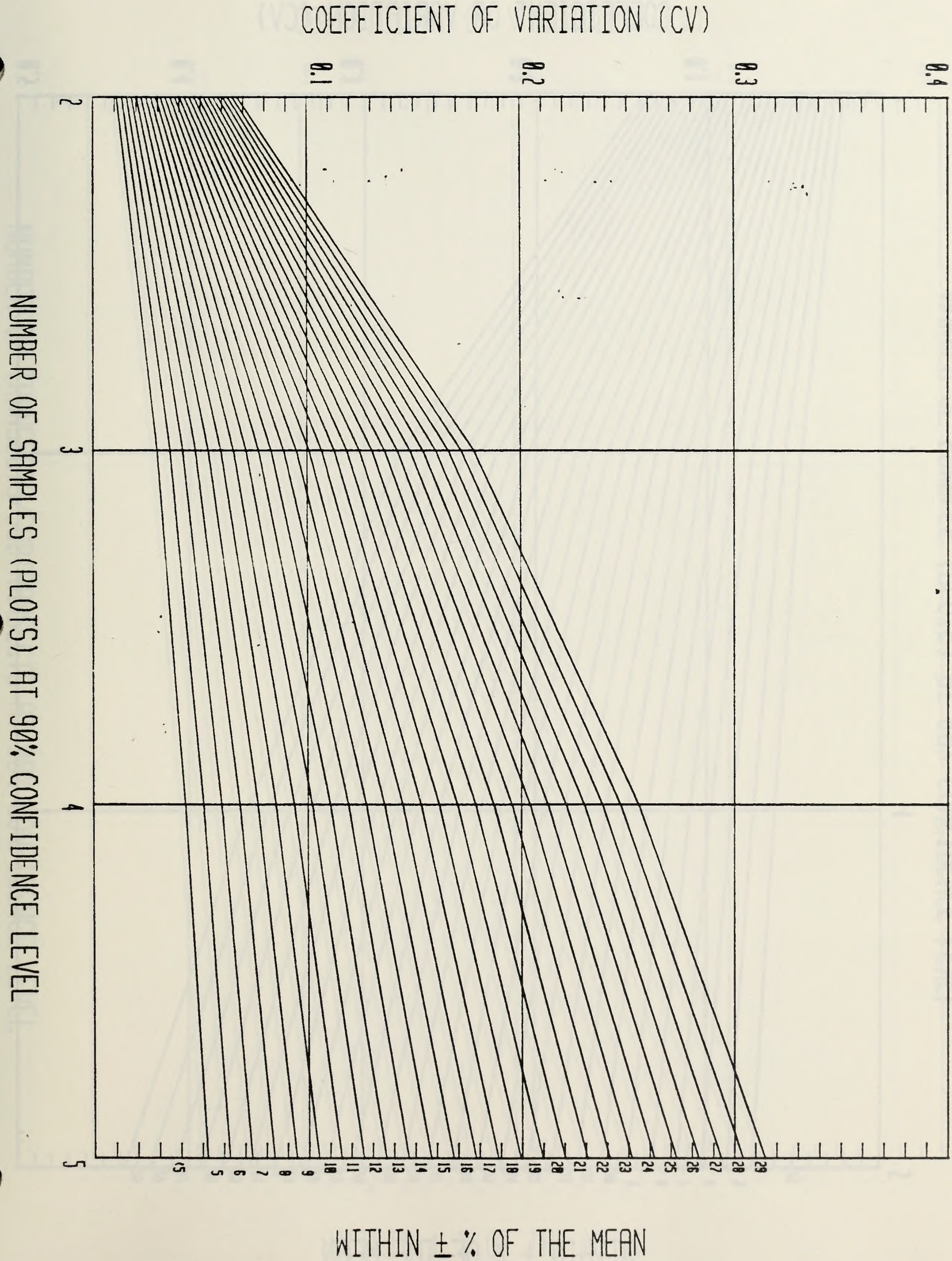
ALLOTMENT: Sheep Allotment 10
DATE: 11/31/89
OBSERVER: Where's d'Beef
LOCATION: 100 ft. SW of bedding ground
PARAMETER: Production
TECHNIQUE: 10 9.6 sq. ft. plots (estimate of grams)

Plot #

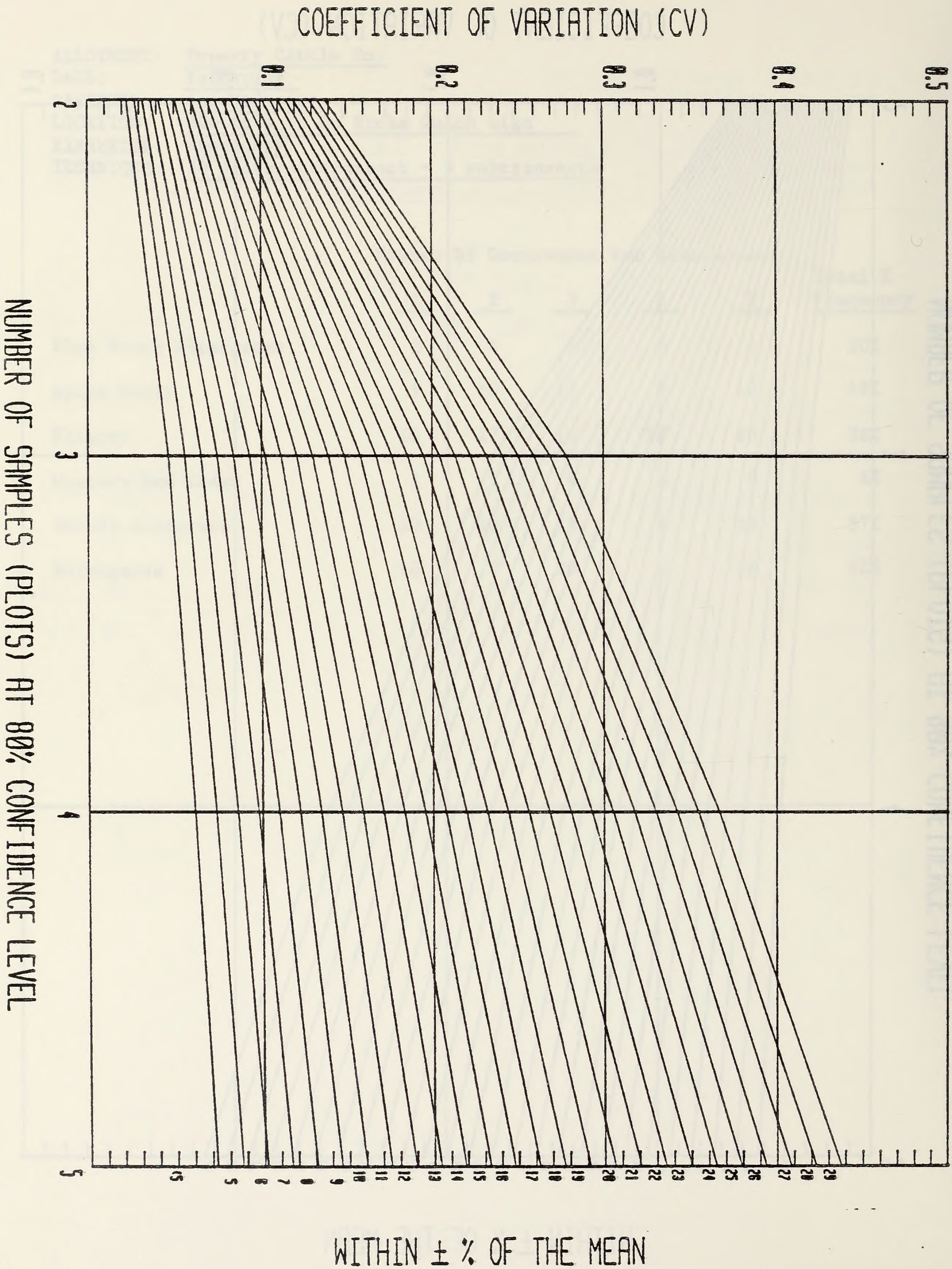
	1	2	3	4	5	6	7	8	9	10
Globe Mallow	2	4	.0	0	1	10	0	4	0	1
Marsh Mallow	3	1	1	0	0	0	0	0	2	0
Barley	5	6	7	8	10	12	0	2	4	6
Single Leaf Pinyon	20	20	9	0	0	0	10	20	30	0
Squirreltail	9	10	8	12	5	3	10	0	0	1
Big Galleta	0	0	0	5	0	0	10	0	10	0
Cactus	5	0	0	0	0	5	0	0	0	0

ALLOTMENT: Poverty Cattle Co.
DATE: Yesterday
OBSERVER: Ace Madrooga
LOCATION: 300 ft w of Go Broke Gulch sign
PARAMETER: Frequency
TECHNIQUE: 20 plots/subtransect - 5 subtransects

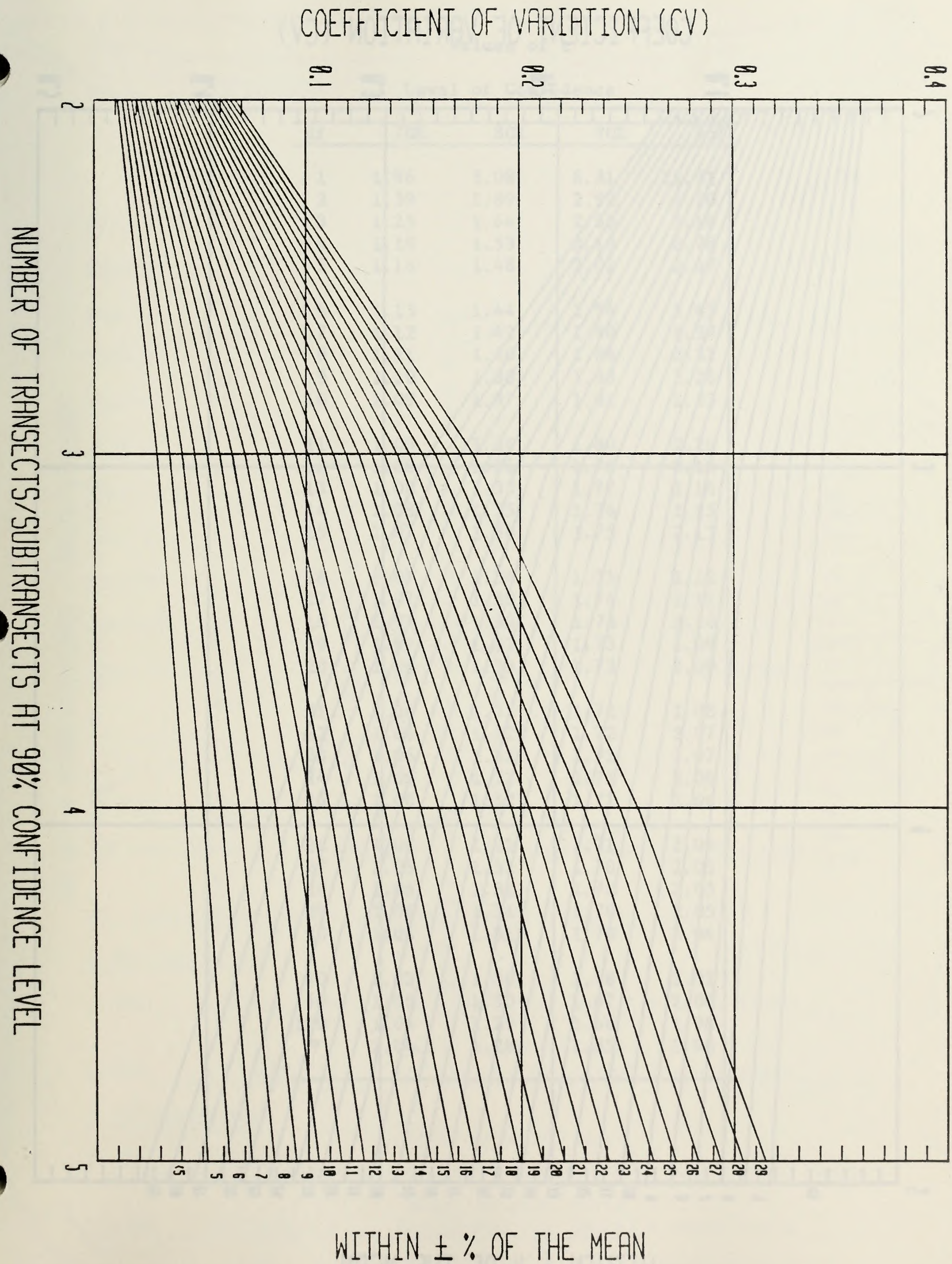
	Number Of Occurences Per Subtransect					
	1	2	3	4	5	Total % Frequency
Blue Bunch Wheatgrass	2	4	3	5	6	20%
Spike Muhly	9	10	11	9	10	49%
Filaree	16	17	16	19	20	88%
Western Red Cedar	1	1	0	2	0	4%
Nevada Bluegrass	10	12	13	9	13	57%
Burrograss	16	7	20	3	16	62%

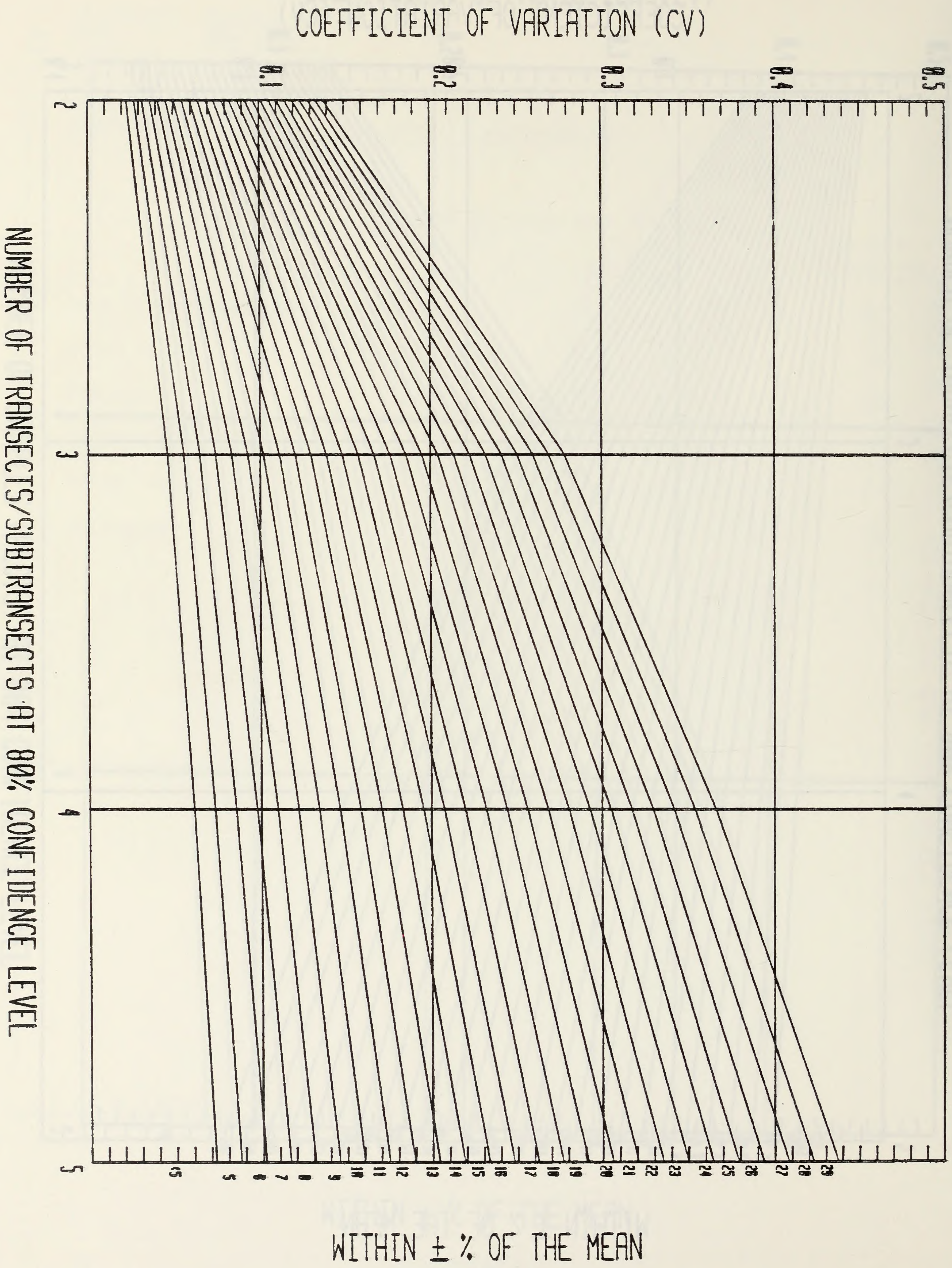

COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
NUMBER OF SAMPLES (PLOTS) AT 90% CONFIDENCE LEVEL
2
3
4
5
WITHIN ± % OF THE MEAN

Appendix 5


COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
NUMBER OF SAMPLES (PLOTS) AT 80% CONFIDENCE LEVEL
2
3
4
5
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
WITHIN ± % OF THE MEAN

Appendix 6


COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
2
3
4
5
NUMBER OF TRANSECTS/SUBTRANSECTS AT 90% CONFIDENCE LEVEL
<5 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
WITHIN ± % OF THE MEAN


COEFFICIENT OF VARIATION (CV)
0.1
0.2
0.3
0.4
0.5
2
3
4
5
NUMBER OF TRANSECTS/SUBTRANSECTS AT 80% CONFIDENCE LEVEL
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
WITHIN ± % OF THE MEAN

Values of t

Level of Confidence

df	70%	80%	90%	95%
1	1.96	3.08	6.31	12.71
2	1.39	1.89	2.92	4.30
3	1.25	1.64	2.35	3.18
4	1.19	1.53	2.13	2.78
5	1.16	1.48	2.02	2.57
6	1.13	1.44	1.94	2.45
7	1.12	1.42	1.90	2.37
8	1.11	1.40	1.86	2.31
9	1.10	1.38	1.83	2.26
10	1.09	1.37	1.81	2.23
11	1.09	1.36	1.80	2.20
12	1.08	1.36	1.78	2.18
13	1.08	1.35	1.77	2.16
14	1.08	1.35	1.76	2.15
15	1.07	1.34	1.75	2.13
16	1.07	1.34	1.75	2.12
17	1.07	1.33	1.74	2.11
18	1.07	1.33	1.73	2.10
19	1.07	1.33	1.73	2.09
20	1.06	1.33	1.73	2.09
21	1.06	1.32	1.72	2.08
22	1.06	1.32	1.72	2.07
23	1.06	1.32	1.71	2.07
24	1.06	1.32	1.71	2.06
25	1.06	1.32	1.71	2.06
26	1.06	1.32	1.71	2.06
27	1.06	1.31	1.70	2.05
28	1.06	1.31	1.70	2.05
29	1.06	1.31	1.70	2.05
30	1.06	1.31	1.70	2.04
40	1.05	1.30	1.68	2.02
60	1.05	1.30	1.67	2.00
120	1.04	1.29	1.66	1.98
∞	1.04	1.28	1.65	1.96

Appendix 9

This certifies that:

knows as much about statistics as
anyone in this office and should
only be ~~insulted~~ consulted in
case of an emergency!

signed this   day of   ,19

ima Notta Numbercruncher
IMA NOTTA NUMBERCRUNCHER   CHIEF FIGURER

Species ____________ Date ____________ State ____________
Attribute ____________ Dist. ____________
Number of Plots, Frames, or Hoops ________ (n) Allot. ____________
Study # ____________

	(X)	-	$(\bar{X})$	=	$(X-\bar{X})$	x	$(X-\bar{X})$	=	$(X-\bar{X})^2$
Plot 1	____	-	____	=	____	x	____	=	____
Plot 2	____	-	____	=	____	x	____	=	____
Plot 3	____	-	____	=	____	x	____	=	____
Plot 4	____	-	____	=	____	x	____	=	____
Plot 5	____	-	____	=	____	x	____	=	____
Plot 6	____	-	____	=	____	x	____	=	____
Plot 7	____	-	____	=	____	x	____	=	____
Plot 8	____	-	____	=	____	x	____	=	____
Plot 9	____	-	____	=	____	x	____	=	____
Plot 10	____	-	____	=	____	x	____	=	____

TOTAL (X) ____ ÷ ____ (n) = ____ $(\bar{X})$ TOTAL A ____

____ (TOTAL A) ÷ ____ (n-1) = ____ (S^2)

$\sqrt{\_\_\_\_ (S^2)}$ = ____ (S) ____ (S) ÷ ____ $(\bar{X})$ = ____ (CV)

INTERCEPT (n) and CV:

90% confidence ____ (% ∓ mean) 80% confidence ____ (% ∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND A MEAN OR DATA

@ 90% CONFIDENCE

(100%- ____ (%∓ mean)) x ____ mean, density, cover (or production value) = lower limit ____

(100%+ ____ (%∓ mean)) x ____ mean, density, cover (or production value) = upper limit ____

@ 80% CONFIDENCE

(100%- ____ (%∓ mean)) x ____ mean, density, cover (or production value) = lower limit ____

(100%+ ____ (%∓ mean)) x ____ mean, density, cover (or production value) = upper limit ____

Species ______________ Date ______________ State ______________
Attribute ______________ Dist. ______________
Number of transects (or subtransects) ______ (n) Allot. ______________
Study # ______________

	(X)	-	($\bar{X}$)	=	(X-$\bar{X}$)	x	(X-$\bar{X}$)	=	(X-$\bar{X}$)^2
Transect 1	____	-	____	=	____	x	____	=	____
Transect 2	____	-	____	=	____	x	____	=	____
Transect 3	____	-	____	=	____	x	____	=	____
Transect 4	____	-	____	=	____	x	____	=	____
Transect 5	____	-	____	=	____	x	____	=	____
Transect 6	____	-	____	=	____	x	____	=	____
Transect 7	____	-	____	=	____	x	____	=	____
Transect 8	____	-	____	=	____	x	____	=	____
Transect 9	____	-	____	=	____	x	____	=	____
Transect 10	____	-	____	=	____	x	____	=	____

TOTAL (X) ____ ÷ ____ (n) = ____ ($\bar{X}$) TOTAL A ____

____ (TOTAL A) ÷ ____ (n-1) = ____ (S^2)

$\sqrt{\_\_\_\_ (S^2)}$ = ____ (S) ____ (S) ÷ ____ ($\bar{X}$) = ____ (CV)

INTERCEPT (n) and CV:

90% confidence ____ (% ∓ mean) 80% confidence ____ (% ∓ mean)

TO CALCULATE CONFIDENCE INTERVALS AROUND A MEAN OR DATA

@ 90% CONFIDENCE

(100%- ____ (% ∓ mean)) x ____ (mean or frequency value) = lower limit ____

(100%+ ____ (% ∓ mean)) x ____ (mean or frequency value) = upper limit ____

@ 80% CONFIDENCE

(100%- ____ (% ∓ mean)) x ____ (mean or frequency value) = lower limit ____

(100%+ ____ (% ∓ mean)) x ____ (mean or frequency value) = upper limit ____

SOIL - WATER ISSUES

Course 7000.1
Instructors: Vandas
Murphy

Water Resources Issues

Objective

To review some of the most important water resources issues in BLM and learn the soil and water specialist's role in dealing with them.

Topics[1/]

I. Salinity

II. Energy Environmental Analyses

III. Dam Safety

IV. Water Rights

V. Riparian Area Management

VI. Discussion

1/ Subject outlines for each main topic are attached

Biographical Sketch

Name: Stephen J. Vandas

Current Job Title: Hydrologist
Division of Lands and Renewable Resources
Colorado State Office
2020 Arapaho Street
Denver, Colorado 80205
FTS 564-7121 Comm (303) 294-7121

Previous Experience: 1975 - 1976
Temp. BLM
Montrose and Grand Junction District Office

1976 - 1978
U.S. Geological Survey Water Resources Division
Pueblo, Colorado

1978 - 1981
Bureau of Reclamation
Lower Missouri Region

Education: B.S. - Watershed Sciences
Colorado State University

Interests: Beer drinking
Sports
Stock Market
Salinity Control
Surface Water Hydrology

Publications: 2 Professional Papers
4 EIS's
Review of more EIS's than can remember.

RESUME: DENNIS M. MURPHY

Educational Background

AA Business Administration - Burlington County Community College, Pemberton, New Jersey

BS Forest-Watershed Management, Utah State University

1 Year Graduate School - Wildland Hydrology, Utah State University

Career Summary

7/76 - 6/77	Forest Technician, Utah State University
3/78 - 6/78	Laboratory Instructor for the Wood Anatomy and Principles of Conservation Courses at Utah State University
6/78 - Present	Hydrologist, Bureau of Land Management, Montrose, Colorado

Address: USDI-BLM
2465 South Townsend Avenue
Montrose, Colorado 81401

Office Telephone: (303) 249-7791
FTS 322-7300

Water Resources Issues - Salinity

I. Introduction

A. Elements of Water Resource Management
1. Quality
2. Quantity
3. Availability

B. Discussion of Economic Considerations for Water Resources
1. Benefit/Cost Ratios
2. Profitability

C. Non-Point Source Pollution
1. Types
2. 208 Planning Process

II. Background Salinity Control

A. History
1. Colorado River Compact
2. Populations Served

B. Legislation
1. Federal Water Pollution Control Act 1972
a. Salinity Control Forum
b. Control Standards
2. Colorado River Basin Salinity Control Act 1974
a. Authorized Construction
b. Established Advisory Council
3. Amendments Colorado River Basin Salinity Control Act 1984
a. USDA Involvement
b. Requires report to Congress July 1, 1987
4. Other adopted policies

C. Salinity Control Organizations
1. Forum
2. Advisory Council
3. Work Group

D. Salinity Impacts to Lower Basin Users
1. Review of Reclamation Economic Analysis
2. Other Economic Analysis

III. Salinity Control and SCS

A. SCS Involvement
1. Amendments to Colorado River Basin Salinity Control Act
2. [illegible] Land Use in Basin

Water Resources Issues - Salinity

I. Introduction

A. Discussion of Water Resource Management
   1. Quality
   2. Quantity
   3. Availability

B. Discussion of Economic Determinations for Water Resources
   1. Benefits/Detriments
   2. Onsite/Offsite

C. Non-Point Source Pollution
   1. Types
   2. BLM Planning System

II. Background Salinity Control

A. History
   1. Colorado River Compact
   2. Population Served

B. Legislation
   1. Federal Water Pollution Control Act 1972
      a. Salinity Control Forum
      b. Number Standards
   2. Colorado River Basin Salinity Control Act 1974
      a. Authorized Construction
      b. Established Advisory Council
   3. Amendments Colorado River Basin Salinity Control Act 1984
      a. BLM involvement
      b. Requires report to Congress July 1, 1987
   4. Forum adopted policy

C. Salinity Control Organizations
   1. Forum
   2. Advisory Council
   3. Work Group

D. Salinity Impacts to Lower Basin Users
   1. Bureau of Reclamation Economic Analysis
   2. Other Economic Analysis

III. Salinity Control and BLM

A. BLM Involvement
   1. Amendments to Colorado River Basin Salinity Control Act
   2. BLM Major Land Owner in Basin

B. Budget and Salinity Control
   1. Forum Testimony

C. Diffuse Sources of Salinity
   1. Water Engineers and Technology Report
   2. Landform Dependency
   3. Additional Needs

D. GIS and Salinity Control

E. Report to Congress
   1. Progress

F. Using Salinity Control to BLM Advantage
   1. Using Salt to justify range projects
   2. Example of Salinity Benefit Computations

SALINITY SUMMARY PAPER

Background

The Colorado River Salinity Control Forum was established as part of the Federal Water Pollution Control Act of 1972. The Forum is one of the most powerful water lobbying groups in the West, and was established to develop water quality standards for the Colorado River. The Forum was instrumental in the development and passage of amendments to the Colorado River Basin Salinity Control Act which specifically identifies BLM. BLM is required to develop a comprehensive salinity control program, and to report to Congress concerning the program and implementation actions by July 1, 1987.

The amendments also require that advanced planning be done on Sinbad Valley. No time or description were given for this work. A report was written on Sinbad Valley in April 1983.

The Salinity Control Forum has been instrumental in maintaining the 4341 funding levels at the FY 82 base.

Limited direction and policy exist from the Washington Office. Of importance are Instruction Memorandum 82-151 and 82-694, Information Memorandum 84-102, and a letter from Gary Carruthers to Jack Barnett dated March 14, 1983.

Conclusions

Salinity control provides the opportunity for new Federalism with the seven Basin States and new program funding possibilities. The program must be developed in such a way that salinity control is one of many benefits not the only benefit. Such an approach fits nicely into our planning system, especially activity planning. The development of the comprehensive report due in 1987 provides great opportunities for utilizing the planning system for multiple use land management. The potential also exists for cost sharing with the Basin States. Sinbad Valley should not be implemented by BLM, and the advanced planning should show this.

SALINITY CONTROL BRIEFING

Salinity Control Program in Colorado

The Colorado State Office Hydrologist has been the BLM representative to the Colorado River Basin Salinity Control Forum Work Group and Advisory Council since 1982. Thus, Colorado has taken the lead in salinity control work. The Craig, Grand Junction, and Montrose Districts are all involved. The following is a list of salinity control work that has been accomplished in the State:

1. Each of the above three Districts have written reports identifying potential salinity control areas within their Districts.

2. Salinity control has been identified as a major issue in the San Juan and Grand Junction RMPs. Salinity is also an issue in the Little Snake Uncompahgre RMP, and should be in the White River plan.

SALINITY SUMMARY PAPER

Background

The Colorado River Salinity Control Forum was established as part of the Federal Water Pollution Control Act of 1972. The Forum is one of the most powerful water lobbying groups in the West, and was established to develop water quality standards for the Colorado River. The Forum was instrumental in the development and passage of amendments to the Colorado River Basin Salinity Control Act which specifically identifies BLM. BLM is required to develop a comprehensive salinity control program, and to report to Congress concerning the program and implementation actions by July 1, 1987.

The amendments also require that advanced planning be done on Sinbad Valley. No time or description were given for this work. A report was written on Sinbad Valley in April 1985.

The Salinity Control Forum has been instrumental in maintaining the 1985 funding levels at the FY 82 base.

Limited direction and policy exist from the Washington Office. Of importance are Instruction Memorandums 83-131 and 82-595, Information Memorandum 84-362, and a letter from Gary Carruthers to John Barnett dated March 11, 1985.

Conclusions

Salinity control provides the opportunity for new relations with the seven Basin States and new program funding possibilities. The program must be developed in such a way that salinity control is one of many benefits not the only benefit. Such an approach fits nicely into our planning system, especially activity planning. The development of the comprehensive report due in 1987 provides great opportunities for selling the planning system for multiple use land management. The potential also exists for cost sharing with the Basin States. Sinbad Valley should not be implemented by BLM, and the advanced planning should show this.

SALINITY CONTROL ACTIVITIES

Salinity Control Program in Colorado

The Colorado State Office Hydrologist has been the BLM representative to the Colorado River Basin Salinity Control Forum Work Group and Advisory Council since 1981. Thus, Colorado has taken the lead in salinity control work. The Craig, Grand Junction, and Montrose Districts are all involved. The following is a list of salinity control work that has been accomplished in the State:

1. Each of the above three Districts have written reports identifying potential salinity control areas within their Districts.

2. Salinity control has been identified as a major issue in the San Juan and Grand Junction RMPs. Salinity is also an issue in the Little Snake Resource Area RMP, and should be in the White River plan.

3. Three activity plans, one in the White River Resource Area, one in the Grand Junction Resource Area, and the other in the Uncompahgre Resource Area, have been written for salinity control projects. Activity plans are currently being developed in the Glenwood Springs and Little Snake Resource Areas with salinity control as a major objective.

4. There are approximately $300,000 worth of watershed improvement projects, which have salinity control as an objective, which are ready for implementation. These projects have been identified in the three completed activity plans.

5. Watershed improvement work with salinity control as a primary objective was implemented in FY 1984 in the Grand Junction and White River Resource Areas.

6. A salinity control verification project called "Elephant Skin Wash" has been implemented in the Uncompahgre Resource Area.

7. A report entitled "Sinbad Valley Salinity Report" was completed in April 1983. Sinbad Valley is located in the Grand Junction Resource Area.

<u>Recommendation for Salinity Control Program</u>

It is recommended that the BLM pursue salinity control as part of the agencies objectives (see Pros/Cons). Salinity control should be pursued through the implementation of watershed improvements which provide for multiple-use benefits. These multiple-use benefits include erosion and flood control, water supply for livestock and wildlife, and/or improved forage production. Projects should be placed on moderately saline soils which are in poor watershed condition.

The exact locations of project work on moderately saline soils should be directed by the nonsalt benefits. A few "verification" projects should be placed on highly saline soils for study and political reasons. These projects will provide insight to the maintenance requirements and quanity of the salt reduction possibilities.

It is not recommended that we implement the Sinbad Valley Unit. P.L. 98-569 requires that BLM conduct advance planning studies but not implementation. If implementation is to take place it should be done by USBR. This would require a Department level change.

A positive salinity control program by the BLM would meet with favor from the Basin States, and improve federal, state relationships. A salinity control program based on watershed improvement provides BLM with multiple-use projects and funding to do these projects.

The report which is to be delivered to Congress provides BLM with the vehicle to develop a salinity control policy based upon new and creative land management options. Through the report, the potential also exists for cost sharing of watershed improvements on saline soils with the Basin States. A draft report and policy is currently being written by the CSO Hydrologist and DSC and is due for review in the middle of FY 86.

3. Three activity plans, one in the White River Resource Area, one in the Grand Junction Resource Area, and the other in the Uncompahgre Resource Area, have been written for salinity control projects. Activity plans are currently being developed in the Glenwood Springs and Little Snake Resource Areas with salinity control as a major objective.

4. There are approximately $200,000 worth of watershed improvement projects, which have salinity control as an objective, which are ready for implementation. These projects have been identified in the three completed activity plans.

5. Watershed improvement work with salinity control as a primary objective was implemented in FY 1984 in the Grand Junction and White River Resource Areas.

6. A wildlife control modification project called "[illegible]" has been implemented in the Uncompahgre Resource Area.

7. A report entitled "Sinbad Valley Salinity Report" was completed in April 1983. Sinbad Valley is located in the Grand Junction Resource Area.

Recommendations for Salinity Control Programs

It is recommended that the BLM pursue salinity control as part of the agencies objectives (see Functional). Salinity control should be pursued through the implementation of watershed improvements which provide for multiple-use benefits. These multiple-use benefits include erosion and flood control, water source for livestock and wildlife, and/or improved forage production. Projects should be placed on moderately saline soils which would have watershed benefits.

The major emphasis of project work on moderately saline soils should be directed at the overall benefits. A few "verification" projects should be placed on highly saline soils for study and political reasons. These projects will require budget on the maintenance requirements and quality of the salt reduction possibilities.

It is not recommended that we implement the Sinbad Valley Unit. P.L. 98-569 requires that BLM conduct advance planning studies but not implementation. If implementation is to take place it should be done by USBR. This would require a Departmental level change.

A positive salinity control program by the BLM would meet with favor from the Basin States, and improve federal, state relationships. A salinity control program based on watershed improvement provides BLM with multiple-use projects and funding to do these projects.

The report which is to be delivered to Congress provides BLM with the vehicle to develop a salinity control policy based upon use and practical land management options. Through the report, the potential also exists for good sharing of watershed improvements on saline soils with the Basin States. A draft report and policy is currently being written by the CSO hydrologist and USU and is due for review in the middle of FY 86.

Background

The high salt load of approximately nine million tons annually, entering Lake Mead in the lower Colorado River Basin, adversely affects more than 16 million people and one million acres of irrigated land. In 1982 damages resulting from high salt concentrations amounted to 113 million dollars. Damages in the amount of $580,000 are projected to occur for each increase of 1 mg/l at Imperial Dam when concentrations reach the 875 to 1,224 mg/l range.

As a result of amendments to the Federal Water Pollution Control Act, P.L. 92-500, the Colorado River Salinity Control Forum was established. The Forum is composed of water resource and water quality representatives from each of the seven Basin States appointed by its respective governor. The Forum was established to develop water quality standards for the Colorado River. The Forum reviews these standards every three years, and reports on salinity control progress every year. These reports and the resulting recommendations are presented to the Secretaries' of the Department of the Interior and Agriculture and to the Administrator of E.P.A.

In the past several years, the forum has become a very effective lobbying group. They have hired their own lobbyist, Jack Barnett. Mr. Barnett has proved to be very effective especially regarding recent legislation, P.L. 98-569, Amendments to the Colorado River Basin Salinity Control Act.

Public Law 98-569 identified BLM in the following subsections:

"(b)(5) The Secretary of the Interior is directed to develop a comprehensive program for minimizing salt contributions to the Colorado River from lands administered by the BLM. He is to submit a report, which describes the program and recommends implementation actions, to the Congress and the members of the Advisory Council established by Section 204(a) of this title by July 1, 1987;

(b)(5) The Secretary of the Interior is directed to undertake advance planning activities on the Sinbad Valley Unit, Colorado, as described in the Bureau of Land Management Salinity Status Report covering the period 1978-1979 and dated February 1980."

Subsection (b)(3) concerns all BLM states within the Colorado River drainage, while (b)(5) just involves Colorado.

Sinbad Valley Unit

Sinbad Valley is located in the Grand Junction Resource Area, just southwest of the town of Gateway. The project is point source disposal of saline waters from a series of springs. A report entitled "Sinbad Valley Salinity Report" was completed by the Colorado State Office and Grand Junction District in April 1983. This report was based upon greater information than the February 1980 report cited in the legislation. Project implementation was estimated to cost approximately seven million dollars, operations and maintenance between 20-40 thousand dollars annually. The Sinbad Valley salinity report recommended that the Bureau of Reclamation, and not the BLM, take on this project.

Background

The high salt load of approximately nine million tons annually, entering Lake Mead in the Lower Colorado River Basin, adversely affects more than 10 million people and one million acres of irrigated land. In 1982 damages resulting from high salt concentrations amounted to 113 million dollars. Damages in the amount of $450,000 are projected to occur for each increase of 1 mg/l at Imperial Dam when concentrations reach the 875 to 1,125 mg/l range.

As a result of amendments to the Federal Water Pollution Control Act, P.L. 92-500, the Colorado River Salinity Control Forum was established. The Forum is composed of water resource and water quality representatives from each of the seven Basin States appointed by its respective governor. The Forum was established to develop water quality standards for the Colorado River. The Forum reviews these standards every three years, and reports on salinity control progress every year. These reports and the resulting recommendations are presented to the Secretaries of the Department of the Interior and Agriculture and to the Administrator of E.P.A.

In the last several years, the Forum has become a very effective lobbying group. They have hired their own lobbyist, Jack Barnett. Mr. Barnett has proved to be very effective in obtaining supportive Congressional legislation, P.L. 98-569, amendments to the Colorado River Basin Salinity Control Act.

Public Law 98-569 obligates BLM to the following subsections:

"(a)(1) The Secretary of the Interior is directed to develop a comprehensive program for minimizing salt contributions to the Colorado River from lands administered by the BLM. He is to submit a report, which describes the program and recommends implementation actions, to the Congress and the members of the Advisory Council established by Section 204(a) of this title by July 1, 1987;

(b)(1) The Secretary of the Interior is directed to undertake advance planning activities on the Sinbad Valley unit, Colorado, as described in the Bureau of Land Management Salinity Status Report covering the period 1978-1979 and dated February 1980."

Subsection (a)(1) concerns all BLM areas within the Colorado River Drainage, while (b)(1) just involves Colorado.

Sinbad Valley Unit

Sinbad Valley is located in the Grand Junction Resource Area, just southwest of the town of Gateway. The project is point source disposal of saline waters from a series of springs. A report entitled "Sinbad Valley Salinity Report" was completed by the Colorado State Office and Grand Junction District in April 1983. This report was based upon current information that the February 1980 report cited in the legislation. Project implementation was estimated to cost approximately seven million dollars. Operations and maintenance between 10-40 thousand dollars annually. The Sinbad Valley salinity report recommended that the Bureau of Reclamation, and not the BLM, take on this project.

In a March 14, 1983 letter written to the Executive Director of the Forum from Gary Carruther, the decision was made that if the Sinbad Valley unit is to be implemented, BLM would do it. BLM has recommended through the Washington Office that Sinbad be transferred to the Bureau of Reclamation. Final transfer is awaiting Secretary approval.

Comprehensive Salinity Control Program

This section of the act is the only legislation that I am aware of concerning water, in which the BLM is specifically mentioned and is required to deliver a product by a specific date. This report will require a multi-state effort and coordination on this report should begin as soon as possible. Salinity control opportunities exist for the BLM in the following areas:

1. Watershed improvement structures
2. Mine spoil piles
3. Oil and gas discharge waters
4. Stream improvements
5. Grazing
6. ORV usage
7. Project maintenance
8. Soil survey inventories

The development of a comprehensive program, for minimizing salt contributions to the Colorado River, and the resulting report due to Congress and the Colorado River Basin Salinity Control Advisory Council by July 1, 1987, presents a major task for BLM. While the report demands a significant workload and a major coordination effort, it also provides great opportunities for new and creative land management options and the potential for cost sharing with the Basin States.

The implementation of watershed improvements on moderately saline soils provides management options which not only benefit water users in the Colorado River Basin, but also provide range and wildlife benefits and erosion and flood control. These watershed improvement projects could be a major part of BLM's salinity control effort. Salinity "verification" projects which would have multiple-use benefits could also be implemented.

P.L. 98-569 provides for reimbursement by the Basin States for 30 percent of the costs of construction, operation, maintenance, and replacement of the Department of the Interior's units authorized by the act. A similar cost sharing provision could be recommended for BLM salinity control projects through the 1987 report to Congress. It is these multiple use projects in which BLM stands to gain credibility with both the downstream water users in the Colorado River Basin and onsite land users.

Salinity Control Program - Pros/Cons

Pros

1. Salinity control provides the opportunity for new program funding. Proposed FY 1986 funding levels for the Bureau of Reclamation and the Soil

In a March 16, 1983 letter written to the Executive Director of the Forum from Gary Carruthers, the decision was made that if the Sinbad Valley unit is to be implemented, BLM would do it. BLM has recommended through the Washington Office that Sinbad be transferred to the Bureau of Reclamation. Final transfer is awaiting Secretary approval.

Comprehensive Salinity Control Program

This section of the act is the only legislation that I am aware of concerning water, in which the BLM is specifically mentioned and is required to deliver a product by a specific date. This report will require a multi-state effort and coordination so this report should begin as soon as possible. Salinity control opportunities exist for the BLM in the following areas:

1. Watershed improvement structures
2. Mine spoil piles
3. Oil and gas discharge waters
4. Stream improvements
5. Grazing
6. Oil seeps
7. Project maintenance
8. Soil survey information

The development of a comprehensive program, for minimizing salt contributions to the Colorado River, and the resulting report due to Congress and the Colorado River Basin Salinity Control Advisory Council by July 1, 1987, presents a major task for BLM. While the report demands a significant workload and a major coordination effort, it also provides great opportunities for new and creative land management options and the potential for cost sharing with the Basin States.

The implementation of watershed improvements on moderately saline soils provides management options which not only benefit water users in the Colorado River Basin, but also provide range and wildlife benefits and erosion and flood control. These watershed improvement projects could be a major part of BLM's salinity control effort. Salinity "mitigation" projects which would have wildlife-use benefits could also be implemented.

P.L. 98-569 provides for reimbursement by the Basin States for 30 percent of the costs of construction, operation, maintenance, and replacement of the Department of the Interior's units authorized by the Act. A similar cost sharing provision could be recommended for BLM salinity control projects through the 1987 report to Congress. It is these multiple use projects in which BLM stands to gain credibility with both the downstream water users in the Colorado River Basin and public land users.

Salinity Control Program - Priorities

1986

1. Salinity control provides the opportunity for new program funding. Proposed FY 1986 funding levels for the Bureau of Reclamation and the Soil

Conservation Service are 30 million dollars, and seven million dollars, respectively. BLM has as great a potential for doing salinity control as either of these agencies and at a low cost per ton of salt removed.

2. Mexico has a large vested interest in salt reductions to the Colorado River, thus, there are international ramifications for the program.

3. New Federalism. Salinity control has the backing of the seven Basin States (14 senators and 124 representatives). The states feel so strongly about salt reductions in the basin that under P.L. 98-569 they are cost sharing salinity control work with both USBR and S.C.S.

4. For FY 1983-1986, the executive director of the Colorado River Salinity Forum, Jack Barnett, has testified before the House Appropriations Subcommittee requesting additional funds over and above the budget requested by the President for BLM soil, water, and air subactivities. In all budget years, the soil, water, and air program received the funding level the Forum requested.

5. Provides the BLM with the opportunity to implement many rangeland improvements which provide multiple-use benefits.

6. Possibilities exist for cost sharing with the Basin States for rangeland improvements and other management on saline soils.

7. Maintenance of existing structures on saline soils can be considered as part of a salinity control program. Funds are desperately needed for maintenance work.

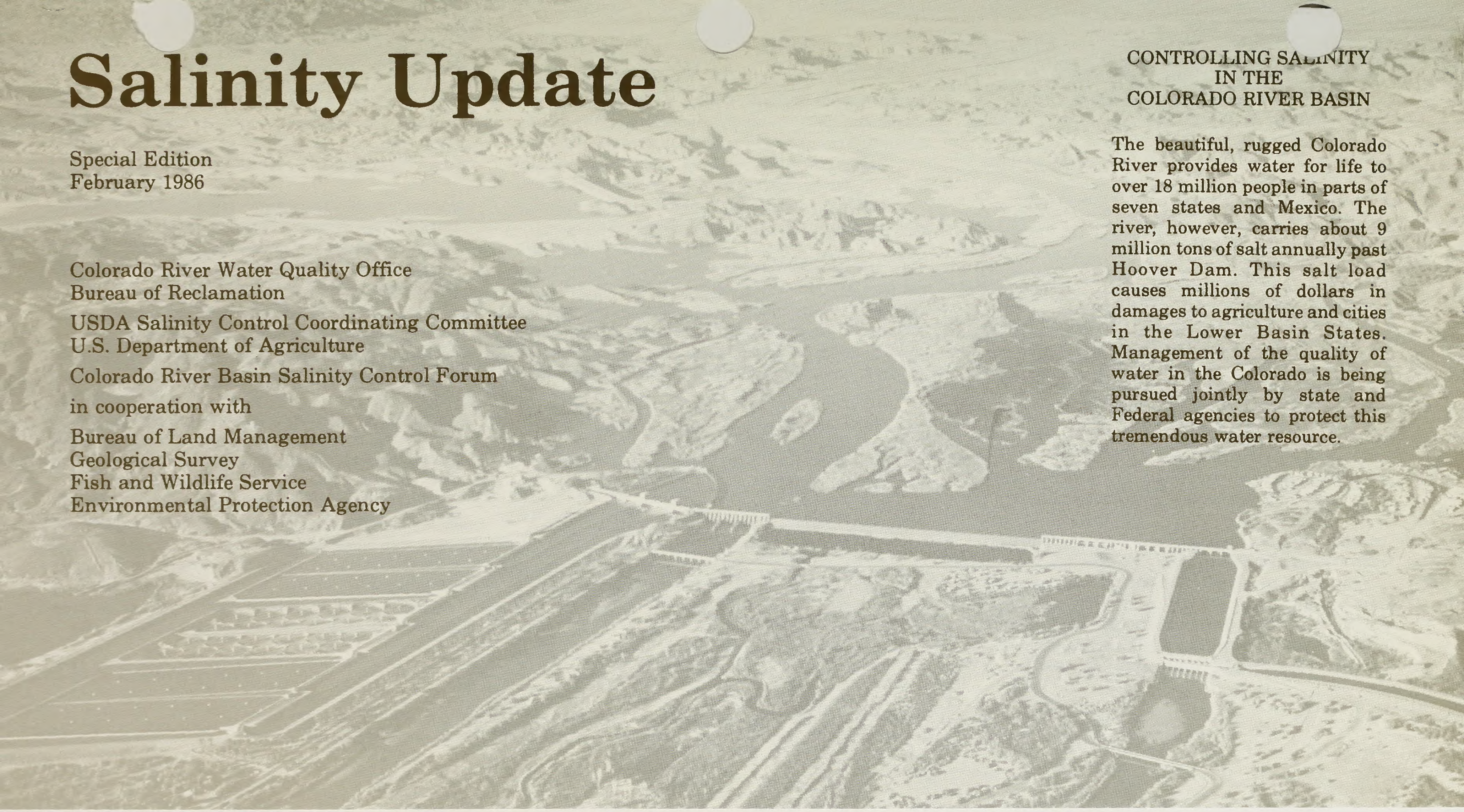
Cons

1. If projects are located on highly saline soils, they become single-use projects with little onsite benefits.

2. A major implementation program could result in creating more problems in the future that could require perpetual maintenance.

3. Salinity control has a bad reputation in the BLM, because past efforts have been focused on grazing reductions.

4. There is a lack of policy or direction in the Agency concerning salinity control. This is primarily a result of ignorance.



Salinity Update

Special Edition
February 1986

Colorado River Water Quality Office
Bureau of Reclamation

USDA Salinity Control Coordinating Committee
U.S. Department of Agriculture

Colorado River Basin Salinity Control Forum

in cooperation with

Bureau of Land Management
Geological Survey
Fish and Wildlife Service
Environmental Protection Agency

CONTROLLING SALINITY IN THE COLORADO RIVER BASIN

The beautiful, rugged Colorado River provides water for life to over 18 million people in parts of seven states and Mexico. The river, however, carries about 9 million tons of salt annually past Hoover Dam. This salt load causes millions of dollars in damages to agriculture and cities in the Lower Basin States. Management of the quality of water in the Colorado is being pursued jointly by state and Federal agencies to protect this tremendous water resource.

Cover Photo—Upstream view of Imperial Dam, desilting works, Imperial Oasis Camp, Senator Wash Dam and Reservoir, and the lower portion of Imperial Reservoir. Note that one of the desilting basins has been dried up for maintenance activity.

THE PROBLEM

The Colorado River Basin encompasses portions of seven states. The river flows over 1,400 miles from its headwaters in Colorado to its terminus in the Gulf of California in the Republic of Mexico. On its journey, it joins with tributaries from Wyoming, Utah, and New Mexico; flows through the Grand Canyon; and provides state boundaries for Nevada, Arizona, and California.

The river's water, now and in future years, has been fully allocated through a long history of appropriations and negotiations that include acts, compacts, decrees, and an international treaty, known collectively as "The Law of the River."

About half of the present salinity concentration in the Colorado River at Hoover Dam near Las Vegas, Nevada, is attributed to natural sources. The remaining half is man-induced as indicated in figure 1.

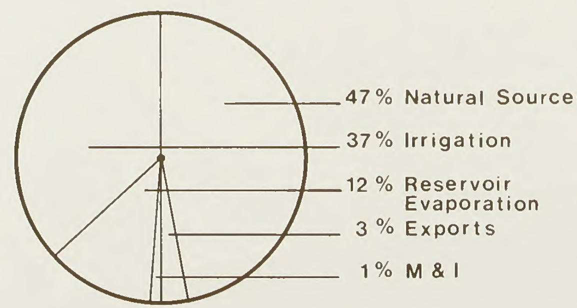


Figure 1. Salt loading sources.

High salinity concentrations result from two general processes: salt loading and salt concentration. Salt loading increases the amount of salt added to a given amount of water, and salt concentration decreases the amount of dilution water available for a given amount of salt.

Specifically, salt loading in the Colorado River system results in the addition of mineral salts from natural and manmade sources. Salt concentration results in the rise in salinity through beneficial consumptive use of waters and associated streamflow depletions in the Basin that concentrate the salt burden into a lesser volume of water. Generally, the application of irrigation water results in increased salt loading because of salt leaching and the concentrating effects of consumptive use. The total salt concentration in the river fluctuates annually with the overall Basin water supply.

The Colorado River, at its headwaters in the mountains of north-central Colorado, has a salinity (dissolved minerals) concentration of only about 50 mg/L (milligrams per liter). The salinity concentrations progressively increase as the river flows downstream as a result of water diversion, evaporation from reservoirs, and salt contributions from a variety of sources. Recent record high flows have flushed and filled the major reservoirs, resulting in significantly lower salinity levels at Imperial Dam—from an annual average of 826 mg/L in 1982 to 608 mg/L (provisional) in 1985. Without control measures, however, the concentration is projected to increase, following the overall rising trend shown in figure 2, possibly reaching a level of 1005 mg/L* at Imperial Dam by about 2010.

* The current projection is from 1985 Evaluation of Salinity Control Programs in the Colorado River Basin.

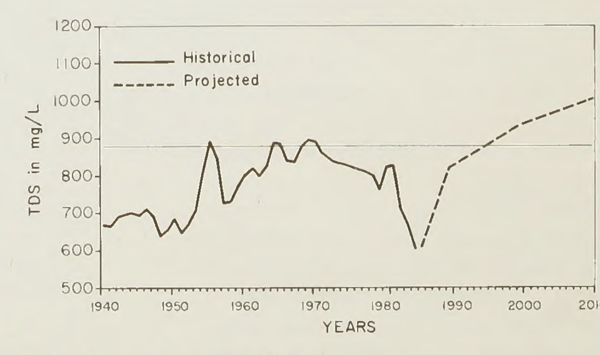


Figure 2. Historical and projected salinity concentrations at Imperial Dam.

A total salt load of about 9 million tons annually entering Lake Mead in the Lower Colorado River Basin adversely affects more than 18 million people and 1 million acres of irrigated farmland in the United States. Damages in the amount of $580,000 (based on January 1985 costs) are projected to occur for each increase of 1 mg/L at Imperial Dam (when salinity concentrations reach the 875 to 1225 mg/L range) as shown in figure 3.

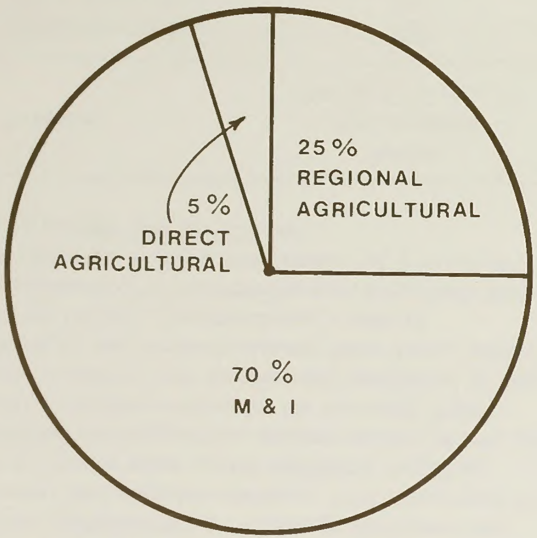


Figure 3 Total losses per mg/L increase.

The losses associated with municipal and industrial use occur primarily from increased water treatment costs, accelerated pipe deterioration and appliance wear, increased soap and detergent needs, and decreased water palatability. According to the EPA (Environmental Protection Agency) water standards, public drinking water should contain no more than 500 mg/L of TDS (total dissolved solids).

For irrigators, the higher salinity concentrations cause lower crop yields, altered crop patterns, higher leaching and drainage requirements, and higher management costs. Agricultural losses (either through lower yields or higher production/management costs) begin when salinity levels of applied irrigation water reach 700 to 850 mg/L, depending upon soil conditions and type of crop grown. A summary of the effects is presented below:

mg/L	Effect
Below 500	Good drinking water
Above 500	Municipal and industrial losses
700–850 and above	Agricultural losses

In the late 1960's and early 1970's, leaders at the regional and national levels began to recognize the problem and to seek solutions.

Effect of salt on irrigated lands.

THE PROBLEM

THE SOLUTION

In 1972, an amendment to the Federal Water Pollution Control Act, Public Law 92–500 (now known commonly as the Clean Water Act) sets forth a public policy embracing the restoration and maintenance of water quality, pollution effluent discharge limitation, and eventual zero pollution discharge. EPA interpreted the Act to require water quality standards, including beneficial use designations, numeric salinity criteria, and a plan of implementation for the Colorado River. Numeric criteria were subsequently established at three stations by the Forum (Colorado River Basin Salinity Control Forum). The criteria and a plan of implementation were adopted by each of the Basin States, and approved by EPA. The criteria, set in terms of milligrams per liter of TDS, are:

Location	Annual flow-weighted average TDS (mg/L)
Below Hoover Dam	723
Below Parker Dam	747
At Imperial Dam	879

To meet these criteria, an additional 1.3 million tons of salt annually will need to be kept from the river's waters. The overall approach in meeting the standards is to prevent salt from entering and mixing with the river's flow. A number of agricultural, point, and diffuse sources of salinity have been identified throughout the Basin. The salinity control program will implement controls at those sites which contain salt sources that can be intercepted and prevented from entering the river at least cost.

In June 1974, Congress enacted the Colorado River Basin Salinity Control Act, Public Law 93–320, which directed the Secretary of the Interior to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and the Republic of Mexico. Title I of Public Law 93–320 enables the United States to comply with its obligations under the agreement with Mexico of August 30, 1973 (Minute No. 242 of the International Boundary and Water Commission, United States and Mexico), concluded pursuant to the Treaty of February 3, 1944.

Title II of Public Law 93–320 directed the Secretary of the Interior to expedite the completion of planning reports on 12 salinity control units and to proceed with construction of the Paradox Valley, Grand Valley, Crystal Geyser, and Las Vegas Wash Units.

The President signed a law on October 30, 1984, which amends Public Law 93–320. It directs the Secretary of Agriculture to establish a major voluntary onfarm cooperative salinity control program within the Department of Agriculture. The new Agriculture program provides for cost sharing of onfarm improvements consistent with the degree of onsite and offsite downstream benefits as determined for the project area. Maximum Federal cost shares are not to exceed 70 percent unless higher levels are approved by the Secretary of Agriculture. The new authority also requires that 30 percent of the Federal cost shall be repaid from power revenues generated through the Upper and Lower Basin funds.

For Interior, the amendment to Public Law 93–320 provides for the following actions not previously included in the Reclamation program:

1. Authorization of construction of Stage I of the Lower Gunnison Basin Unit and the McElmo Creek Unit as a part of the Dolores Project.
2. The use of cost-effectiveness as a decisionmaking criterion.
3. Joint feasibility studies with industrial water users as a part of ongoing Saline Water Use and Disposal Opportunities activities.
4. Authority for the Secretary of the Interior to contract with non-Federal entities for organization, construction, operation, maintenance, and replacement of authorized salinity control facilities.
5. Authority to concurrently replace incidental fish and wildlife values foregone as salinity control units are constructed.
6. Thirty percent reimbursable from the Upper and Lower Basin funds on the newly authorized units to be repaid either during the year the expenditures are made or over time with interest. By comparison, 25 percent of the construction costs of previously authorized units are to be repaid from the Basin Funds over 50 years without interest.
7. Compliance with procedural and substantive State water law.
8. Deauthorization of the Crystal Geyser Unit initially authorized for construction under Public Law 93–320.

In addition, the Secretary of the Interior was directed to do advance planning studies on Sinbad Valley, a Bureau of Land Management (BLM) project.

Basin States and Federal Agencies Coordination

An issue as complex as salinity control affects many people. Various governmental entities have capabilities that can be combined to most effectively implement control measures. In addition, public participation plays a key role in salinity control.

At the state level, all seven Colorado River Basin States (Colorado, Utah, Wyoming, Arizona, New Mexico, California, and Nevada) have joined efforts to adopt standards and to implement a plan to meet those standards while water supplies continue to be developed.

To accomplish needed coordination, the Governors of each of the Basin States appointed representatives to the Forum and the Council (Colorado River Basin Salinity Control Advisory Council). These groups coordinate State actions and advise the Federal Government of the State views on issues affecting the salinity standards and ways to meet those standards. These groups were established pursuant to Public Laws 92–500 and 93–320, respectively.

At the Federal level, salinity control requires coordination efforts of the Department of the Interior, including FWS (Fish and Wildlife Service), USGS (U.S. Geological Survey), BLM (Bureau of Land Management), and USBR (Bureau of Reclamation); the EPA (Environmental Protection Agency); and the USDA (Department of Agriculture), including SCS (Soil Conservation Service), ASCS (Agricultural Stabilization and Conservation Service), ARS (Agricultural Research Service), CSRS (Cooperative State Research Service), and ES (Extension Service).

The capabilities of the Federal agencies are coordinated through an Interagency Salinity Control Committee. Its purposes include coordination of management of irrigated agriculture, research and implementation of off- and onfarm improvements, and implementation of selected point and nonpoint control measures.

Coordination between USDA and Reclamation is enhanced through the activities of an SCS/BR Technical Policy Coordination Committee and the staffing of the USDA Basin Coordinator for Salinity Control in Reclamation's Colorado River Water Quality Office.

Interagency coordination within USDA is maintained through a USDA Salinity Control Coordinating Committee.

The States

The Colorado River Basin States support the salinity control program through water quality management plans, effluent discharge control, and education in the control of salinity.

The Basin States individually developed water quality management plans to conform with the requirements of section 208 of the Clean Water Act. These requirements include: public involvement, problem assessment, identification of best management practices, establishment of control programs, and designation of management agencies.

State programs also include the control of total dissolved solids from point discharges through the NPDES (National Pollutant Discharge Elimination System) permit program. Fish hatcheries, lumber products mills, sewage treatment plants, and powerplant wastes are some of the municipal and industrial effluent sources under control. Reuse of treated wastewater is encouraged as a general principle. Industries are also encouraged to use saline water in place of fresh water.

Education and public involvement are emphasized. The basinwide nature of salinity requires an awareness of salinity—sources, impacts, and alternative methods of control. The Basin States continue to work through the Forum with concerned agencies to increase public understanding of salinity.

Colorado River Basin Salinity Control Forum and Colorado River Basin Salinity Control Advisory Council

The Forum is composed of up to three water resource and/or water quality representatives from each of the seven Colorado River Basin States, appointed by their respective governors. The Advisory Council is also composed of up to three members appointed by the governors of each of the seven Colorado River Basin states.

As a result of Public Law 92–500, the Forum was established in 1973 as a mechanism for interstate cooperation and to develop water quality standards. Section 303 of the Clean Water Act requires that these water quality standards be reviewed from time to time, but at least once every three years.

The seven-state Forum, with the aid of its internal Work Group, prepares a review of the water quality standards, including numeric criteria and the plan of implementation previously developed by the Forum. The 1984 review included the modifications or revisions to the plan of implementation that have become necessary as a result of changed conditions and the availability of better information.

In short, the Forum is concerned with the implementation plan progress, the numeric criteria, and whether the standards will be met or maintained.

The Forum's Work Group is the technical arm of the Forum. The Work Group consists of at least one representative from each of the Basin States, who may or may not be a member of the Forum. The basic function of the Work Group is to provide technical review and analysis for the Forum, the policy-making group. The Work Group also serves the Advisory Council in the capacity of an informal technical review and study team.

The Advisory Council (established by Public Law 93–320) receives reports from all Federal agencies on salinity control activities and prepares an annual report which makes recommendations to the Secretaries of the Departments of the Interior and Agriculture and to the Administrator of the EPA. The report addresses all matters relating to the efficient and timely planning and execution of salinity control measures and procedures specified in Public Law 93–320, Title II, as amended. The Advisory Council also makes recommendations covering the budget and other aspects of the program.

The plan of implementation, as set forth in the 1975, 1978, 1981, and 1984 Forum reports, includes the Federal salinity control units discussed in another section of this document. The plan also includes effluent limitations or NPDES Permits for industrial point source discharges with the objective of no salt return whenever practicable.

In 1977, the Forum adopted the "Policy for Implementation of Colorado River Salinity Standards Through the NPDES Permit Program." This policy, adopted by all of the Basin States, provides guidance in applying the salinity standards through the NPDES permitting authority in regulating municipal and industrial point source discharges.

In September 1980, the Forum adopted a "Policy for the Use of Brackish and/or Saline Waters for Industrial Purposes" where it is environmentally sound and economically feasible and where its use would not significantly increase consumptive use of Colorado River system water. Further, the use of brackish waters for industrial purposes is another way to reduce salt contributions to the river system.

Mr. Jack A. Barnett, Executive Director of the Forum, provides a focal point of contact for the Forum in dealing with salinity problems of interstate significance.

Forum Members

Arizona

Ronald L. Miller, Manager
Office of Water & Waste Quality Mgmt
Div of Environmental Health Services

Laurence C. Linser
Deputy Director
AZ Dept of Water Resources

Stewart Udall
Attorney at Law

California

Richard E. Angelos
Principal Engineer
Colorado River Board of California

Myron B. Holburt
Asst General Manager
Metropolitan Water District
of Southern California

Walter G. Pettit
Deputy Executive Director
CA State Water Resources Control Bd

Colorado

Dr. Robert A. Arnott
Asst Director, Dept of Health

David H. Getches, Exec Director
CO Dept of Natural Resources

David W. Robbins
Hill and Robbins, Attorneys

Nevada

Lewis H. Dodgion, Administrator
Div of Environmental Protection
Dept of Conservation & Natural Resources

Jack L. Stonehocker, Director
CO River Commission of Nevada

Roland D. Westergard, Director
Dept of Conservation & Natural Resources

New Mexico

Stephen E. Reynolds
State Engineer

Utah

D. Larry Anderson, Director
Division of Water Resources

Calvin K. Sudweeks, Director
Bureau of Water Pollution Control
UT State Div of Environmental Health

Wyoming

George L. Christopulos
State Engineer

William L. Garland
Administrator, Water Quality Div
Dept of Environmental Quality

INTERIOR'S ROLE

Federal coordination is accomplished using the lead agency concept. The Bureau of Reclamation, acting for the Secretary of the Interior, has the responsibility to implement salinity control measures. Interagency coordination between Interior and USDA is formalized through a series of joint agreements executed at the Departmental level. Coordination at the field administrative/technical level is accomplished through the Colorado River Interagency Salinity Control Committee.

Bureau of Reclamation

Units authorized for construction are the Grand Valley, Paradox Valley, Las Vegas Wash, and Lower Gunnison Basin Units and the McElmo Creek Unit as a part of the Dolores Project. Crystal Geyser was initially authorized but because the plan had poor cost-effectiveness, was deauthorized in Public Law 98–569. Figure 4 shows all units currently under study.

Reclamation's construction of the Grand Valley Unit Stage One is complete. A field station, 7 miles of the Highline Canal lining, and the associated pipe lateral construction were finished for the 1983 irrigation season. A moss and debris removal structure was built to control the trash problems in the lined canal.

Results from Stage One monitoring were evaluated and the lining program is reducing salt loading as projected; therefore, Reclamation is proceeding with advance planning and environmental statement compliance prior to a decision on construction of Stage Two.

Reclamation's data collection and specifications design preparation for initial elements of the Stage Two area are underway. Reclamation funded the Colorado Water Conservation Board, a Colorado State agency, to study how to effectively consolidate private lateral organizations into legal contracting entities for the remaining Stage Two plan elements.

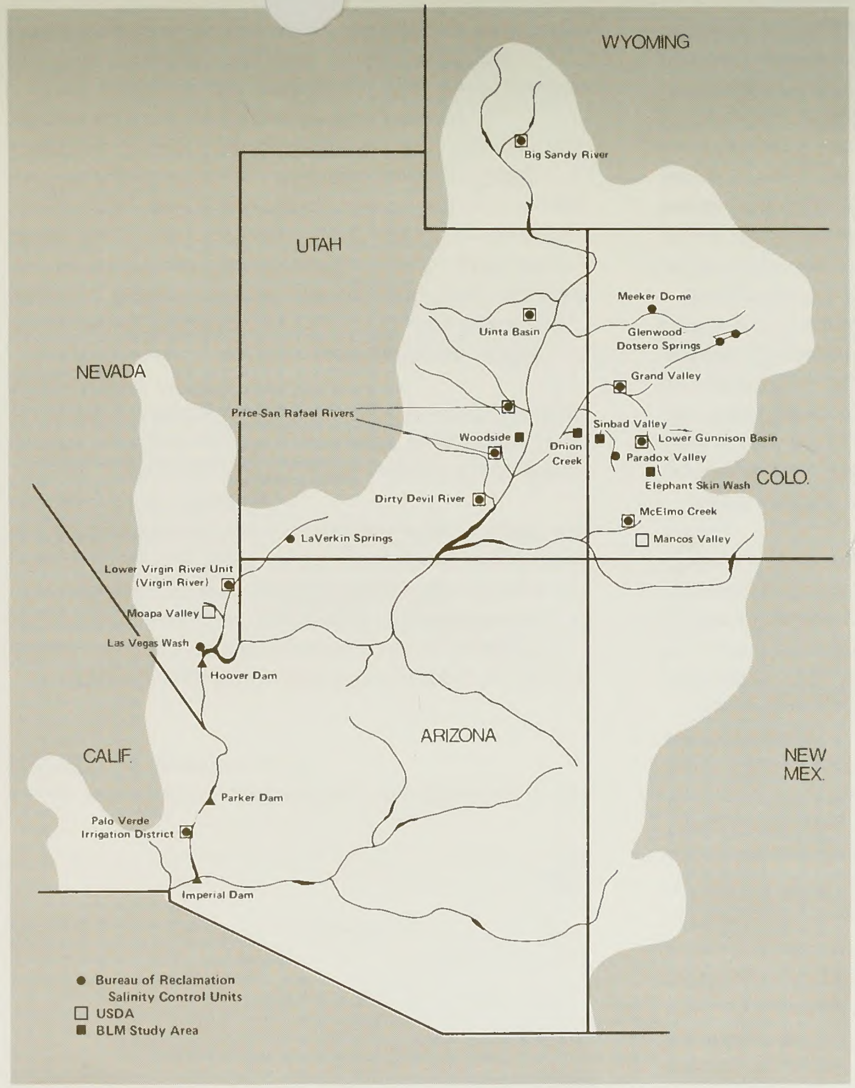


Figure 4. Colorado River Water Quality Improvement Program map.

Reclamation cooperates with USDA in their efforts in the Grand Valley. USDA's off-farm lateral improvements thus far for the project include completing 36.4 miles of pipelines and 11.1 miles of ditch lining, representing 25 percent of the overall project goals in the Grand Valley. Other USDA work is discussed later in this document.

Monitoring thus far has shown a reduction in salt load of over 47,000 tons annually as a result of USDA and Reclamation efforts in the Grand Valley area.

Plans to provide for incidental wildlife habitat replacement to compensate for losses resulting from the program are proceeding concurrently with project development.

Before initiation of salinity control activities, the entire Grand Valley contributed an average of 580,000 tons of salt annually to the Colorado River. Most of the salt is leached from the soil and underlying marine shale by water delivery system losses and deep percolation from over-irrigation in agricultural areas. The total USDA and Reclamation efforts in the Grand Valley area are expected to reduce the salt load by about 370,000 tons annually.

Paradox Valley in southwestern Colorado is a collapsed salt anticline underlain by a salt dome. The dome adds about 205,000 tons of salt annually to the Dolores River from ground water which originates in the valley. The plan is designed to prevent 180,000 tons of salt annually from entering the Colorado River system by pumping the saline ground water (brine of 260,000 mg/L TDS) from shallow collection wells along the Dolores River, thus preventing it from surfacing in the riverbed.

Deep well injection was selected as a test method to dispose of the brine because it is technically sound, and environmentally and economically attractive. After construction of an injection well, filtration plant, and pipeline to test the injection formation for disposal capacity, a decision will be made whether to use deep well injection as a permanent disposal method.

In the Las Vegas Wash Unit, a 3.5 mile pipeline (Pittman Bypass) to detour fresh water around saline soils is complete and in operation. The expected salt load reduction is 7,000 tons annually.

Large salt crystals surrounding the Paradox Valley temporary evaporation pond.

Another strategy being considered in the area is to use underground barriers in selected areas to develop a groundwater detention basin system to reduce underflows where salt pick-up theoretically occurs and to prevent salt from entering the Wash. A dike and slurry trench/wall will be constructed near the Whitney area to verify the feasibility of this strategy.

Other units in the CRWQIP (Colorado River Water Quality Improvement Program) have been or are under study and are categorized by the type of control method being studied for each unit.

Irrigation source salinity control activities within Reclamation would reduce salt loading by improving irrigation delivery systems that currently leach salt from marine shales and other saline sources. In addition to Grand Valley and Dolores Project (formerly McElmo Creek Unit), the lower Gunnison Basin Unit in Colorado, the Uinta Basin Unit in Utah, and the Palo Verde Irrigation District Unit in California are irrigation salt sources under investigation by Reclamation.

Point source salinity control activities would remove salt from localized areas such as mineral springs, abandoned oil wells, and geysers. In addition to Paradox Valley and Las Vegas Wash, Glenwood-Dotsero Springs and Meeker Dome Units in Colorado, as well as LaVerkin Springs Unit in Utah are point sources.

During verification studies, three wells in the Meeker Dome area were successfully plugged, reducing salt loading by 19,000 tons annually. Studies have been concluded on LaVerkin Springs Unit and are being concluded on Glenwood-Dotsero Springs Unit. Costs of salinity control programs at these sites were determined to be beyond an acceptable cost-effectiveness range.

Diffuse source salinity control activities would involve watershed management, land treatment, and the collection and disposal of irrigation return flows. Utah's Dirty Devil River and Price-San Rafael Rivers Units, Wyoming's Big Sandy River Unit, and the Lower Virgin River Unit in Nevada are identified diffuse sources currently under study.

Saline Water Use and Disposal Opportunities: A September 1981 Special Report suggested opportunities for collecting saline waters in the Colorado River Basin for use in the energy industry. The concepts developed are alternatives to conventional structural control methods involving lined evaporation ponds and/or desalination plants.

About 610,000 acre-feet of saline water per year could be collected for disposal or for use in energy production, such as for cooling coal-fired powerplants. If about half of this water were collected for use, about 500,000 tons of salt annually could be removed from the Colorado River system. Of special concern in the studies are legal, institutional, environmental, and cost-sharing issues.

Reclamation research activities include such items as saline water for cooling systems, solution mining with saline water, power production from solar salt gradient ponds, ion exchange water softening, and use of saline water in a salt tolerant emergent plant process. Installation of a saline water cooling system at Etiwanda Power Plant at Ontario, California, appears to be the most cost effective way to verify that using saline water provides salinity control benefits and addresses the concerns of the industry regarding equipme performance [hole-punch] ter of agreement for cost-sharing, equipment design, and an operational plan for the verification unit was completed in FY 1985; installation of the facilities will soon be complete and operational.

Bureau of Land Management

Recently BLM has concentrated on developing a comprehensive salinity control program for all public lands that they administer in the Colorado River Basin. They are also planning for land use activities and implementing projects with salinity control features.

Public Law 98-569, which amends Public Law 93-320, directed the Secretary of the Interior to develop a comprehensive program to minimize salt contributions from lands administered by BLM. A BLM task force has developed an outline and draft policy for the mandated July 1987 report.

Salinity control has been identified as a resource issue in several resource management plans within the Colorado River Basin. Through the planning system three activity plans were developed in 1985 in which salinity control has been identified as one of the objectives—two plans in Colorado and one in Utah.

Geological Survey

In cooperation with State, local, and other Federal agencies, the USGS-WRD (Water Resources Division) maintains 22 stations strictly for the analysis of the salinity control program. In addition, the Geological Survey conducts hydrological studies and maintains a much larger hydrologic data network.

Results of the hydrologic studies and information from the data networks form the basis for a better understanding of salinity mechanisms. As an integral part of the hydrologic studies, the WRD has developed a data base to support site specific salinity studies as well as to evaluate data at several key stations in the river system. USGS in one study is analyzing the variations in salinity over time and defining man's influence on salinity.

Fish and Wildl[hole-punch] Service

The FWS activities are important to the implementation and progress of the CRWQIP. FWS provides guidance for replacing habitat potentially lost primarily through canal and lateral lining and voluntary onfarm programs.

Fish and Wildlife Coordination Act reports, planning aid letters, and comments on draft environmental statements are some of the many services that FWS provides under the CRWQIP. FWS provides membership to HEP (Habitat Evaluation Procedure) Teams that conduct field work and analyze the impacts of program implementation and construction on the area's habitat. Lists of endangered species in a project area and biological opinions are provided by FWS under provisions of the Endangered Species Act.

Fish and wildlife measures planned to offset possible impacts include acquisition and development of wildlife habitat, construction of watering ponds, and installation of fences or escape structures to reduce big game losses. Voluntary SCS onfarm improvements such as select plantings, strip-harvesting of some crops, windbreak development, and small ponds are also planned.

Through the close cooperation and coordination of Reclamation, the SCS, the FWS, the States, and local entities, habitats will be evaluated and recommendations for replacement developed. Implementation of incidental wildlife habitat replacement will proceed concurrently with implementation of Reclamation projects.

EPA ROLE

The principal EPA programs dealing with salinity control are: (1) Water Quality Management Planning, (2) Water Quality Standards, and (3) the National Pollutant Discharge Elimination System (NPDES) Permits. Primary implementation of these programs is generally delegated to the States; however, EPA retains oversight and approval responsibilities.

Additional EPA activities include program support and guidance for State and Forum salinity control activities. Examples of these activities inc[hole-punch]stimony before Congress in support of the cooperat[hole-punch]sin-wide salinity control effort; and working with individual states to assist in implementing state salinity control activities.

EPA reviews all environmental statements and comments on Interior and USDA environmental statements on salinity control projects because of its responsibilities under the Clean Air Act and the National Environmental Policy Act. EPA encourages alternatives that minimize and mitigate adverse salinity impacts through various approaches, including water conservation and industrial use of saline water. EPA has also been working with Reclamation on salinity control projects where underground disposal options are considered.

USDA ROLE

Numerous agencies within USDA are involved in Colorado River salinity control activities as designated by the Secretary of Agriculture to carry out the provisions of Public Law 93-320 as amended by Public Law 98-569. Specifically section 202(c) authorizes USDA to establish a voluntary cooperative salinity control program with landowners to improve onfarm water management. Improvements include related irrigation laterals and reduction of erosion on private land. Major USDA activities include:

1. Irrigation salt source studies (SCS)
2. Project implementation including
   a. Technical assistance (SCS)
   b. Financial assistance (ASCS)
   c. Educational and informational assistance (ES)
3. Research and demonstration (ARS, CSRS)
4. Monitoring and evaluation (SCS)

Poor water management systems on irrigated agricultural lands have resulted in excessive distribution system seepage, over-irrigation, low irrigation efficiencies, excessive deep percolation, and high surface runoff. Collectively, these problems have resulted in increased salinity problems by leaching salts into the river system. Approximately 1 million acres are irrigated in 17 identified irrigation salt source areas in the Colorado River Basin. SCS (Soil Conservation Service) estimates onfarm water management and salinity control measures would be cost-effective on over 600,000 acres in 11 different salt source areas.

Irrigation Salt Source Studies

The SCS conducts the salinity control studies of irrigation salt source areas in the Basin. These studies are done under the River Basin Studies authority of Public Law 83–566. The studies evaluate the magnitude of salt loadings, the treatment and management alternatives for salinity control, and estimated project implementation costs. Working in cooperation with Reclamation, other Federal agencies, and concerned state agencies, USDA has completed eight major studies to date—Grand Valley, Colorado; Uinta Basin, Utah; Big Sandy, Wyoming; Moapa Valley, Nevada; Virgin Valley, Nevada and Arizona; and Lower Gunnison, McElmo Creek, and Mancos Valley, Colorado. Studies are underway in the Price-San Rafael Rivers Unit, Utah, and studies are pending on Palo Verde Irrigation District. Three other areas have been investigated: one was suspended and two had no recommended plans.

Salt accumulation on field and on bank of canal.

Project Implementation

Present USDA salinity control project implementation activities are being accomplished under existing USDA authorities and funding. The two implementation projects underway are Grand Valley (initiated in 1979) and Uinta Basin (started in 1980). These projects focus primarily upon improvements of onfarm irrigation systems, related lateral delivery systems, and irrigation water management practices to improve irrigation efficiencies and reduce deep percolation.

Technical assistance for planning, design, and installation of onfarm irrigation systems and water management is provided by SCS under the conservation technical assistance program. Funding for financial assistance to landowners to install irrigation water management system improvements and related salinity control measures is provided by the ASCS (Agricultural Stabilization and Conservation Service) with the ACP (Agricultural Conservation Program). Educational and Information support and assistance is provided through funds allocated by the ES (Extension Service) and the State Cooperative Extension Services of Utah and Colorado. Educational and Information assistance is necessary to inform farmers and landowners about the salinity control projects, new technologies, and how improved irrigation water management can benefit individual farmers and downstream Colorado River water users.

Research and Demonstration

The development and testing of new technology, improved irrigation equipment, and different irrigation techniques are vitally important research activities presently being funded by the Agricultural Research Service. Additional research support is being provided by the CSRS (Cooperative State Research Service) through several Western State agricultural experiment stations. Progress is being made through research efforts and demonstration sites within the Grand Valley and Uinta Basin implementation projects.

On farm irrigation improvements—laser land levelling technique.

Monitoring and Evaluation

SCS has responsibility to monitor and evaluate the progress and impacts of onfarm salinity control activities. Limited funding has restricted the scope of earlier monitoring activities; however, more thorough and comprehensive monitoring plans have been developed and are being implemented.

WHERE TO NOW?

The Evaluation Process

USDA and Interior will continue to use the annual joint evaluation process. Using a budget constraints computer model, the evaluation process will determine the optimal combination of projects and construction timing necessary to meet salt load reduction goals at minimum investment levels. This process provides a program management tool to support accomplishment of salinity control objectives at overall maximum cost-effectiveness. This approach to long-term, program-wide analysis is helpful to Federal program managers when weighing the many budget choices each year.

Based on the analysis, it appears that total construction costs for the program to meet the numeric criteria and required salt load reduction are now projected to be about $570 million (1984 price level). That is significantly less than previous estimates ($1.9 billion in 1983) and is due to a basic change in the evaluation of the program.

A repayment analysis model has been developed to evaluate the Lower Colorado River Basin Fund's ability to repay its share of the total program costs. It indicates at the $570 million investment level, that the Fund can meet its upfront payment obligations, assuming inflation is no more than 4–1/2 percent annually.

Pursue Beneficial Use of Saline Waters

Congressional authority for joint feasibility studies with industrial water users allows efforts to continue in the area of beneficial water use.

Some of the current structural methods of salinity control, such as desalting and lined evaporation ponds for point and diffuse salt sources, are proving expensive when compared to irrigation improvements. Therefore, development of alternative beneficial uses of saline water and innovative measures to reduce salinity concentrations are necessary.

Continue Program Implementation

Interior and USDA agencies' investigations to refine the plans will continue as funding permits on irrigation salt source control units as well as other units to define the most cost-effective measures. Construction on Grand Valley Stage Two will soon begin, preconstruction activities (deep well injection testing) will continue on Paradox Valley, and reformulation of plans will continue on the Las Vegas Wash Unit. USDA onfarm implementation in Grand Valley, Uinta Basin, and other units will proceed as program funding permits.

The Forum has indicated it will continue to work with Interior and Agriculture on program implementation to be certain the quality of Colorado River water is maintained at the 1972 historical levels as the Basin States continue to develop their compact-apportioned waters.

For questions concerning the program or specific projects, contact the

Colorado River Water Quality Office
Bureau of Reclamation, D–1000
PO Box 25007
Denver, Colorado 80225
Telephone: FTS 776–6782
Commercial: 303 –236–6782

For questions about State activities, contact the

Executive Director
Colorado River Basin Salinity Control Forum
106 West 500 South, Suite 101
Bountiful, Utah 84010
Telephone: FTS 588–6320
Commercial: 801 –292–4663

Details regarding the program can be found in the *Status Report, Colorado River Water Quality Improvement Program, January 1983;* the *1985 Evaluation of Salinity Control Programs in the Colorado River Basin*; and the *Quality of Water, Colorado River Basin Progress Report No. 12, January 1985.*

Also, the *Proposed Report on the 1984 Review, Water Quality Standards for Salinity, Colorado River System,* and the *Seventh Annual Progress Report, Water Quality Standards for Salinity, Colorado River System, December 1985.*

The enjoyment of good quality water.

Estimates of Salinity Control Potential—January 1986 *

Unit and Agency	Projected Salt Reduction k ton/yr	Est Salt Reduction to date k ton/yr	Annual Cost Effectiveness $/ton	Status
Palo Verde Irrig Dist CA, BR/USDA	1/		1/	Under investigation
Sinbad Valley CO, BLM	7,470		101	Advance planning to begin 1988
Meeker Dome CO, BR	19,000	19,000	14	Completed during verif studies
Grand Valley, Stage One CO, BR	24,000	19,900	123	Construction complete
Stage Two, BR	120,300		93	Preconstruction planning
Stage Two Balance, BR	23,200		297	
USDA	230,000	27,300	23	Under construction
Paradox Valley CO, BR	180,000		32	Preconstruction planning
Lower Gunnison Stage I WW CO, BR	74,300		17	Preconstruction planning
Stage I Deferred, BR	66,300		183	
North Fork, BR	1/		1/	Under investigation
USDA	335,000		32	Plan complete; plan to rescope
Dolores Project (McElmo) CO, BR	23,420		89	Preconstruction planning
McElmo Creek CO, USDA	38,000		67	Extended to future yrs
Glenwood-Dotsero Springs CO, BR	287,000		109	Deferred
Mancos CO, USDA	8,800		56	Planning complete
Lower Virgin NV, BR	270,000 2/		69	Under investigation
Virgin Valley, NV-AZ, USDA	37,200		16	Planning complete, pending funding
Moapa Valley NV, USDA	19,500		35	Plan complete, pending funding
Las Vegas Wash Stg I, Pittman, BR	7,000	7,000	24	Construction complete
Stage I, Whitney, BR	10,000 2/		16	Verification studies underway
Stage II, BR	66,000 2/		17	Under reformulation
San Juan River NM, BR	1/		1/	Under investigation
Uinta Basin Stage One UT, BR	25,500		85	Planning complete
Stage Two, BR	1/		1/	Under construction
USDA	98,200 3/	15,600	59	Under construction
Price-San Rafael UT, BR	22,000		47	Considering new combined alternative
Price-San Rafael UT, USDA	1/		1/	Investigations underway
Dirty Devil UT, BR	20,600		97	Planning complete
Big Sandy River WY, BR	1/		1/	Reformulation studies
USDA	52,900 3/		25	Based on off-farm canal lining and onfarm low pressure alternative

* All figures are from the 1985 Evaluation of Salinity Control Programs in the Colorado River Basin and dollars used to figure cost effectiveness have been adjusted to reflect 1984 dollars and 8–3/8 percent interest.

1/ Studies have not progressed far enough to make estimates.
2/ Best estimates at this time.
3/ Revised estimates that differ from published USDA reports because of new information and data now available.

GPO 849-924

Colorado River Basin

Salinity Control Forum

MEMORANDUM: 86-27

TO: Forum & Work Group Members

FROM: Jack A. Barnett JAB

SUBJECT: B.L.M. Budget

DATE: April 18, 1986

Enclosed you will find a copy of proposed testimony in support of the Bureau of Land Management's Budget. Testimony is similar to last years testimony and includes in the last paragraph some specific funding requests as recommended in the Advisory Council Report. I would appreciate Forum and Work Group members reviewing the testimony and advising me on or before April 29th of any changes that need to be made to the testimony. This is the last of the testimonies that need to be prepared for the Congress this year. Forum and Work Group members will receive copies of all of the testimonies as they are placed in final form. Your support of the requested appropriations should be expressed to your Senator or Congressman and their staff at every opportunity if we are to succeed in getting the funds needed this year for salinity control.

[illegible]

Proposed
Statement of
the

COLORADO RIVER BASIN SALINITY CONTROL FORUM

to the
COMMITTEE ON APPROPRIATIONS
SUBCOMMITTEE ON INTERIOR
SENATE

presented by
JACK A. BARNETT, EXECUTIVE DIRECTOR
April 29, 1986

Requesting additional funds over and above the FY 87 budget request by the President for Bureau of Land Management Renewable Resource Management activities, particularly with respect to the subactivities under the classification of Soil, Water and Air Management. Funds requested, $16,544,000; funds identified in the President's budget, $14,469,000.

****

The waters of the Colorado River system serve some 17 million people and irrigate about 1.6 million acres in the seven Colorado River Basin states. The river also provides domestic and irrigation water to Mexico. Salinity has long been recognized as one of the major problems in the river. Water users, situated lower in the river system, have suffered significant adverse impacts due to the river's salinity. It has been estimated that salinity damages have occurred in amounts over $100 million a year. Without salinity control measures, and with increased demands for Colorado River water in the Basin, the river's salinity is projected to increase, further impairing the usefulness of this water supply, and it is projected that the economic damages suffered by water users will double by the turn of the century without salinity control.

The Basin states concerns with the river's increasing salinity led them to create the Colorado River Basin Salinity Control Forum in 1973. The Forum, whose members are appointed by the governors of the respective states, developed a salinity control policy that calls for maintaining salinity concentrations at

or below those levels found in the lower river in 1972 while the Basin states continue to develop their compact apportioned waters. The Forum has a continuing responsibility to see that a salinity control plan is implemented to meet the policy objectives.

In 1974, after discussion between the federal government, the Republic of Mexico, and the seven Colorado River Basin states, Congress enacted the Forum sponsored Colorado River Basin Salinity Control Act (P.L. 93-320). Title I of the Act established a program to reduce the concentration of salts in the Colorado River below Imperial Dam, the last diversion point in the United States, so that the United States could honor its commitments to Mexico. In Title II, the Act established a program which allowed the states and the federal government to work together to prevent salinity increases in the Colorado River above Imperial Dam, benefiting users in the United States as well as Mexico. The 1974 Act also created a Colorado River Basin Salinity Control Advisory Council, composed of governor appointed representatives of the Basin states, to advise the Secretaries of the Interior and Agriculture and the Administrator of the Environmental Protection Agency as to needed annual adjustments to the salinity control effort.

In 1984, Congress enacted much needed amendments to the 1974 Act that were advanced by the Forum. The amendments, Public Law 98-569, authorized additional activities for the Departments of the Interior and Agriculture that are needed in order to meet the objectives of the act. In recognition of the vast amount of Federal land within the Basin, managed by the Bureau of Land Management (BLM) the Congress assigned certain responsibilities. This included a requirement that an appraisal of the amount of salt being contributed to the river by BLM managed lands, with a report due back to the Congress by July, 1987.

Salinity is one of the major problems in the Colorado River system. It is imperative that the salinity control activities of the BLM not be curtailed and that adequate funding be appropriated in 1987 so that the Congressionally directed salinity objectives can be achieved. Therefore, we request that the funds for the BLM as identified in the opening paragraph of this statement be appropriated by the Congress. Of the funds appropriated for Soil, Water and Air Management we believe that with respect to salinity control in the Colorado River Basin there should be spent $240,000 for Planning activities, $400,000 on Project Work, $525,000 on Inventory in search of potential salinity control ares, and $125,000 for Monitoring of already completed control measures.

The Forum appreciated the opportunity to testify on this important matter and we offer our continued cooperation with the Federal entities as we collectively look for cost effective ways to maintain the quality of the river.

POLICY FOR IMPLEMENTATION OF THE COLORADO RIVER SALINITY STANDARDS THROUGH THE NPDES PERMIT PROGRAM

Prepared By

The Colorado River Basin Salinity Control Forum
February 28, 1977

In November 1976, the United States Environmental Protection Agency Regional Administrators notified each of the seven Colorado River Basin states of the approval of the water quality standards for salinity for the Colorado River System as contained in the document entitled "Proposed Water Quality Standards for Salinity Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System, June 1975", and the supplement dated August 25, 1975. The salinity standards including numeric criteria and a plan of implementation provide for a flow weighted average annual numeric criteria for three stations in the lower mainstem of the Colorado River: below Hoover Dam, below Parker Dam and at Imperial Dam.

The Plan of Implementation is comprised of a number of Federal and non-Federal projects and measures to maintain the flow-weighted average annual salinity in the Lower Colorado River at or below numeric criteria at the three stations as the Upper and Lower Basin states continue to develop their compact-apportioned waters. One of the components of the Plan consists of the placing of effluent limitations, through the National Pollutant Discharge Elimination System (NPDES) permit program, on industrial and municipal discharges.

The purpose of this policy is to provide more detailed guidance in the application of salinity standards developed pursuant to Section 303 and through the NPDES permitting authority in the regulation

of municipal and industrial sources. [See Section 402 of the Federal Water Pollution Control Act.] This policy is applicable to discharges that would have an impact, either direct or indirect on the lower mainstem of the Colorado River System. The lower mainstem is defined as that portion of the main river from Hoover Dam to Imperial Dam.

I. Industrial Sources

The Salinity Standards state that "the objective for discharges shall be a no-salt return policy whenever practicable." This is the policy that shall be followed in issuing NPDES discharge permits for all new industrial sources, and upon the reissuance of permits for all existing industrial sources, except as provided herein. The following addresses those cases where no-discharge of salt may be deemed not to be practicable.

A. New Construction.

1. New construction is defined as any facility from which a discharge may occur, the construction of which is commenced after October 18, 1975. [Date of submittal of water quality standards as required by 40 CFR 120, December 11, 1974.] Appendix A provides guidance on new construction determination.

a. The permitting authority may permit the discharge of salt upon a satisfactory demonstration by the permitee that it is not practicable to prevent the discharge of all salt from proposed new construction.

b. The demonstration by the applicant must include information on the following factors relating to the potential discharge:

(1) Description of the proposed new construction.

(2) Description of the quantity and salinity of the water supply.

(3) Description of water rights, including diversions and consumptive use quantities.

(4) Alternative plans that could reduce or eliminate salt discharge. Alternative plans shall include:

(a) Description of alternative water supplies, including provisions for water reuse, if any.

(b) Description of quantity and quality of proposed discharge.

(c) Description of how salts removed from discharges shall be disposed of to prevent such salts from entering surface waters or ground water aquifers.

(d) Costs of alternative plans in dollars per ton of salt removed.

(5) Of the alternatives, a statement as to the one plan for reduction of salt discharge that the applicant recommends be adopted.

(6) Such other information pertinent to demonstration of non-practicability as the permitting authority may deem necessary.

c. In determining what permit conditions shall be

required, the permit issuing authority shall consider, but not be limited to the following:

(1) The practicability of achieving no discharge of salt.

(2) Where no-discharge is determined not to be practicable:

(a) The impact of the total proposed salt discharge of each alternative on the lower mainstem in terms of both tons per year and concentration.

(b) Costs per ton of salt removed from the discharge for each plan alternative.

(c) Capability of minimizing salinity discharge.

(3) With regard to both points, one and two above, the compatibility of state water laws with either the complete elimination of a salt discharge or any plan for minimizing a salt discharge.

(4) The no-salt discharge requirement may be waived in those cases where the salt load reaching the mainstem of the Colorado River is less than one ton per day or 350 tons per year, whichever is less. Evaluation will be made on a case-by-case basis.

B. Existing Facilities

1. The permitting authority may permit the discharge of salt upon a satisfactory demonstration by the permittee

that it is not practicable to prevent the discharge of all salt from an existing facility.

2. The demonstration by the applicant must include information, in addition to that required under Section I,A,1,b; the following factors relating to the potential discharge:
   (a) Existing tonnage of salt discharged and volume of effluent.
   (b) Cost of modifying existing industrial plant to provide for no salt discharge.
   (c) Cost of salt minimization.

3. In determining what permit conditions shall be required, the permit issuing authority shall consider the items presented under I,a,1,c (2), and in addition; The annual costs of plant modification in terms of dollars per ton of salt removed for:
   a) No salt return.
   b) Minimizing salt return.

4. The no-salt discharge requirement may be waived in those cases where the salt load reaching the main-stem of the Colorado River is less than one ton per day or 350 tons per year, whichever is less. Evaluation will be made on a case-by-case basis.

II. Municipal Discharges

The basic policy is that a reasonable increase in salinity shall be established for municipal discharges to any portion of the Colorado River stream system that has an impact on the lower mainstem. The incremental increase in salinity shall be 400 mg/l or less, which is considered to be a reasonable incremental

increase above the flow weighted average salinity of the intake water supply.

A. The permitting authority may permit a discharge in excess of the 400 mg/l incremental increase at the time of issuance or reissuance of a NPDES discharge permit, upon satisfactory demonstration by the permittee that it is not practicable to attain the 400 mg/l limit.

B. Demonstration by the applicant must include information on the following factors relating to the potential discharge:

1. Description of the municipal entity and facilities.
2. Description of the quantity and salinity of intake water sources.
3. Description of significant salt sources of the municipal waste-water collection system, and identification of entities responsible for each source, if available.
4. Description of water rights, including diversions and consumptive use quantities.
5. Description of the waste water discharge, covering location, receiving waters, quantity, salt load, and salinity.
6. Alternative plans for minimizing salt contribution from the municipal discharge. Alternative plans should include:
   (a) Description of system salt sources and alternative means of control
   (b) Cost of alternative plans in dollars per ton, of salt removed from discharge.

7. Such other information pertinent to demonstration of non-practicability as the permitting authority may deem necessary.

C. In determining what permit conditions shall be required, the permit issuing authority shall consider the following criteria including, but not limited to:

1. The practicability of achieving the 400 mg/l incremental increase.
2. Where the 400 mg/l incremental increase is not determined to be practicable:
   (a) The impact of the proposed salt input of each alternative on the lower mainstem in terms of tons per year and concentration.
   (b) Costs per ton of salt removed from discharge of each alternative plan.
   (c) Capability of minimizing the salt discharge.

D. If, in the opinion of the permitting authority, the data base for the municipal waste discharger is inadequate, the permit will contain the requirement that the municipal waste discharger monitor the water supply and the wastewater discharge for salinity. Such monitoring program shall be completed within 2 years and the discharger shall then present the information as specified above.

E. Requirements for establishing incremental increases may be waived in those cases where the incremental salt load reaching the mainstem of the Colorado River is less than one ton per day or 350 tons per year whichever is less. Evaluation will be made on a case-by-case basis.

F. All new and reissued NPDES permits for all municipalities shall require monitoring of the salinity of the intake water supply and the wastewater treatment plant effluent in accordance with the following guidelines:

Treatment Plant Design Capacity	Monitoring Frequency	Type of Sample
$<$ 1.0 MGD	Quarterly	Discrete
1.0 - 5.0 MGD	Monthly	Composite
5.0 - 50.0 MGD	Weekly	Composite
$>$ 50.0 MGD	Daily	Composite

1. Analysis for salinity may be either as total dissolved solids (TDS) or by electrical conductivity where a satisfactory correlation with TDS has been established. The correlation should be based on a minimum of five different samples.
2. Monitoring of the intake water supply may be at a reduced frequency where the salinity of the water supply is relatively uniform.

APPENDIX A

GUIDANCE ON NEW CONSTRUCTION DETERMINATION

For purposes of determining a new construction, a source should be considered new if by October 18, 1975, there has not been:

(1) Significant site preparation work such as major clearing or excavation; and/or

(2) Placement, assembly, or installation of unique facilities or equipment at the premises where such facilities or equipment will be used; and/or

(3) Any contractual obligation to purchase unique facilities or equipment. Facilities and equipment shall include only the major items listed below, provided that the value of such items represents a substantial commitment to construct the facility:

   (a) structures; or

   (b) structural materials; or

   (c) machinery; or

   (d) process equipment; or

   (e) construction equipment.

(4) Contractual obligation with a firm to design, engineer, and erect a completed facility (i.e., a turnkey plant).

1985 ANNUAL REPORT ON THE COLORADO RIVER BASIN SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN SALINITY CONTROL ADVISORY COUNCIL

February 1986

1985 ANNUAL REPORT ON THE COLORADO RIVER BASIN SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN SALINITY CONTROL ADVISORY COUNCIL

February 1986

Background

Public Law 93-320, the "Colorado River Basin Salinity Control Act of 1974," authorized construction, operation, and maintenance of certain works in the Colorado River Basin to control the salinity of water available in the Colorado River for use in the United States and Mexico. Section 204 of the Act established a Colorado River Basin Salinity Control Advisory Council. A Charter for the Council was originally approved by the Secretaries of the Interior and Agriculture and the Administrator of the Environmental Protection Agency on February 6, 1976, and revised on June 22, 1976 and subsequently renewed in 1978, 1980, 1982, and October 5, 1984.

The Council is comprised of up to three members, appointed by the Governor, from each of the seven Colorado River Basin states. The current membership is shown on Attachment A. During 1985, David Robbins, Colorado, served as Council Chairman and Myron Holburt, California, as Vice Chairman. The permanent Work Group of the Colorado River Basin Salinity Control Forum continues to serve the Council in the capacity of a technical review and study team. Ernest M. Weber, California, is Chairman of the Work Group. The

1988 ANNUAL REPORT ON THE COLORADO RIVER BASIN
SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN SALINITY
CONTROL ADVISORY COUNCIL

February 1989

BACKGROUND

Public Law 93-320, the "Colorado River Basin Salinity Control Act of 1974," authorized construction, operation, and maintenance of certain works in the Colorado River Basin to control the salinity of water available in the Colorado River for use in the United States and Mexico. Section 204 of the Act established a Colorado River Basin Salinity Control Advisory Council. A Charter for the Council was originally approved by the Secretaries of the Interior and Agriculture and the Administrator of the Environmental Protection Agency on February 6, 1976, and revised on June 12, 1976 and subsequently renewed in 1978, 1980, 1982, and October 5, 1984.

The Council is comprised of up to three members, appointed by the Governors, from each of the seven Colorado River Basin States. The current membership is shown in Attachment A. During 1988, David Robbins, Colorado, served as Council Chairman and Myron Holburt, California, as Vice Chairman. The permanent Work Group of the Colorado River Basin Salinity Control Forum continued to serve the Council in the capacity of a technical review and study team. Gerald R. Zimmerman, California, is Chairman of the Work Group. The that meeting, the Council received status reports from the federal agencies involved in salinity control.

Council Comments and Recommendations

The Council offers the following comments and recommendations on the salinity control activities of the federal agencies. The reports: "1985 Joint Evaluation of Salinity Control Programs" November 1985 and "Seventh Annual Progress Report - Water Quality Standards for Salinity - Colorado River System" December 1985, describe the individual salinity control projects and their status. Therefore, the Council will make no attempt to repeat this information in this annual report as has been done in the past.

General Comments

On October 30, 1984, the Colorado River Basin Salinity Control Act, P.L. 93-320, was amended by the passage of P.L. 98-569. In that legislation, Congress mandated that several new or revised programs or efforts be implemented by the Departments of the Interior and Agriculture and the Council looks forward to the timely implementation of the directives. The Council wishes to thank the federal agencies for their assistance and support in securing the passage of P.L. 98-569.

The Council wishes to commend the Department of the Interior and the Department of Agriculture on the publication of the jointly prepared 1985 Evaluation Report. It represents a vast improvement over the previous year's that meeting, the Council received status reports from the Federal agencies involved in salinity control.

Council Comments and Recommendations

The Council offers the following comments and recommendations on the salinity control activities of the Federal agencies. The reports: "1985 Joint Evaluation of Salinity Control Programs" November 1985 and "Seventh Annual Progress Report - Water Quality Standards for Salinity - Colorado River System" December 1985, describe the individual salinity control projects and their status. Therefore, the Council will make no attempt to repeat this information in this annual report as has been done in the past.

General Comments

On October 30, 1984, the Colorado River Basin Salinity Control Act, P.L. 93-320, was amended by the passage of P.L. 98-569. In that legislation, Congress mandated that several new or revised programs or efforts be implemented by the Departments of the Interior and Agriculture and the Council looks forward to the timely implementation of the directives. The Council wishes to thank the Federal agencies for their assistance and support in securing the passage of P.L. 98-569.

The Council wishes to commend the Department of the Interior and the Department of Agriculture on the publication of the jointly prepared 1985 Evaluation Report. It represents a vast improvement over the previous year's projects include: Glenwood-Dotsero Springs, Price-San Rafael Rivers, San Juan River, LaVerkin Springs, Lower Virgin River, Big Sandy River, Upper Virgin Valley, Virgin Valley, Mancos Valley, Moapa Valley, Colorado River Indian Reservation, Palo Verde Irrigation District, and Little Colorado River.

Bureau of Reclamation (Reclamation)

Paradox Valley Unit. The Council is heartened by the progress shown on the Paradox Valley Unit and urges continued efforts to expedite the processing of the proposals for drilling of the Paradox Valley Unit Injection Test Well No. 1.

Grand Valley Unit. The Colorado Water Conservation Board and Reclamation are to be commended for their cooperative efforts to organize the private laterals in the Grand Valley into contracting entities. Reclamation should continue to fund and expedite this activity. Staged construction on Stage Two of the unit should be initiated during 1986.

Las Vegas Wash Unit. Reclamation should continue with the effluent monitoring program established in the Wash to evaluate the effectiveness of the Pittman Bypass. Reclamation should also proceed with the start of construction of the verification phase of a ground water barrier detention basin in the Whitney area.

Dolores Project (McElmo Creek Unit). The Council supports continued implementation of authorized salinity

cooperative cost-sharing efforts between federal and state government, utilities, and private industry. The Council looks forward to the results of this verification program.

In regard to another potential use by the power industry, Reclamation should proceed with the use of a consultant to study the onsite saline water use at the proposed Harry Allen Power Plant in Nevada. In addition, Reclamation should continue to study the potential saline water supplies and alternative water uses from the Lower Virgin River Unit. This unit should be given priority and Advance Planning initiated in FY 1988.

Reclamation has undertaken a preliminary evaluation of the use and disposal of Glenwood Springs saline water using the concept of growing salt tolerant emergent plants. This unique technology appears to offer some potential for salinity reduction at other sites within the basin. The Council believes this technology offers some promise for the economical use and disposal of saline water and supports the current study. However, before further detailed studies are made, the Council feels that a small-scale, field verification of the concept should be undertaken. This study should not only test the ability to grow the proposed crops but also the use and marketability of those products and the impacts of this technology on salinity.

Other. The Council supports current study efforts by Reclamation to update the economic impacts of salinity control in the Basin.

U.S. Geologic Survey (USGS)

The Council has become increasingly concerned over the reduction in the number of gaging stations, both those measuring stream flow and water quality, which are being maintained by the USGS. The Council questions whether the network will continue to be adequate to meet the needs of the basinwide salinity control program. The Council believes that it is a federal obligation to provide the necessary information to carry out this program.

The Council recommends that no further reduction in the data collection program be made at this time. Further the Council recommends that the Survey, in consultation with the Forum Work Group, develop a data collection and evaluation program which will adequately monitor Colorado River salinity.

The continuing cooperative efforts between USGS, Reclamation, and Agriculture in improving the data base for both water and salt and in developing better methodologies to evaluate the data base as well as salinity impacts are to be commended and continued.

Department of Agriculture (USDA)

The USDA should continue its efforts to get line item funding for the Salinity Control Program.

Grand Valley Unit. The Council is pleased with the progress in the Grand Valley area, specifically the monitoring and evaluation program, and supports the continued effort.

basin wide salinity control program. The Council has become concerned with the recent lack of attention given to Colorado River Basin salinity by EPA. We urge EPA to restore the level of priority given to the salinity issue. The Council requests that EPA apply the Forum policies related to the approval of the NPDES permits where EPA is responsible for issuing such permits.

Finally, the Council urges EPA to work with the states in order to assure expeditious approval of the individual state adopted triennial reviews.

Budget Recommendations

The following tabulation contains the Council's recommendations for appropriations for FY 1987 and FY 1988. Tentative recommendations for FY 1989 funding to provide program continuity are also offered.

	Fiscal Years (In 1000's of $)		
	1987	1988	Tentative 1989
DEPARTMENT OF THE INTERIOR Bureau of Reclamation			
Construction			
Paradox Valley	12,000	6,000	4,000
Grand Valley	12,000	20,000	25,000
Las Vegas Wash	100 1/	2,000	500
Lower Gunnison Basin (Stage 1 - Winter Water)	-	10,000	10,000
Dolores (McElmo Creek)	-	-	2/
Subtotal	24,100	38,000	39,500

DEPARTMENT OF AGRICULTURE

Colorado River Salinity Control Program			
Federal Cost Share[5/]	4,000	5,000	8,000
Technical and Program Support[6/]	2,000	2,000	3,000
TOTAL - USDA	6,000	7,000	11,000

Conclusion

The Council wishes to express its appreciation for the opportunity to submit its comments and suggestions to the federal agencies. The Council is pleased with the efforts put forth in FY 1985. With the passage of new salinity legislation, the Council looks forward to significantly greater accomplishments in the ensuing years.

1/ Recommended total FY 1987 program of $1.1 million, includes $1.0 million in FY 1986 funds.

2/ Advance planning and construction will be a component of the Dolores Project.

3/ Does not include private-joint venture funding for industrial use of saline water.

4/ Program transferred from BLM to Reclamation and Advance Planning initiated in 1988.

5/ Federal salinity cost share funds to be administered by ASCS (with 30 percent reimbursement from the Basin Funds subject to P.L. 98-569).

6/ Includes funds for SCS, Extension Service, and research agencies for technical assistance, monitoring, planning, education, and research activities (no reimbursement, subject to P.L. 98-569).

Attachment A

ADVISORY COUNCIL MEMBERSHIP

ARIZONA

Laurence C. Linser
Deputy Director
Department of Water Resources
Phoenix, Arizona

Ronald L. Miller, Ph.D., Chief
Bureau of Water Quality Control
Department of Health Services
Phoenix, Arizona

Stewart Udall
Attorney at Law
Central Arizona Water
Conservation District
Phoenix, Arizona

CALIFORNIA

Richard E. Angelos
Principal Engineer
Colorado River Board
of California
Los Angeles, California

Myron B. Holburt,
Assistant General Manager
The Metropolitan Water District
of Southern California
Los Angeles, California

Walter G. Pettit
Deputy Executive Director
State Water Resources Control
Board
Sacramento, California

COLORADO

J. William McDonald, Director
Colorado Water Conservation
Board
Denver, Colorado

David Robbins
Attorney at Law
Denver, Colorado

NEVADA

Lewis H. Dodgion, Administrator
Division of Environmental
Protection
Carson City, Nevada

Jack L. Stonehocker
Director
Colorado River Commission
of Nevada
Las Vegas, Nevada

Roland D. Westergard, Director
Department of Conservation
and Natural Resources
Carson City, Nevada

NEW MEXICO

Denise Fort, Director
Environmental Improvement
Division
Santa Fe, New Mexico

Stephen E. Reynolds
State Engineer
Santa Fe, New Mexico

Carl Slingerland, Office Manager
Water Resources Associates, Inc.
Santa Fe, New Mexico

UTAH

D. Larry Anderson, Director
Division of Water Resources
Salt Lake City, Utah

Dallin W. Jensen
Assistant Attorney General
Salt Lake City, Utah

Calvin K. Sudweeks, Director
Bureau of Water Pollution
Control
Salt Lake City, Utah

DRAFT/B:FRED/3-20-85

Attachment #1
Page 1 of 2
3/20/85

SALINITY COST-EFFECTIVENESS ANALYSIS AGREEMENTS:

I. Applicable program costs:

DOI:

1. Total salinity construction costs including lands and rights and engineering.
2. IDC (Interest During Construction) - Economic
3. Salinity OM&R costs.
4. Economic cost of power.
5. Advance planning costs.
6. M & E (Monitoring and Evaluation) costs.
7. Habitat costs including capital investments and OM&R.
8. Research costs excluded.
9.

USDA:

1. Total Federal cost-share expenses for construction.
2. IDC
3. Replacement component whether Federal or local cost.
4. Local O&M costs, including energy costs, are excluded.
5. Technical assistance, conservation planning, and engineering costs.
6. M & E costs.
7. Federal capital investments for habitat.
8. Information and education costs.
9. Local cost-share expenses, including habitat costs, are excluded.
10. ARS, CSRS, and Experiment Station costs are excluded.

DRAFT/B:FRED/3-20-85

SALINITY COST-EFFECTIVENESS ANALYSIS AGREEMENTS:

I. Applicable program costs:

DOI:	USDA:
1. Total salinity construction costs including lands and rights and engineering.	1. Total Federal cost-share expenses for construction.
2. IDC (Interest During Construction) - Economic	2. IDC
3. Salinity OM&R costs.	3. Replacement component whether Federal or local cost.
4. Economic cost of power.	4. Local O&M costs, including energy costs, are excluded.
5. Advance planning costs.	5. Technical assistance, conservation planning, and engineering costs.
6. M & E (Monitoring and Evaluation) costs.	6. M & E costs.
7. Habitat costs including capital investments and OM&R.	7. Federal capital investments for habitat.
8. Research costs excluded.	8. Information and education costs.
9.	9. Local cost-share expenses, including habitat costs, are excluded.
	10. ARS, CSRS, and Experiment Station costs are excluded.

DRAFT/B:FRED/3-20-85

SALINITY COST-EFFECTIVENESS ANALYSIS AGREEMENTS:

II. DOI and USDA will use the 8-3/8 percent discount rate for plan formulation and evaluation during FY 1985 for analysis of cost-effectiveness.

III. DOI and USDA will index all costs to October 1984 dollars using the 8-3/8 percent discount rate for analysis of cost-effectiveness.

IV. DOI and USDA will use a 50-year period for cost-effectiveness analysis.

DRAFT/B:KRAUSS/3-20-85

Attachment #2
3/20/85

BASIN FUND REPAYMENT CRITERIA:

I. Applicable program costs:

DOI: (75-25) - PL 93-320 (70-30) - PL 98-569	USDA: (70-30) - PL 98-569
1. Total salinity construction costs including land and rights and engineering.	1. Total Federal salinity cost-share expenses including on-farm, canal and lateral, and habitat replacement capital costs.
2. IDC - Financial	2. IDC
3. Salinity OM&R costs.	
4. Financial cost of power.	
5. Advance planning costs incurred after construction authorization.	
6. M & E costs.	
7. Habitat costs including capital investments and OM&R.	

II. IDC will be adjusted annually and computed at the interest rate specified in P.L. 98-569.

B/C WORKSHEET

Compute Costs

Project Costs (All done 1 yr) ____________________
Operation and Maintenance (annual) ____________________
Monitoring (annual) ____________________

Present Value

Project Cost ____________________
Operation and Maintenance ____________________
Monitoring ____________________

P.V. Costs Total ____________________

Compute Benefits

P.V.

Project Benefits (annual)
1. Range ____________________
2. Wildlife ____________________
3. Salt ____________________
4. Sediment ____________________

Present Value ____________________
Total B ____________________

B/C Ratio
P.V. Benefit/P.V. Costs = __________

Net Value Computation

P.V. Benefits - P.V. Costs = __________

COMPOUND INTEREST AND ANNUITY TABLES FOR
8.3750 PERCENT

NO. OF YRS. HENCE	PRESENT VALUE OF 1	AMORTI-ZATION	PRESENT VALUE OF AN ANNUITY OF 1 PER YEAR	AMOUNT OF AN ANNUITY OF 1 PER YEAR	PRESENT VALUE OF AN INCREASING ANNUITY	PRESENT VALUE OF A DECREASING ANNUITY
1	.92272	1.08375	.92272	1.00000	.92272	.92272
2	.85142	.56365	1.77414	2.08375	2.62555	2.69686
3	.78562	.39066	2.55976	3.25826	4.98241	5.25662
4	.72491	.30444	3.28467	4.53114	7.88205	8.54129
5	.66889	.25294	3.95356	5.91063	11.22650	12.49484
6	.61720	.21878	4.57076	7.40564	14.92969	17.06560
7	.56950	.19454	5.14026	9.02586	18.91622	22.20586
8	.52549	.17650	5.66575	10.78178	23.12016	27.87161
9	.48488	.16258	6.15064	12.68475	27.48412	34.02225
10	.44741	.15156	6.59805	14.74710	31.95825	40.62030
11	.41284	.14264	7.01089	16.98217	36.49947	47.63119
12	.38093	.13528	7.39182	19.40443	41.07069	55.02301
13	.35150	.12914	7.74332	22.02955	45.64015	62.76633
14	.32433	.12395	8.06765	24.87453	50.18083	70.83398
15	.29927	.11952	8.36692	27.95777	54.66988	79.20091
16	.27614	.11570	8.64307	31.29923	59.08817	87.84397
17	.25480	.11239	8.89787	34.92054	63.41983	96.74184
18	.23511	.10949	9.13298	38.84514	67.65185	105.87483
19	.21694	.10695	9.34993	43.09842	71.77378	115.22475
20	.20018	.10471	9.55011	47.70791	75.77736	124.77486
21	.18471	.10272	9.73481	52.70345	79.65625	134.50967
22	.17044	.10096	9.90525	58.11736	83.40583	144.41492
23	.15726	.09938	10.06251	63.98469	87.02291	154.47744
24	.14511	.09797	10.20763	70.34341	90.50558	164.68506
25	.13390	.09670	10.34152	77.23467	93.85302	175.02659
26	.12355	.09556	10.46507	84.70307	97.06532	185.49166
27	.11400	.09453	10.57908	92.79695	100.14338	196.07074
28	.10519	.09360	10.68427	101.56870	103.08877	206.75501
29	.09706	.09275	10.78133	111.07507	105.90362	217.53634
30	.08956	.09199	10.87089	121.37761	108.59049	228.40723
31	.08264	.09129	10.95354	132.54299	111.15238	239.36077
32	.07626	.09066	11.02979	144.64346	113.59254	250.39056
33	.07036	.09009	11.10015	157.75735	115.91449	261.49071
34	.06492	.08956	11.16508	171.96953	118.12193	272.65579
35	.05991	.08909	11.22499	187.37198	120.21869	283.88077
36	.05528	.08865	11.28026	204.06438	122.20870	295.16104
37	.05101	.08825	11.33127	222.15477	124.09593	306.49231
38	.04706	.08789	11.37833	241.76024	125.88438	317.87064
39	.04343	.08755	11.42176	263.00766	127.57805	329.29240
40	.04007	.08725	11.46183	286.03455	129.18091	340.75423
41	.03697	.08697	11.49881	310.98994	130.69688	352.25304
42	.03412	.08671	11.53293	338.03535	132.12982	363.78597
43	.03148	.08647	11.56441	367.34581	133.48350	375.35037
44	.02905	.08626	11.59345	399.11102	134.76162	386.94383
45	.02680	.08606	11.62026	433.53657	135.96777	398.56409
46	.02473	.08587	11.64499	470.84526	137.10545	410.20908
47	.02282	.08571	11.66781	511.27855	138.17803	421.87689
48	.02106	.08555	11.68887	555.09812	139.18878	433.56575
49	.01943	.08541	11.70830	602.58759	140.14085	445.27405
50	.01793	.08528	11.72623	654.05430	141.03728	457.00028

CO-933
4000/9500

MAY 17 1985

Memorandum

To: Director (220), Premier Building, Room 909

From: State Director, Colorado

Subject: Colorado Price List for Updating Sageram Model for 1984 Values

The following Table is the Colorado price list representing 1984 values for the Sageram Model. These values, once programmed, will be used in the FY 1985 rangeland benefit-cost analysis.

1984 Colorado Price List

Outputs	Value
Livestock (AUM's)	$ 8.92
Deer (AU's)	45.56
Elk (AU's)	130.63
Antelope (AU's)	18.04*
Other Big Game Hunting (Hunter Day)	22.86*
Waterfowl Hunting (Hunter Day)	6.46*
Warm Water Angling (ADs)	3.58*
Cold Water Angling (ADs)	3.95*
Dispersed Use (Recreation Day)	3.38*

*RPA Values for 1982, update using Consumer Price Index (CPI).

Wildlife values are from a 1980 survey by the Colorado Division of Wildlife and were also updated using the CPI.

/s/ Kannon Richards

bcc:
WO (240), Premier Building, Room 903
DSC-470 (Buck West), DMs

TDanna:bas:5/16/85:7116

COST EFFECTIVENESS

Compute Cost

	Actual	P.V.
Planning Costs		
Construction Costs		
O & M Costs		
Monitoring Costs		
Total Costs		

P.V. Total Costs - 50 = Annual Cost ________

Compute Salt Reduction.

Annual Salt reduction per yr ________

$ $\frac{\text{Annual P.V. Cost/Yr}}{\text{tons 1 yr}}$ = Annual Cost Effectiveness

Table 1. - Cost-effectiveness Summary in Best Cost-effectiveness Order (From Basic Data Table, Appendix A - 1984 Values)

Unit	Onsite at Project Area: Projected Salt Reduction (kton/yr)	Estimated Salt Reduction to Date (kton/yr)	Annual Cost Effectiveness ($/ton)
Meeker Dome (BR)	48.0	48 3/	14
Virgin Valley (USDA)	37.2		16
Las Vegas Wash, Whitney (BR) 1/	10.0 2/		16
Lower Gunnison, WW (BR)	74.3		17
Las Vegas Wash, Stg II (BR)	66.0 2/		17
Grand Valley (USDA)	230.0	27.3	23
Las Vegas Wash, Pittman (BR) 1/	7.0	7	24
Big Sandy (USDA)	52.9		25
Paradox Valley (BR)	180.0		32
Lower Gunnison (USDA)	335.0		32
Moapa Valley (USDA)	19.2		35
Price-San Rafael Rivers (BR)	22.0		47
Mancos Valley (USDA)	8.8		56
Uinta Basin (USDA)	82.6	15.6	59
McElmo Creek (USDA)	38.0		67
Lower Virgin River (BR)	270.0		69
Uinta Basin Stage I (BR)	25.5		85
Dolores Project (BR)	23.4		89
Grand Valley Stage Two (BR)	120.3		93
Dirty Devil River (BR)	20.6		97
Sinbad Valley (BLM)	7.5		101
Glenwood-Dotsero Springs	287.0		109
Grand Valley Stage One (BR)	24.0	19.9	123
Lower Gunnison Stage I Balance (BR)	66.3		183
Grand Valley Stage Two Balance (BR)	23.2		297
Lower Gunnison N Fork (BR)			
San Juan River (BR)			
Uinta Basin Stage II (BR)			
Price-San Rafael Rivers (USDA)			
Big Sandy River (BR)			
PVID (BR/USDA)			

1/ Stage I
2/ Best estimates at this time
3/ Cost effectiveness based on 19,000 tons

United States Department of the Interior

IN REPLY REFER TO:

CO-933
4120

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
1037 20th STREET
DENVER, CO 80202

August 7, 1984

Instruction Memorandum No. CO-84-402
Expires: 9/30/85

To: District Managers

From: State Director, Colorado

Subject: Worksheet #3 - Rangeland Investment Ranking for FY '85 AWP

Forthcoming annual work plan directives will require completion of Worksheet #3. A blank and a sample copy are enclosed for your use. Completion of Worksheet #3 is in response to the Office of Management and Budget requirement that we prepare a special analysis of range investment.

We are sending you this information prior to AWP preparation so that you have enough time available to gather the required data for timely AWP submission.

Any questions should be addressed to Hans Hess (CO-933) at 844-3264 or FTS 564-3264.

Kannon Richard

Enclosures (2)

State *Arizona* Resource Area *Gila*

District *Safford* Preparer *Smith*

WORKSHEET #3

Rangeland Investment Ranking For FY AWP

Page *1*

Date Prepared *9-9-84*

INVESTMENT ANALYSIS — PROJECT WORK SCHEDULE

	Allotment	Mgmt. Cat.	B/C Ratio	IROR	RPS Rank	User Coop.	Dist. Adv. Bd. Rank	Area Mgr. AWP Rank	Dist. Mgr. Rank	PROJECT No.	PROJECT Name	CONSTR. UNITS No.	CONSTR. UNITS Type	Sub-Activity	Job Code	CONSTR. Type	Est. Costs BLM	Est. Costs Contr.	Comments
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Maint.	Logo	M				—	1	1		5012	Dible Pipeline	10	mi.	7120	4457	F		500	12 stocktanks on this pipeline
	#4520									2561	Study Excl. #1	1	ea	4322	4462	F	100		Range study comparison area
	Bruno									1210	Big Reservoir	1	ea.	4322	4457	C	200		Multiple use reservoir, used
	#4960					—	1	1						4350	5557		200		by lvst., waterfowl, and flood
														4340	5257		200		and sediment control.
2 Old Plans	Wabash	I	1.6/1	12.0	5	A	2	2		7501	Dunn Seeding	500	ac.	8100	4455	C	10,000		Tame spring pasture will
	#4600													4350	5355		5,000		allow deferred turn-out on native rng
3 New plans	Bryce	I	4.3/1	44.8	7	A	4	3		1600	Hot Spr. Catchment	1	ea	8100	4457	F	7,200	6,200	Materials contributed by permittee
	#4608									2019	B.P. Pipeline Ext.	1.7	mi.	8200	4452	C	9,000	1,700	labor contributed by permittee
	Whitetail	I	.5/1	-1.9	–	D	3	4		6011	Whitetail Pipeline	3.0	mi.	7120	4457	C		3,368	Contributions deposited
	# 5150									5018	Whitetail Tank	1	ea.	8100	4452	E	1,500		
4 Addit. Project Needs	Tollgate	I	1.4/1	11.2	10	A	6	5		6218	Yellowstone Pipeline	.4	mi.	8100	4457	F	1300		
	#5033									5020	Yellowstone Tank	1	ea.	8100	4457	E	3,720		
	Slickrock	I	.5/1	-2.3	11	0	5	6		5016	Sliderock Tank	1	ea.	8100	4457	E	3,500		SCS Ranch Plan
	#5113																		

Group Projects and separate with with a heavy horizontal line:

1. all maintenance projects
2. projects needed to fully implement a plan (column 6) already cleared for funding
3. projects needed to implement new plans
4. additional projects (25% above cost target) next in line for implementation should extra funds become available because of budget add ons, contract savings, etc.

Enclosure 2

State ______ Resource Area ______

District ______ Preparer ______

WORKSHEET #3

Rangeland Investment Ranking For FY AWP

Page ______

Date Prepared ______

INVESTMENT ANALYSIS									PROJECT WORK SCHEDULE									
									PROJECT		CONSTR. UNITS				CONSTR.			
																Est. Costs		
Allotment	Mgmt. Cat.	B/C Ratio	IROR	RPS Rank	User Coop.	Dist. Adv. Bd. Rank	Area Mgr. AWP Rank	Dist. Mgr. Rank	No.	Name	No.	Type	Sub-Activity	Job Code	Type	BLM	Contr.	Comments
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Group Projects and separate with with a heavy horizontal line:

1. all maintenance projects
2. projects needed to fully implement a plan (column 6) already cleared for funding
3. projects needed to implement new plans
4. additional projects (25% above cost target) next in line for implementation should extra fun... become available because of budget add ons, contract savings, etc.

Enclosure 1

Column	
1	Allotment name and/or number
2	Management category M = maintain I = improve C = custodial
3	Benefit/Cost ratio from Sageram
4	Internal Rate of Return from Sageram
5	Rangeland Program Summary rank
6	User cooperation A = allotment management plan H = habitat management plan C = cooperative management agreement R = coordinated resource mgt. plan D = development plan O = other (explain)
7	District Advisory Board Rank
8	Area Manager Annual Work Man Rank

Column	
9	District Manager Rank
10	Project number assigned
11	Project name (list all the projects planned for each allotment)
12	Number of units planned for construction
13	Type of units (primary) Ac = acres Mi = miles Ft = feet Ea = each
14	Subactivity (show more than one subactivity if project is jointly funded)
15	Job Code
16	Construction type C = contract F = force account R = range user O = other
17	BLM Cost (material, labor, equipment or contract costs)
18	Contributed Cost (material, labor, equipment or cash from permittee/lessee, State Fish and Game, etc.)
19	Briefly explain any B/C less than 1:1, project without a plan, etc.

EA # CO-030-U84-27

Elephant Skin Wash
Salinity Control Project

Decision/Record Rationale

I. Elephant Skin Wash Salinity Control Project

Proposed is the construction of a salinity control project to retain salt and sediment laden runoff, consequently preventing it from entering the Colorado River system. The project area is comprised of saline soils derived from marine shales and is located approximately 7 miles northeast of Montrose, Colorado.

II. Alternatives

A. Alternative I - Ponding Dike Project - Proposed Action (see page 17 of the attached Activity Plan).

B. Alternative II - Retention Pond Project (see page 17 of the attached Activity Plan).

C. Alternative III - No Action (see page 17 of the attached Activity Plan).

III. Decision and Rationale

A. Decision

Adopt the proposed action.

B. Rationale

1. The proposed project would be in compliance with several laws which are listed on page 17 of the attached Activity Plan.

2. The proposed project would reduce sediment and salinity in the Colorado River system. Secondary benefits would include: flood control, improved wildlife habitat, and seasonal water for livestock and wildlife. These benefits are discussed in more detail on page 3 of the attached activity plan.

C. Mitigation

No mitigation is necessary for the proposed project.

D. Compliance/Monitoring

Contract compliance would be handled by the UBRA Engineering Technician.

A monitoring plan is outlined on page 24 of the attached Activity Plan.

IV. Conclusion

Based on the analysis in the attached EA, I conclude that selecting the preferred alternative will not result in significant impacts to the environment, and therefore conclude an EIS is not necessary.

Area Manager ______ Date 7/16/84

District Manager ______ Date 7/19/84

WATERSHED ACTIVITY PLAN

ELEPHANT SKIN WASH

SALINITY CONTROL PROJECT

Date: August, 1983

Table of Contents

Table of Contents
(Continued)

June 1984

ADDENDUM

Due to unforeseen circumstances which arose during the field survey (May 1984) of the Elephant Skin Wash-Salinity Control Project, the following changes, to the original activity plan, were necessary:

1. The original cost estimate, for the project, was low - only sites #1, 2A and 2B will be constructed with the $29,747 as earmarked in the FY 84 AWP.

2. The starting date, for project construction, has been rescheduled for the spring of 1985. The funding, however, will be obligated before the end of FY 84.

3. Site-specific topographic conditions have resulted in the following project design modifications on site #1.

   - The maximum water depth behind the ponding dikes is being reduced from three feet to one foot.

   - Due to limited area suitable for dike construction, the total ponding volume is being reduced from approximately nine to five acre-feet (see Table 2).

   - The storage area behind the diversion dam will initially have a capacity of 4.3 acre-feet. The diversion dam will result in sediment reduction benefits, but no salinity control benefits.

   - For design changes on site #1, See Figure 1A. and compare with original design in Figure 4.

4. Due to limited area suitable for ponding dike construction, sites #2A and 2B have been designed to retain approximately four acre-feet, instead of the eight acre-feet originally proposed (see Table 2). The storage area behind the diversion dams will initially store a total of approximately three acre-feet which, like site #1, will provide sediment reduction benefits, but no salinity control benefits. Also, due to an oversight in the original project design, the freeboard (on sites 2A and 2B only) is being increased from one foot to three feet (see Figure 4).

5. Due to the above-noted changes, a revised benefit analysis is necessary.

<u>Revised Benefit Analysis</u>

<u>Assumptions</u>

1. $\overline{X}$ Annual Sediment Yield = 3-6 tons/acre (average = 4.5)

2. $\overline{X}$ Annual Salt Yield = 0.08-0.17 tons/acre (average = 0.13)

3. Salt Content = 3% of Sediment by Weight

4. One half of the $\bar{X}$ annual salt and sediment yield is retained by the proposed project.

5. Benefit of salinity reduction is equal to $56.66 per ton of salt (Water and Power Resource Service, 1980).

6. Benefit of sediment reduction is equal to $1 per ton of sediment.

7. Depreciation Rate/Opportunity Cost/Interest Rate = 0.078.

Computations

Cost of Project = $29,747

- Sediment Storage Capacity of Project

  Ponding Dikes = 9 acre-feet
  Diversion Dams = 7.3 acre-feet
  16.3 acre-feet of sediment storage

  16.3 acre-feet x 2069 tons/acre-foot = 33725 tons

- Total $\bar{X}$ Annual Sediment Yield
  4.5 tons/acre/year x 776 acres = 3492 tons/year

  One-half retained by project $\frac{3492}{2}$ = 1746 tons/year

- Project Life $\frac{\text{33725 ton capacity}}{\text{1746 tons/year}}$ = 19.3 or 19 years

- Salt content 3% x 9 acre-feet of sediment (salinity benefits only calculated from ponding dike sediments) = 0.27 acre-feet x 2069 tons/acre-foot = 558 tons of salt over 19 year project life.

- Total cost of Project amortized over 19 years = $58083
- Annual Cost of Project = $ 3057
- Total Benefits from Salt Reduction ($56.66 x 558 tons) = $31616
- Annual Benefits from Salt Reduction = $ 1664
- Total Benefits from Sediment Reduction ($1 x 33725) = $33725
- Annual Benefits from Sediment Reduction = $ 1775
- Total Annual Benefits (Salt and Sediment) = $ 3439

  B1//C2/ Ratio = $\frac{\$3439}{\$3057}$ = 1.12

  1/ Does not include additional benefits as described under section I.D. of the Activity Plan.

  2/ Maintenance costs not included.

- Cost Effectiveness

  Total Project Cost (FY 84) = 29,747 = $53.31/ton of salt
  Tons of Salt Retained = 588

COMPUTATION SHEET

BY TBAIRD DATE MAY84 PROJECT ELEPHANT SKIN-WASH SHEET NO. 1 OF

CHKD. BY ____ DATE ____ FEATURE DIKE DESIGN ACTIVITY 4340

OFFICE MTJ DO DETAIL No Scale

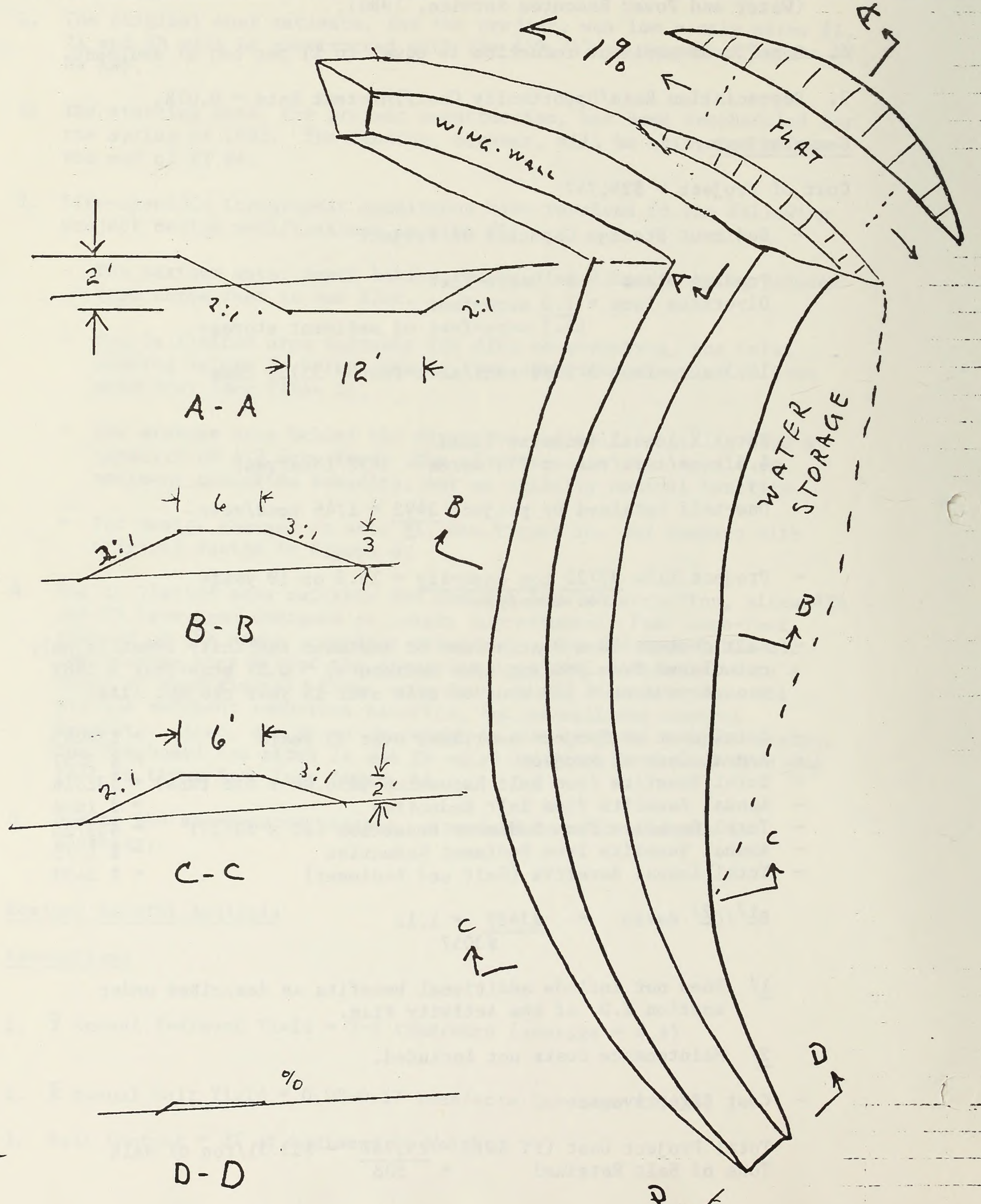


Fig. 1A

I. Overview

A. Introduction

The Agreement between the United States and Mexico in 1973 and the Clean Water Act of 1977 provide direction to reduce salinity in the Colorado River Basin. The BLM, as a major landowner in the river basin, is charged with helping to obtain this goal.

The Montrose BLM District contains several salinity source areas, one of which is the "adobes" northeast of the City of Montrose. This area is characterized by sandstone-capped, deeply incised shale badlands. The badlands are comprised of weathered shales, generally unvegetated, with surface soils high in salts. Rilling is the major erosion process on shale badlands. The alluvial bottomlands usually have well developed gully systems. They generally occur at the base of badlands or in valleys between badland hills and ridges. Runoff is generally high from both badlands and shale-derived alluvial soils.

The Montrose District has selected Elephant Skin Wash, a 3.70 square mile watershed located 5 miles northeast of Montrose, Colorado (Figure 1), for salinity control work. This watershed is representative of much of the Mancos Shale derived landscape extending from Orchard Corner northwest to the North Fork Gunnison River. This area is a substantial sediment and salt contributor within the District.

B. Background

Elephant Skin Wash - formerly referred to as Watershed IB - was originally identified, by the BLM, as a potential salinity control project site in 1983 (USDI, 1983). The report suggested that watershed treatments could be implemented to reduce saline runoff, help promote continued recovery of the bottomland gully system, and possibly provide some increased forage for livestock, and cover and food for wildlife. The Brush Point Allotment Managemant Plan #5008 (USDI, 1981) noted a need for a more reliable water source for livestock in the project basin. While Elephant Skin Wash is ungaged, local observers have identified several occasions where peak flows from the basin have caused downstream flooding of agricultural land and damage to an irrigation canal.

C. Objectives

The objectives of this project are to:

1. Reduce sediment and salt yields in the Upper Colorado River Basin.

2. Decrease downstream peak flows (flood control).

3. Provide seasonal water for livestock and wildlife.

4. Increase vegetation production and available forage for both livestock and wildlife.

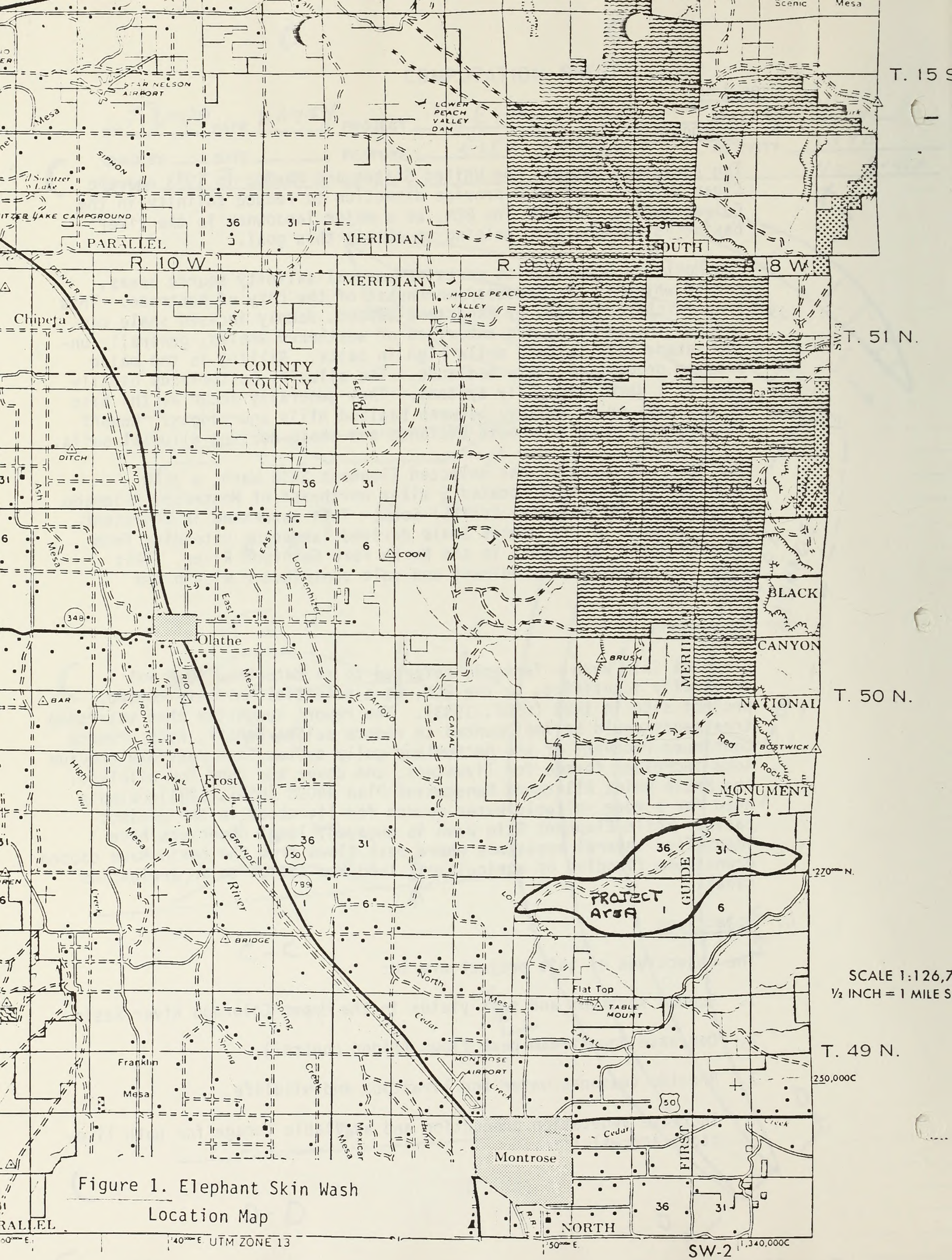


Figure 1. Elephant Skin Wash Location Map

5. Improve habitat (cover) for wildlife.

D. Benefits

The proposed project would produce several benefits. The primary benefit would be the reduction of sediment and salt yields. Assuming that one-half of the total salt and sediment yield would be retained in Elephant Skin Wash, this would amount to 103,450 tons of sediment and 3,100 tons of salt over the 20 year project life. The ratio of annual benefits to costs from reduced sediment and salt yields is 2.8 (also see Section VI. - Benefit Analysis).

Some portion of runoff from flood events would be retained by the proposed project. This would result in diminished flood peaks downstream. Other benefits would include: an increase in vegetation and improved habitat (cover) for wildlife on approximately 50 acres, and better livestock and wildlife distribution resulting from seasonal water produced from the proposed project.

II. Project Area Description

A. Location

Elephant Skin Wash is located in the Uncompahgre River Drainage, which is part of the Upper Colorado River Basin (see Figure 2). More specifically, Elephant Skin Wash is in Montrose County, Colorado and is described by the following legal description:

N.M.P.M., T.49N., R.9W., Sections 1, 2, 3 (Part)
N.M.P.M., T.50N., R.9W., Sections 35, 36 (Part)
N.M.P.M., T.50N., R.8W., Sections 31, 32 (Part)
N.M.P.M., T.49N., R.8W., Section 6 (Part)

B. Physical Characteristics

1. Climate

The climate is semi-arid with annual precipitation ranging from 9 to 12 inches. August is the month of heaviest precipitation with most coming from violent convective thunderstorms. May and June are extremely dry. The area has an average annual temperature of 49 degrees F and averages 144 frost-free days.

2. Geology and Topography

The geology of the area is dominated by Mancos Shale. Mancos shale is a marine derived shale of Cretaceous age. The formations consist of grey shales, with some limestone beds. On steeper slopes the shale is either just a few inches below the surface or exposed. Bedrock can be as deep as 5,000 feet. The terrain consists of rough and broken successions of rolling to very steep, nearly barren slopes on southern exposures within a fairly steep-walled box canyon.

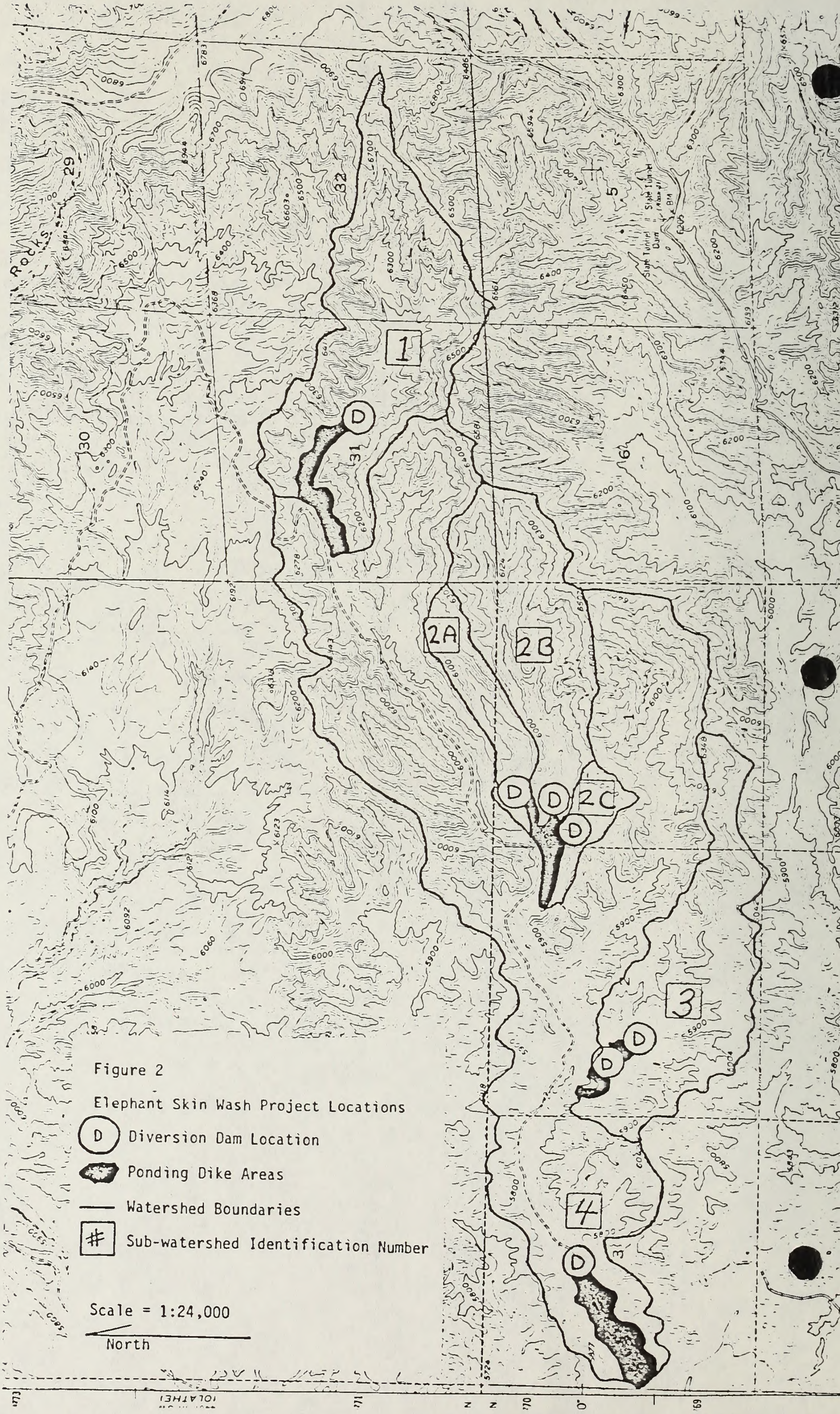


Figure 2

Elephant Skin Wash Project Locations

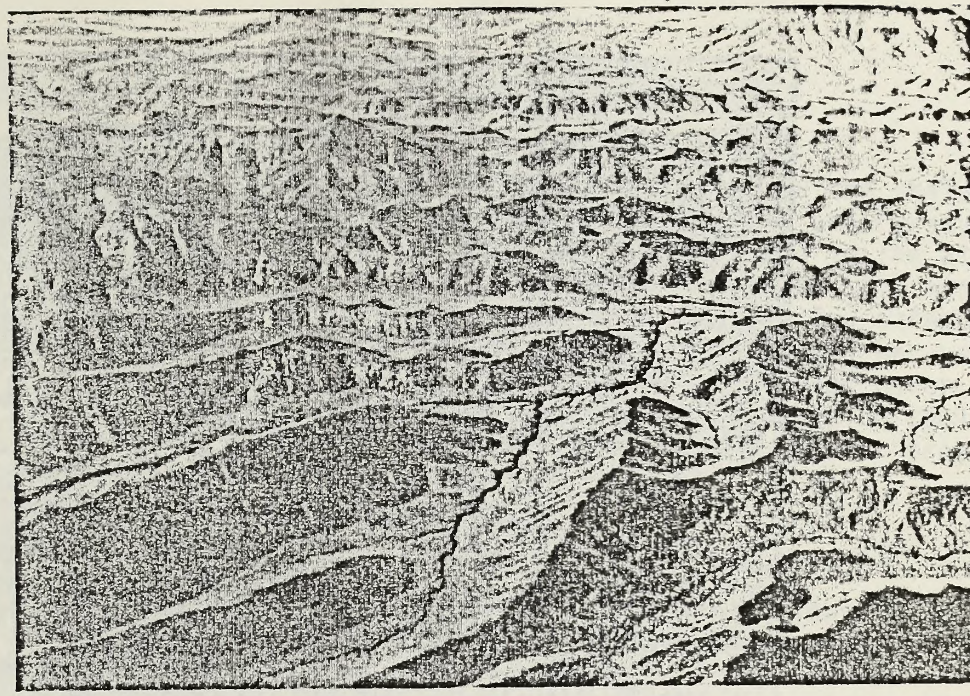


Photo. 1- Aerial view of project site locations 2A,B,C
(also see figure 2).

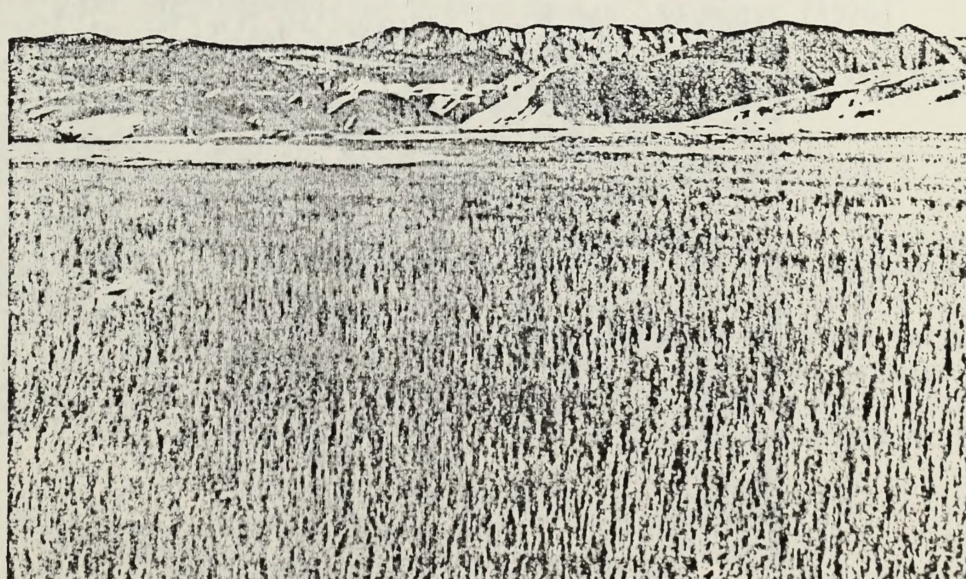


Photo. 2- Looking upstream from project site location 4 (also see
figure 2).

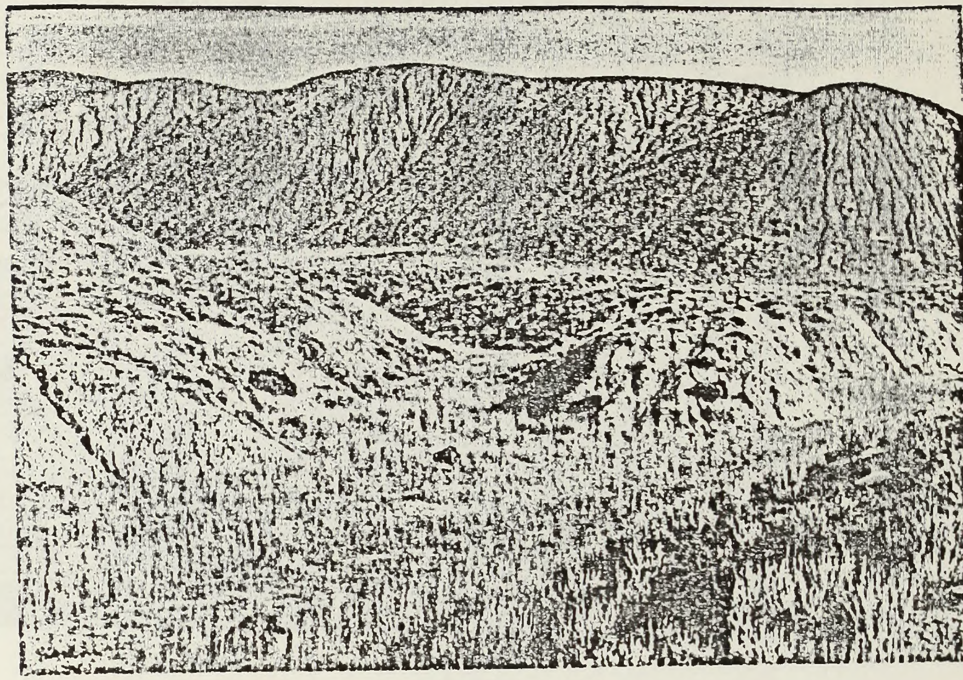


Photo. 3- Increased vegetation in sediment wedge behind an abandoned retention structure.

Photo. 4- Debri deposited by past flooding at the mouth of Elephant Skin Wash.

3. Soils

The soils of the basin are largely undeveloped on the shale uplands, except for inclusions of shallow, clayey Chipeta and Persayo soils on north slopes. Billings silty clay loam formed in the alluvium of the drainage floodplains. This deep, well drained soil has moderate limitations for building dikes due to piping and low strength when wet. Erosion is severe (4-6 tons per acre per year) because of the nature of the soils and the sparseness of vegetation cover. Mass erosion and rilling are the major erosion processes on shale badlands. Gully, rill, and interrill are the predominant erosion processes on the alluvial bottomland.

4. Water Resources

Elephant Skin Wash is an ephemeral stream that flows in response to snowmelt and rainfall events. The wash drains westward into the Loutsenhizer Canal, and eventually into the Uncompahgre River. The watershed relief is approximately 1,356 feet with maximum and minimum elevations of 7,076 and 5,720 feet, respectively. Water quality is poor, due largely to saline sediment (3-6 tons/acre/year) derived from sheet, rill, and gully erosion. Ground water, if present, is only in the alluvium, in very small quantities, and of very poor quality.

C. Land Use, Recreation, Aesthetics

The area is grazed by sheep. Recreational activities include limited chukar and dove hunting, ORV use, and possibly firearm target practice. Elephant Skin Wash is a VRM Class IV area, the least restrictive class.

For a more detailed description of past and present land uses refer to the Brush Point Allotment Management Plan #5008 and the Uncompahgre Basin Resource Area Grazing Environmental Statement (1978).

The proposed project would result in no conflicts with the Gunnison Gorge-Management Framework Plan, 1970.

D. Description of Existing Hydrologic and Edaphic Conditions

The present hydrologic condition of Elephant Skin Wash is characterized by sparse watershed cover (5-15 percent), a naturally high erosion rate and sediment yield, low infiltration capacities ($\leq$ 0.5 inch per hour), and a high drainage density. As a result of these factors and other physiographic features, the percent of the total precipitation subsequently resulting in overland flow is extremely high. Table 1 presents estimated rainfall/runoff relationships for Elephant Skin Wash.

TABLE 1

Rainfall/Runoff Relationships
for Elephant Skin Wash, Colorado

Return Period Years	6-Hour Design Storm			24-Hour Design Storm		
	Precip.* Inches	Peak Flow Ft^3/Sec.	Runoff Acre-Ft.	Precip.* Inches	Peak Flow Ft^3/Sec.	Runoff Acre-Ft.
2	0.8	95	25	1.0	85	45
5	1.0	178	45	1.5	240	105
10	1.2	283	67	1.7	312	134
25	1.5	475	105	2.2	508	210
50	1.6	545	106	2.4	590	243

*Precipitation data obtained from NOAA Atlas.

The soils of the basin are classified as moderately saline. The salt content of the soil is believed to be approximately three percent by weight. Applying this salt content to the estimated average sediment yield (3-6 tons/acre/year) results in an average annual salt yield between 0.08-0.17 tons per acre or 200-400 tons from the Elephant Skin Wash watershed.

III. Project Identification

A. Project Description

The proposed project would consist of a series of diversion dams, each with a system of ponding dikes. These structures would serve to divert and retain the most salt and sediment laden runoff being discharged from Elephant Skin Wash. The project is designed to capture and pond the discharge from all surface runoff events equal to or less than that produced from the 2 year-24 hour storm. Most of the discharge from larger flood events would by-pass the ponding dikes by being routed over an emergency spillway or weir on the diversion dam (see Figure 3). Studies conducted in the Price River Basin, Utah, found that the highest salt and sediment concentrations occurred in the first surface runoff event following long periods of no runoff. The water captured by the project would eventually infiltrate and/or evaporate making room for the next surface runoff event. In most of the area flooded by the ponding dikes (approximately 50 acres), an increase in vegetation can be expected. This would also increase the infiltration rate on these areas. Some factors affecting ponding dike construction, layout and spacing are water ponding depth, land slope, soil type and topography.

The ponding dike systems are spread throughout Elephant Skin Wash to allow benefits such as increased forage, wildlife habitat, and livestock and wildlife drinking water to be better utilized. In addition, by retaining some of the surface runoff in upper parts of the watershed, potential flash flood damage to the lower project site would be minimized.

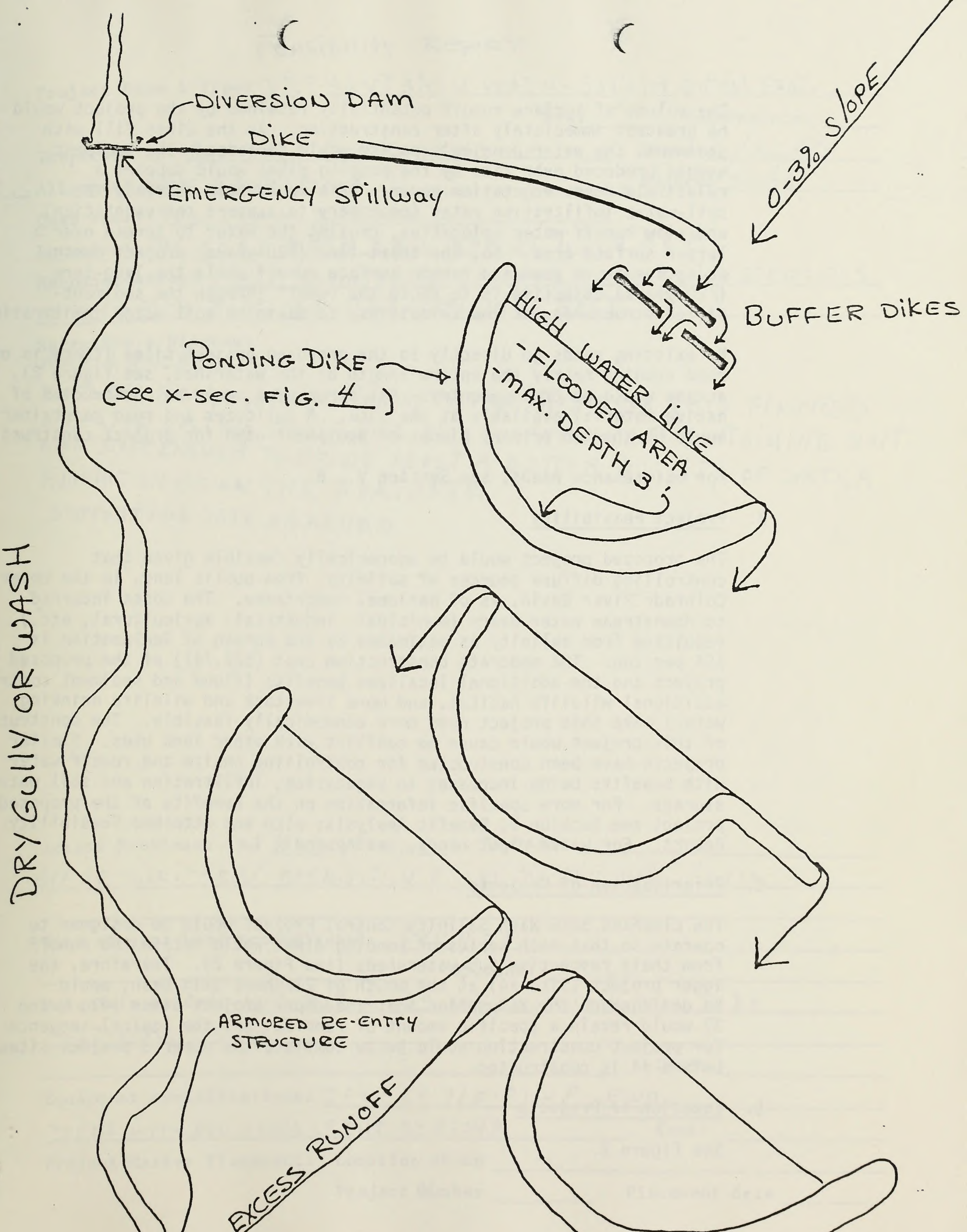


FIG. 3
- DIAGRAM OF TYPICAL PONDING DIKE SYSTEM

The volume of surface runoff potentially retained by the project would be greatest immediately after construction. As the dikes fill with sediment, the water ponding capacity would decrease. The sediment wedges produced over time by the ponding dikes would support a relatively dense vegetation cover. This would help increase the soil-water infiltration rates (necessary to support the vegetation) and slow runoff water velocities, causing the water to spread over a larger surface area. So, the short-term ($\leq$20 years) project design objective is to pond and retain surface runoff while the long-term ($>$20 years) objective is to route the runoff through the sediment-filled structures, at low velocities, to maximize soil-water infiltration.

No existing roads go directly to the proposed project sites (there is one road running nearly the entire length of the watershed, see figure 2), so access would be cross-country. All structures would be constructed of native material available at the site. A bulldozer and road maintainer would be the two primary pieces of equipment used for project construction.

For maintenance needs, see Section V., B.

B. Project Feasibility

The proposed project would be economically feasible given that controlling diffuse sources of salinity, from public land, in the Upper Colorado River Basin, is of National importance. The costs incurred to downstream water users (municipal, industrial, agricultural, etc.) resulting from salinity as estimated by the Bureau of Reclamation is $54 per ton. The moderate construction cost ($29,747) of the proposed project and the additional localized benefits (flood and sediment control, additional wildlife habitat, and more livestock and wildlife drinking water) make this project even more economically feasible. The construction of this project would cause no conflict with other land uses. Similar projects have been constructed for controlling onsite and runoff water with benefits being increases in vegetation, infiltration and soil water storage. For more specific information on the benefits of the proposed project see Section V, Benefit Analysis; also see attached Feasibility Report. For water right needs, see Appendix I.

C. Prioritzation of Projects

The Elephant Skin Wash Salinity Control Project would be designed to operate so that each series of ponding dikes would retain the runoff from their respective sub-watersheds (see Figure 2). Therefore, the lower project (Site #4) at the mouth of Elephant Skin Wash, would be designed on the assumption that the upper project sites (#1, 2 and 3) would retain a specific amount of runoff. So, the logical sequence for project construction would be to complete the upper 3 project sites before #4 is constructed.

D. Location of Projects

See Figure 2.

FEASIBILITY REPORT

Project Name & Type: ELEPHANTSKIN WASH - SALINITY CONTROL PROJ.

New: ✓ Maintenance: ____

Inspected by: [illegible] Date: 2/23/84

Allotment Name: BRUSH POINT Number: 5008

Quad Name: RED ROCK CANYON

Location: SEC 1, 2 & 3 T. 49N R 9 W. SEC. 31 T. 50N R 8 W

Recomendation: BUILD SALINITY SPREADERS & DIVERSION STRUCTURES TO HOLD BACK SURFACE RUNOFF CONTAINING SALT

Narrative & Diagram:

MAP ATTACHED.

DUE TO THE HEAVY CONSENTRATION OF SALT IN THIS AREA THIS PLANNED SPREADER SYSTEM SHOULD HOLD BACK SURFACE RUNOFF CONTAINING SALT AND SILT ENOUGH TO BRING ABOUT A BETTER QUALITY OF WATER RUNNING ON DOWN THE DRAINAGE.

SUPPORTING DATA ATTACHED

Access Problems: No X Yes ____ Explain: ____

HAVE WRITTEN PERMISSION FROM [illegible] WILLIAMS

Time of year best accomplished: SUMMER

Options: FALL

Materials needed: ANY MATERIALS NOT KNOWN NOW PLAN TO BE CONTRACTOR FURNISHED

Cost: ____

Equipment specifications: GRADER 115 F.W.HP FWD DOZER WITH HYD. ANGLE OR TILT 95 F.W.HP

Cost: ____

Project Marker Placement: Location shown ____

Project number ____ Placement date ____

E. Number and Kind of Projects

The Elephant Skin Wash Salinity Control Project would consist of approximately seven diversion dams (on four project sites), each with a corresponding series of ponding dikes (see Figure 2). The diversion dams would be designed to divert part of the surface runoff out of the original stream channel and onto the adjacent alluvial land where the water would be intercepted by the ponding dikes. An emergency spillway would be constructed on each diversion dam to carry any excess flow.

A site-specific survey would be necessary before the exact number of ponding dikes needed can be determined. The dikes would be designed and constructed to contain an average water depth of one foot when filled to capacity.

On some of the steeper alluvial areas, buffer dikes (non-ponding dikes) may be necessary to divert water to the ponding dikes. Buffer dikes may also be needed to diminish the velocity of the diverted water, preventing rill or gully erosion. On each site, downslope from the last ponding dike, a re-entry site would be constructed to allow any excess diverted water to flow back into the original stream channel.

F. Project Design

The following description of the project design is to provide BLM engineers and technicians with specific guidance, for surveying and constructing the project, so benefits would be maximized from salinity control and other objectives listed under Section I., C.

To survey and construct each series of ponding dikes, a hydrologic analysis is necessary to calculate the estimated runoff volumes and peak flows. The runoff volume, produced from each subwatershed (see Table 2), would determine the amount of acreage that would need to be flooded with each series of ponding dikes. The ponding dikes would be designed to retain water at an average depth of one foot when filled to capacity (see Figure 3). Therefore, for every acre-foot of runoff produced from the 2-year/24-hour storm one acre would need to be flooded.

The peak flow would be used by the engineers to properly size the emergency and re-entry spillways associated with each series of ponding dikes (see Figure 3).

1. Hydrologic Analysis

The SCS procedure (Soil Conservation Service, National Engineering Handbook, Chapter IV) was used to estimate watershed parameters necessary to calculate the runoff and peak flow for both the 2 and 25-year/24-hour storms in Elephant Skin Wash. A curve number of 87 was selected based on vegetation type, hydrologic soil group, hydrologic condition, and antecedent moisture condition (AMC).

A computer program available on the BLM Honeywell 66/80 Computer was used to calculate peak flows and runoff volumes for each sub-watershed proposed for treatment. The results of the design storm-runoff analysis are contained in Table 2 (for precipitation totals, see Table 1, Existing Hydrologic Condition).

TABLE 2

Runoff Analysis for Subwatersheds in Elephant Skin Wash, Colorado

Watershed Subwatershed*	Acres	2-Year/24-Hour Storm Runoff(Ac/Ft**)	2-Year/24-Hour Storm Peak Flow(Ft^3/Sec)	25-Year/24-Hour Storm Runoff(Ac/Ft)	25-Year/24-Hour Storm Peak Flow(Ft^3/Sec)
# 1	430	9	21	38	107
# 2A	90	2	5	8	23
# 2B	256	6	13	23	65
# 2C	51	1	3	5	14
# 3	281	7	14	25	71
# 4	1,261	25	52	112	288

* See Figure 2 for subwatershed locations.

** These values also represent the acreage that must be ponded, at an average depth of 1-foot, by each dike system.

2. Project Survey and Construction

As shown in Figure 3, the diversion dams will be designed to deliver water to a series of ponding dikes. Overflow water - anything in excess of the 2-year/24-hour storm runoff - would be discharged back into the original stream channel via the emergency spillway, on the diversion dam, or through a re-entry structure located below the lowermost ponding dike. Since the topography at each site is different, the specific ponding dike system design may vary somewhat from Figure 3. For the construction sequence of the proposed projects see Section III, Prioritization of Projects.

The construction costs for the diversion dams can be minimized by building the structure at a narrow and shallow point in the drainage, to reduce the size of the dam. The diversion dams would be keyed into the channel banks and the borrow material compacted and possibly wetted, depending on the natural soil-moisture content at the time of construction. Each diversion dam would have an emergency spillway with a cross-sectional area and slope that would safely pass the peak discharge of the 25-year/24-hour storm (see Table 2) with a two-foot minimum freeboard. Each emergency spillway would be designed to prevent the peak discharge water velocity from exceeding three feet per second which is the maximum safe velocity for water transporting fine silts on a silt loam.

In order to prevent debris dams from forming and diverting water in an unwanted direction, wire mesh would be strategically placed within the dike system to capture debris. Buffer dikes may also be needed to divert or slow the velocity of water flowing through the dike system (see Figure 3).

The ponding dikes would be designed to form a crescent or horseshoe shape with water spilling around either or both ends (see Figure 3). The length of each dike would be varied to best fit each site; however, individual dikes should not exceed 1,000-1,500 feet in length, because the flow for larger dikes becomes increasingly large and difficult to control. Sharp curves in the ponding dikes should also be avoided to minimize erosion. All vegetation should be removed and the area scarified before the fill is started. Fill material should come from the downslope side of the dike (see Figure 4), which allows more widespread use of the moisture from small precipitation events. Each system of ponding dikes, as shown in Figure 3, would be designed to fully retain the runoff produced from the 2-year/24-hour storm and safely pass excess runoff from the 25-year/24-hour storm (see Table 2). To effectively accomplish this, the velocity of water being routed through the dike system should never exceed three feet per second (buffer dikes may be necessary to reduce velocities). Ponding dikes would be progressively constructed in a downstream direction until the ponding area, necessary to retain the runoff from the 2-year/24-hour storm, is achieved. The maximum ponding depth in the dikes should not exceed three feet, which would produce an average depth of one foot. Weep pipes may be necessary to aid in the transmission of water through the dike system.

Excess water routed through the dike system would need to be returned to the original stream channel with the minimum of cutting. The excess water would drop most of its suspended solids within the dike system, resulting in clearer water with higher erosivity. Therefore, the maximum velocity of water flowing from the lowermost ponding dike to the re-entry point of the original stream channel should not exceed two feet per second (maximum safe velocity of clear water on silt loam) without the use of mechanical structures (gabions, riprap, etc.). The water carrying capacity of the re-entry site would be designed to handle the excess runoff produced from the 25-year/24-hour storm minus the amount passed through the emergency spillway on the diversion dam.

G. Consultation/Coordination

1. USDA - Soil Conservation Service
2. County Commissioners, Montrose County, Colorado
3. Colorado State Water Engineers Office
4. Uncompahgre Valley Water Users Association
5. Environmental Protection Agency
6. USDI - Bureau of Reclamation
7. Colorado Division of Wildlife

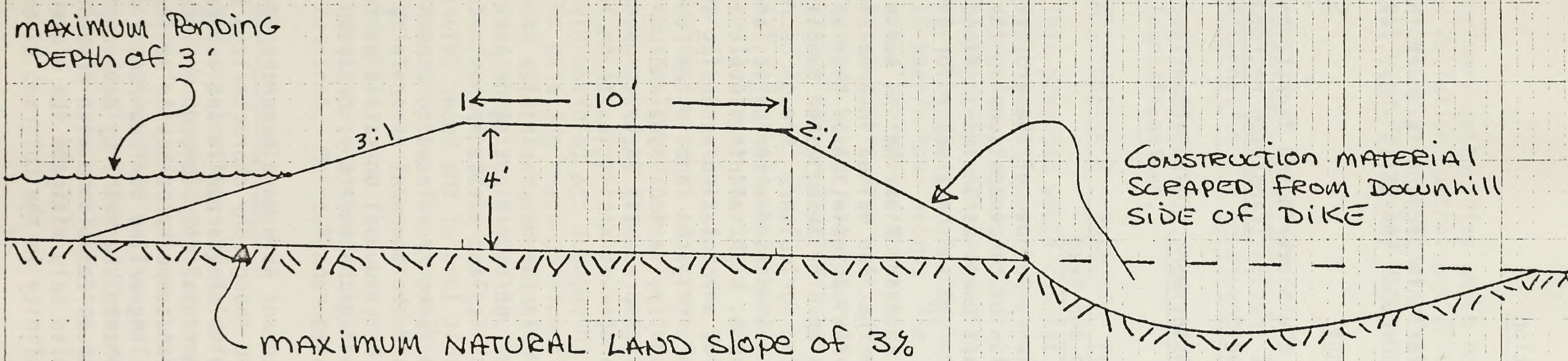


FIG. 4 - TYPICAL CROSS-SECTION OF PONDING DIKE

IV. Project Implementation

A. Funding

Total funding for this project is under the 4340 (water, soil and air) program (CO-030. PP4-32(1) - $29,747, 4340-5257).

B. Project Clearance

Clearances for the black-footed ferret, cultural resources, and sensitive plant species (Penstemon retrorsus) would be needed before project construction.

C. Environmental Assessment (CO-030-U84-27)

1. Chapter 1

a. Purpose and Need

The primary purpose of the proposed action is to reduce sediment and salinity concentrations in the Colorado River system. Secondary purposes include: flood control, improved wildlife habitat, and seasonal water for livestock and wildlife.

In the Colorado River Basin, salinity is a major water quality problem that has gained international prominence in United States-Mexican relations. High salinity levels have detrimental impacts upon drinking water supplies, industrial users, and impact irrigated agriculture through decreased crop yields, altered cro patters, increased water usage, and increased management costs. As of 1980, high salinity levels adversely affected the water supply of a population exceeding 10 million people and over 1 milli acres of irrigated land in the Lower Colorado River Basin. Consequently, various laws and United States Government directives presently instruct government agencies involved in land management activities to implement programs to reduce salt levels throughout the Colorado River Basin.

The BLM has the responsibility of controlling salt from diffuse surface runoff originating on public land. Surface runoff from public land yields approximately eight percent of the total salt load of the Upper Colorado River Basin. This salt load is directly related to content and availability of salt in soils and the movement of soils by erosion. Therefore, salt yields are reduced, on saline surface soils, through any activity which leads to increased infiltration and reduced or controlled runoff.

The Elephant Skin Wash watershed is comprised of saline soils with the topography characterized by deeply incised badlands. Areas with similar soils and topography have been shown to yield more salinity through erosion and runoff processes than other landscape types having saline soils. Therefore, controlling saline surface runoff and increasing infiltration in Elephant Skin Wash, by constructing the proposed project, would be in compliance with present laws and directives. It would also help mitigate the present water quality problem of high salinity in the Colorado River Basin.

The primary authorities which address salinity are the Federal Water Pollution Control Act (P.L. 92-500), the Colorado River Basin Salinity Control Act of 1974 (P.L. 93-320) and the Federal Land Policy and Management Act of 1976 (P.L. 94-579).

2. Chapter 2

a. Description of the Alternatives Including the Proposed Action

1) Alternative 1 - Ponding Dike Project - Proposed Action

See Section II, A, "Location" and Section III "Project Identification".

2) Alternative 2 - Retention Pond Project

This proposal would consist of the construction of one large retention structure and approximately 10 smaller retention plugs in a 250 acre headwater tributary to Elephant Skin Wash (see Figure 5). These structures would be designed to completely retain the runoff from the 10-year/6-hour storm. The 10 small retention plugs would be located to capture the most salt and sediment laden runoff from within the watershed. This would provide better water for livestock and wildlife and extend the project life of the large retention structure.

All structures would be constructed of native material available at the site. A bulldozer would be used on the small structures and for pioneering the medium sized retention pond. A scraper would be used for completion of the larger dam. The large retention structure would not exceed 15 feet in height nor exceed 10 acre-feet capacity.

No existing roads go directly to the work areas (there is one maintained road running nearly the entire length of the watershed, see Figure 2), so access would be cross-country. No roads would be built.

The structures would require periodic maintenance. Maintenance intervals would vary depending on size, intensity, and frequency of storm. Structures would be sized to minimize the frequency of maintenance required. Maintenance needs would need to be monitored.

3) No Action Alternative

Not constructing any Salinity Control Project in Elephant Skin Wash would not have any short-term adverse impacts associated with construction activities. Large amounts of sediment and salt would continue to runoff the area, no additional forage, cover, or water would be produced for livestock or wildlife, and flood control benefits would not result.

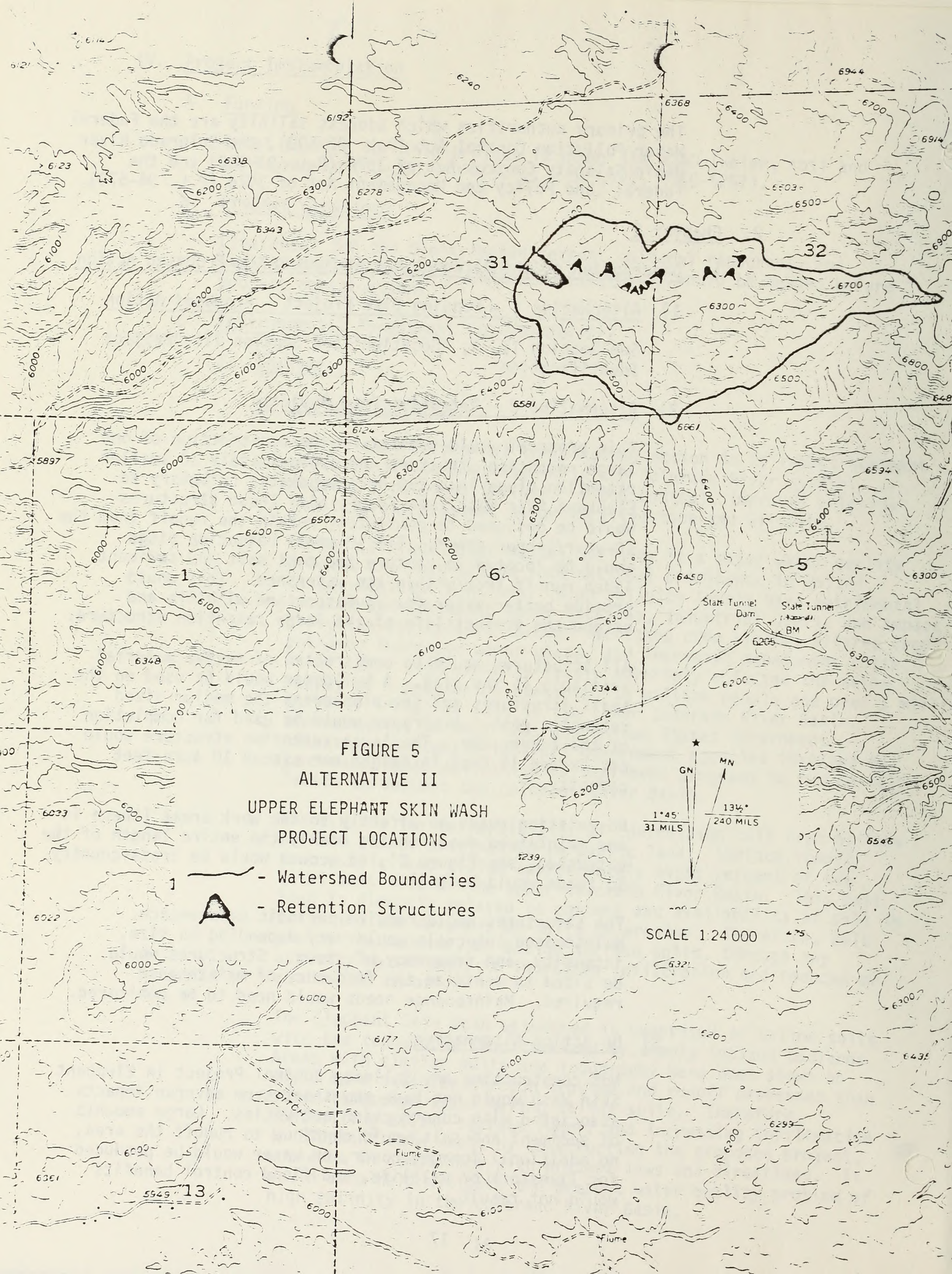


FIGURE 5
ALTERNATIVE II
UPPER ELEPHANT SKIN WASH
PROJECT LOCATIONS

3. Chapter 3 - Affected Environment

For a description of the areas land uses, recreation, aesthetics, climate, geology/topography, soils, and water see the Watershed Activity Plan, Section II, Project Area Description.

a. Vegetation

The project area is a saltbush type with key species being Galleta grass and shadscale saltbush. Other species present include mat saltbush, salina wildrye, greasewood and cheatgrass. Range condition is poor. An endangered plant, Penstemon retrorsus, occurs within the area. It is found where there is a relatively high amount of moisture, usually on north exposures or in drainage areas that slope away from hills onto nearly level areas. Before any construction work begins the area would be cleared to assure this plant would not be impacted.

b. Animal Life

There are prairie dogs, rabbits, raptors, dove, and chukar in the area. This area receives some noncrucial winter deer and elk use.

Sheep graze the project area alternately during the winter or one month in spring with one year rest. There are 29 AUMs licensed use. Because prairie dogs are found within the area potential exists for the presence of the black-footed ferret. The area, therefore, would need to be cleared before any construction activity could be authorized.

c. Cultural and Paleontological Resources

The likelihood of finding cultural resources is small, however, a cultural clearance would still need to be conducted before construction of the plugs or dam.

4. Chapter 4 - Environmental Consequences

a. Proposed Action

1) Climate, Air Quality, Geology, Topography, Minerals, Cultural Features, Paleonotology, Socioeconomics, Land Use, Wilderness and Prime, Unique Farmlands, Areas of Critical Environmental Concern, Wild and Scenic Rivers, or Floodplains and Wetlands

No significant impacts.

2) Soils

Initial disturbance due to construction would cause a short-term increase in erosion. This should return to pre-construction levels or below as vegetation reestablishes.

3) Water

The construction of the proposed ponding dike systems would result in a short and long-term decrease in the sediment yield. Sediment laden water presently flowing out of the watershed would be diverted and stored behind the ponding dikes. Over the estimated 20-year storage life of the project, approximately 103,450 tons of sediment would be deposited. Diverting water out of the presently eroding gullies would also diminish the sediment yield, in addition to allowing the gullies to stabilize.

The amount of salt retained in Elephant Skin Wash would be approximately three percent of the sediment deposited, or 3,100 tons over the 20-year storage life of the project. Beyond the 20-years, additional salt would be retained as the diverted flows are spread over the sediment wedges, produced behind the ponding dikes, and allowed to infiltrate into the soil.

By diverting and retaining water in Elephant Skin Wash, downstream flood control benefits would be realized.

4) Recreation

If improved wildlife habitat increases small game populations there may be an increase in hunting and related activities.

5) Vegetation

The construction activities would cause a localized, short-term disturbance to vegetation. The area of disturbance would be limited to less than five percent of the watershed. In the long-term, vegetation increases can be expected within the ponding dike systems as a result of sediment deposition and a higher soil-moisture content. Including the areas behind the diversion dams, approximately 50 acres should experience increases in vegetation cover.

Penstemon retrorsus may be present in the project area. No construction activities would occur in areas where this plant is found.

6) Animal Life

Wildlife would be adversely affected by construction in the short-term. Following construction increased water, forage, and cover would benefit wildlife and sheep in the area.

7) Aesthetics (VRM)

The work site is a Class IV area. The diversion dams and ponding dikes would have a slight to moderate visual impact, especially right after construction. This impact would be lessened as vegetation reestablishes on the structures.

8) Unavoidable Adverse Environmental Impacts

There would be short-term increases in erosion and disturbance to animals in the area. Plants would temporarily be eliminated from the immediate construction sites, and there would be a change in the visual character of the area.

9) Relationship Between Short-Term Use and Long-Range Productivity

The area is currently being used for winter and spring grazing. Treating it would enhance grazing by supplying additional water for vegetation and animals. Additionally, treatment would help prevent soil loss, thus aiding long-term vegetation production. Reduced salt and sediment loading in the Upper Colorado River Basin enhances water use opportunities downstream.

10) Irreversible or Irretrievable Commitment of Resources

Water formerly running off this area would no longer be available to downstream users in the Colorado River Basin. Removing the diversion dams could reverse this for future years, however.

11) Cumulative Impacts

There would be no cumulative impacts from the proposed action.

b. Alternative II

1) Climate, Air Quality, Geology, Topography, Minerals, Cultural Features, Paleontology, Recreation Resources, Socioeconomics, Land Use, Wilderness and Prime, Unique Farmlands, Areas of Critical Environmental Concern, Wild and Scenic Rivers, or Floodplains and Wetlands

No significant impacts.

2) Soils

Same as proposed action but to a lesser degree.

3) Water

The construction of the 10 small and one large retention structures would result in a decrease of the sediment yield over the 20-year average project life. Approximately 26,000 tons of sediment would be deposited. Ponding the runoff from all precipitation events equal to or less than the 10-year/6-hour storm (8 acre-feet of runoff) would help stabilize the presently eroding gullies.

Approximately 780 tons of salt would be retained, over 20 years, under this proposal.

Some downstream flood control benefits would be realized.

Ponding of water may recharge the alluvial groundwater system, if present.

4) Vegetation

The construction activities would cause a localized, short-term disturbance to vegetation. The area of disturbance would be less than one percent of the Elephant Skin Wash Watershed. As the retention structures fill with sediment and collect additional soil-moisture, vegetation increases on 5-10 acres can be expected.

Penstemon retrorsus may be present in the project area. No construction activities would occur in areas where this plant is found.

5) Animal Life

Same as proposed action, but to a lesser degree.

6) Aesthetics (VRM)

Same as proposed action, but to a lesser degree.

7) Unavoidable Adverse Environmental Impacts

Same as proposed action.

8) Irreversible or Irretrievable Commitment of Resources

Same as proposed action.

9) Relationship Between Short-Term Use and Long-Range Productivity

Same as proposed action, but to a lesser degree.

10) Cumulative Impacts

Same as proposed action.

c. No Action Alternative

No environmental impacts from construction activity would occur from the No Action Alternative. High intensity storms on this poorly vegetated, saline area would continue to produce large amounts of sediment and salt, and potential flood damage downstream. Use of the area by sheep and wildlife would remain very marginal.

5. Chapter 5 - Mitigating Measures and Residual Impacts

None of the alternatives need mitigating measures nor would they result in residual impacts.

6. Chapter 6 - Consulation and Coordination

See Watershed Activity Plan Secion 3,G, Consultation/Coordination.

7. Chapter 7 - List of Preparers

Prepared by:

Signature	Date	Title
Dennis M. Murphy	4-9-84	UBRA - Hydrologist

Reviewed by:

Signature	Date	Title
Thomas E. Jacobs	4-9-84	Range Conservationist
[illegible]	4-9-84	Wildlife Biologist
[illegible]	9 Apr 84	Engineer
[illegible]	Apr 16 84	Landscape Architect
[illegible]	4/9/84	Economist
[illegible]	9 Mar 84	Environmental Coordinator 17 July DO.
William [illegible]	4-9-84	Soil Scientist
Frank [illegible]	4-9-84	Archeologist
H. Rebecca Martin	4/9/84	Realty Specialist
[illegible]	5/17/84	Wilderness Coordinator - Recreation Planner

D. Assistance from Other Disciplines

The Montrose District Engineer and the Uncompahgre Basin Resource Area Engineering Technician are responsible for the project feasibility, project survey, contract preparation, and contract administration.

The Montrose District Soil Scientist would assist the Uncompahgre Basin Resource Area Hydrologist in monitoring the salt content of sediment deposits and control areas.

The Montrose District Cultural Resource Specialist would perform an archeological clearance prior to project construction.

The Uncompahgre Basin Resource Area Wildlife Biologist would perform a sensitive plant and an endangered animal species clearance prior to project construction.

E. Contract

See Section IV, A and D.

F. Construction

Project construction would commence in mid to late July FY-84 and run possibly into October of FY-85.

V. Monitoring/Maintenance

A. Monitoring

Monitoring the Elephant Skin Wash Salinity Control Project is crucial from the standpoint of determining the projects effectiveness and obtaining information for the design of future projects with similar objectives. At a minimum, monitoring would include:

1. A recording rain gage, maintained year-round, would be installed in Elephant Skin Wash to monitor both the intensity and amount of precipitation.

2. Calibrated staffs would be installed in selected areas flooded by ponding dikes to monitor the deposition rate and amount of sediment. These would be read at least once annually.

3. Crest gages would be installed to monitor flow of selected emergency spillways, diversion dikes, and re-entry structures (see Figure 3). These would be read and recharged after major precipitation events or at least once annually, whichever comes first.

4. Biannual (spring/fall) salinity measurements would be taken in selected ponding dike sediments and control areas.

5. Annually, changes in vegetation density would be measured, using the 200 feet pace transect, on selected ponding dike sediments and control areas.

A more detailed monitoring plan would be developed, and referenced in this activity plan, after project completion, when the specific sites for monitoring have been selected.

B. Maintenance

A routine maintenance inspection would be conducted once every 5 years and/or after the occurrence of any storm equal to or greater than the 25-year event. If repairs are needed to any portion of the project, funds would be requested through the annual work plan process.

If livestock are found to be causing damage to any portion of the project, requests may be made to fence these areas, excluding them from livestock grazing.

To maintain a stable hydrologic condition, sediment would not be removed from ponding dikes. If extra storage of water is needed, additional ponding dikes or other retention structures should be constructed.

VI. Benefit Analysis

A. Assumptions

1. $\bar{X}$ Annual Sediment Yield = 3-6 Tons/Acre (Average = 4.5)

2. $\bar{X}$ Annual Salt Yield = 0.08-0.17 Tons/Acre (Average = 0.13)

3. Salt Content = 3% of Sediment by Weight

4. One half of the $\bar{X}$ Annual Salt and Sediment Yield is retained by the Proposed Project

5. Benefit of Salinity Reduction is Equal to $54. Per Ton of Salt (Water and Power Resource Service, 1980)

6. Depreciation Rate/Opportunity Cost/Interst Rate = 0.078

B. Computations

Cost of Project = $29,747

Sediment Storage Capacity of Project = 50 Acre-Feet
(2069 Tons of Sediment per Acre-foot)

50 Acre-Feet x 2069 Tons/Acre-Foot = 103,450 Tons (Project Sediment Storage Capacity)

Total $\bar{X}$ Annual Sediment Yield
4.5 Tons/Acre/Year X 2,368 Acres = 10,656 Tons/Year

One-half Retained by Project $\frac{10,656}{2}$ = 5,328 Tons/Year

Project Life $\frac{\text{103,450 Ton Capacity}}{\text{5,328 Tons/Year}}$ = 19.4 or 20 Years

Salt Content 3% x 103,450 Tons Sediment = 3,100 Tons Salt over 20 Year Project Life

Total Cost of Project Ammortized Over 20 Years	= $ 59,697
Annual Cost of Project	= $ 2,985
Total Benefits from Salt Reduction ($54 X 3,100 Tons)	= $167,400
Annual Benefits from Salt Reduction	= $ 8,370
Ratio of Annual Benefits[△] to Costs*	= 2.8

1. This assumption may require further revisions.

* Maintenance costs not included.

△ Does not include additional benefits as described under Section I.D.

Selected References

1. Valentine, K. A., 1947 - Effect of Water-Retaining and Water-Spreading Structures in Revegetating Semi-Desert Range Land. Agriculture Experiment Station, New Mexico College of A. and M.A. - State College, 22 pp.

2. Hubbell, D. S. and Gardner, S. L., 1950 - Effects of Diverting Sediment-Laden Runoff from Arroyos to Range and Crop Lands. USDA - Soil Conservation Service, Tech. Bulletin No. 1012, 83 pp.

3. USDI - Bureau of Land Management, 1983 Salinity Control Projects, Montrose District.

4. Hawkins, R. H., G. F. Gifford, and J. J. Jurinak, 1977 - Effects of Land Processes on the Salinity of the Upper Colorado River Basin. Final Project Report, USDI, Bureau of Land Management, Contract #52500-CT5-16, Utah State University, 196 p.

5. Jackson, W. L. and R. P. Julander, 1982 - Runoff and Water Quality from Three Soil Landform Units on Mancos Shale. Water Resources Bulletin, 18(6).

6. Stokes, C. M. et al, 1954 - Range Improvement Through Water Spreading Sponsered by Foreign Operations Administration, Washington, D.C. 35 pp.

7. Hubbell, D. S. and Gardner, J. L. Some Edaphic and Ecological Effects of Water Spreading in Range Lands. Ecology, Vol. 25, No. 1, 44 pp.

8. Tromble, J. M., 1983 - Rangeland Ponding Dikes: Design Criteria. Journal of Range Management 36(1), pp. 128-130.

9. Miller, R. F. et al, 1969 - An Evaluation of Range Floodwater Spreaders USDI - Geological Survey, WRD., 11 pp.

10. Pierson, R. K., 1955 - Range Water Spreading as a Range Improvement Practice. USDI - Bureau of Land Management. 4 pp.

11. Branson, F. A., 1956 - Range Forage Production Changes on a Water Spreader in Southeastern Montana. J. of Range Management, Vol. 9, No. 4., July, 1956.

12. Anching, L., Jackson, W. L., Karla, K. D., 1983 - Storm Runoff and Water Quality on Three Ephemeral Wash: Price River Basin, Utah. In press: Jnl. of Soil and Water Conservation.

13. Klienman, A. P., Brown, F. B., 1980 - Colorado River Salinity: Economic Impacts on Agricultural, Municipal, and Industrial Users. USDA - Water and Power Resource Service.

Appendix I

United States Department of the Interior

BUREAU OF LAND MANAGEMENT

Gunnison Basin Resource Area
11 South Park Avenue
Montrose, Colorado 81401

IN REPLY REFER TO:
7250
(162)

JUN 5 1984

Memorandum

To: Dennis Murphy, UBRA Hydrologist

From: Lin Fehlmann, Water Rights Coordinator

Subject: Water Rights - Elephant Skin Erosion Control Project.

On May 22, 1984 I visited with Ralph Kelling, Division Engineer for Water Division 4. We discussed the possibility of BLM acquiring water rights to the erosion control structures for the Elephant Skin Project (a matter you and I had briefly discussed with Ralph on April 3, 1984).

Mr. Kelling does not feel we need to acquire water rights on the erosion control structures. Firstly, the water supply for these structures is of very short duration-i.e., heavy rains and spring runoff from intermittent drainages. Secondly, there are no existing downstream water users that would be injured by our developments and runoff would flow back into the natural drainages/canals.

In my judgment, water rights are unnecessary in this case. If management decides to pursue the issue, the most we could obtain would be an "Application for an Erosion Control Structure" on each development. This would be costly and impractical, due to the short lifespan of these structures.

Lin D. Fehlmann

ELEPHANT SKIN WASH SALINITY CONTROL PROJECT

MONITORING PLAN

I. INTRODUCTION

This monitoring plan, being prepared as part of the Elephant Skin Wash Watershed Activity Plan (see page 24 of said plan), is to evaluate the short- and long-term effectiveness of the project. The objectives of the project are discussed in the activity plan and include: the retention of both sediment and salinity, reduced downstream runoff, and an increase in vegetation and on-site water for livestock and wildlife. This plan will describe the data collection methodologies and time frames necessary to monitor the project for these objectives. It is the intent of this monitoring plan to not only provide useful data for the Elephant Skin Wash project but to aid in the design and location of future projects with similar objectives.

At the time this monitoring plan was prepared (summer 1985) only Project Site 1, Site 2A, and Site 2B (see activity plan page 4) have been funded and constructed. This plan, therefore, will pertain to those sites only. This plan will include monitoring of the remaining sites (Site 3 and Site 4) as they are completed.

The data collected, as described by this plan, will be compiled, interpreted and incorporated into the Uncompahgre Basin Resource Area Project File 7240.

Sediment and Salinity Retention

The benefits of sediment retention will be realized from both the diversion dams and ponding dikes on Project Site 1 and Site 2. In the short-term, sediment retention volumes will be measured annually (late summer/early fall) for five consecutive years immediately following project construction. The first sediment measurements will be taken in 1986. For the long-term, the frequency of sediment volume measurements will be extended to every fifth year, and again measured during late summer or early fall. For sediment measuring methodologies, see Appendix I.

The data from the recording raingage (see Figure 1) will allow the development of a sediment yield/precipitation relationship for the subject area.

Salinity retention benefits are only being calculated from the ponding dikes due to the potential of salt from the diversion dams flushing back into the stream system via the emergency spillway. For specific methodologies see Appendix I.

Photo Points

Photo points are permanently established (using fence posts) to detect visual changes on the project area. For photo point locations see Figure 1. Photo point number 1 on Site 2 is used to photograph both diversion dams and ponding dikes. Photo points number 2 and 3 are located on Project Site 1. Photo point number 2 photographs the ponding dikes while photo point number 3 photographs the diversion dam.

Photographs will be taken annually (late August or early September) for the first five years post project construction and then every fifth year.

Downstream Flood Control

This benefit of the project will not be quantitatively monitored. It is assumed that as long as the diversion dams and ponding dikes are functional, some degree of downstream flood control is being provided. The project will not only retain runoff waters but will increase flow paths and lag times.

Over time, the data collected from the recording raingage at Site 2 will allow a better understanding of the precipitation/runoff relationships for Elephant Skin Wash. This could lead to improved design and location of future projects in this or similar areas.

Seasonal Water for Livestock and Wildlife

As long as the project is functional (has some water storage capacity), water will be seasonally available for livestock and wildlife. However, due to muddy conditions around the project structures, livestock water will need to be pumped from the ponds and into troughs, etc. Also, at certain times, salinity levels may be so high as to render the water unpalatable to livestock and/or wildlife.

As of August 1985, wildlife species using the project's water included prairie dogs, deer, coyote, doves, and raccoon.

Increased Vegetation Cover

The ponding dike areas are expected to support a higher vegetation cover over the long-term than that of the pre-project area. This will be monitored by measuring vegetation cover along established transects (see Figure 1). Transects A and C are within ponding dike areas. Transect B is on the control area. This data will be collected the second year after project construction, then every fifth year. For sampling methodology see Appendix II.

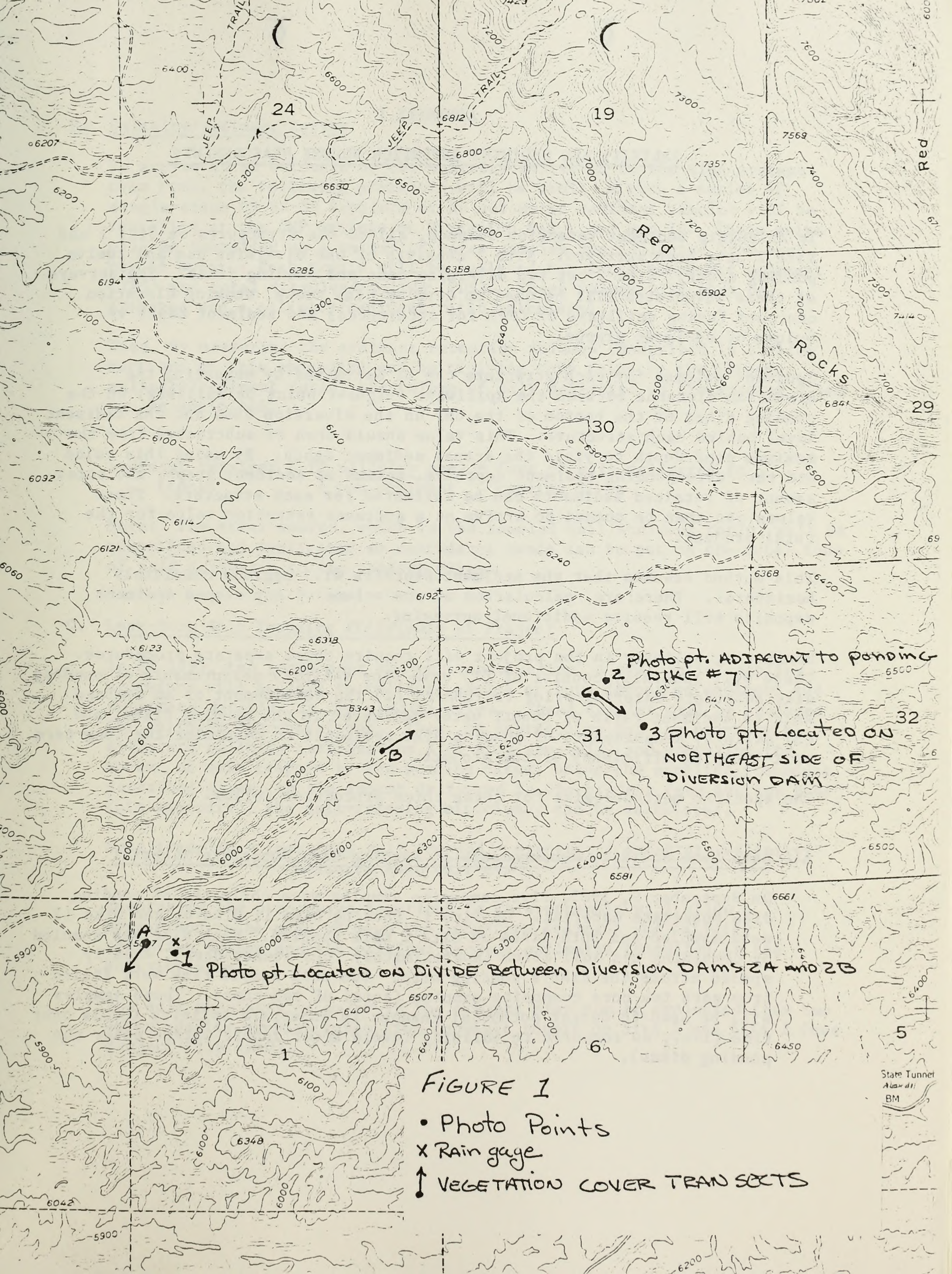

JEEP TRAIL
Red Rocks
24
19
29
30
31
32
1
6
5
Photo pt. ADJACENT to PONDING DIKE #7
3 photo pt. Located ON NORTHEAST side OF Diversion DAM
1 Photo pt. Located ON DIVIDE Between Diversion DAMS 2A AND 2B
A
B
C
2
State Tunnel
BM
• Photo Points
x Rain gage
VEGETATION COVER TRANSECTS

FIGURE 1

APPENDIX I

SALINITY AND SEDIMENT RETENTION VOLUME MEASUREMENTS

To calculate sediment retention volumes, all of the structures on Site 1 and Site 2 have been surveyed. Site 1 consists of one diversion dam and twelve ponding dikes. Site 2 has two diversion dams and ponding dikes. The surveys of these structures will be used to develop plan views, showing elevation contours (using spillways or CMPs for references) and sediment depth vs. volume of sediment graphs.

Sediment volumes for each structure can be estimated by measuring the elevation distance between the spillways (highest point on spillway) on the ponding dikes or the bottom of the CMP on the diversion dams and the sediment level behind each structure. This value should then be subtracted from the maximum pond depth to yield the actual sediment depth. By using this value and the corresponding sediment depth vs. volume of sediment graph, the total amount of retained sediments can be estimated for each structure. These values can then be summed to arrive at a sediment retention value for the total project.

This method assumes that the sediment deposits will aggrade completely horizontal. Therefore, calculation of the volume of any sloped sediment deposits will require additional surveying.

Monitoring salinity in the project will require three separate procedures. These will generally consist of (1) base line salinity measurements of ponding dike substrate material prior to runoff; (2) the development of an average salt to sediment ratio of runoff water delivered to the ponding dikes; and (3) salinity measurements of ponding dike sediments to determine the long-term salt-trapping efficiency of the project.

The specific methodologies for these three procedures follow.

A. Base Line Salinity Measurements of Ponding Dike Substrate Material

On September 9, 1985, five composite samples were collected of ponding dike substrate material. On Site 1, Ponding Dike 1, Dike 6, and Dike 12 were sampled and both dikes on Site 2 were sampled. Each dike was sampled by combining ten soil cores (approximately four inches deep), equally spaced across the dike's ponding area. Two soil sample cans were filled from each ten core composite samples (total of ten cans). These samples will be used to detect potential changes in substrate salinity levels over time (i.e., as compared to salinity levels after runoff waters enter the ponding dikes).

B. Salinity/Sediment Ratios

To arrive at an estimate of the salinity delivered to the dike systems over time, the following procedure will be used: either a series of single-stage US SS-59 samplers or an automatic sediment sampler will be installed at the CMP outlets on Diversion Dam 1 and Dam 2B. These units will be installed so a series of water samples are collected from each runoff event. Each sample will be analyzed for total suspended sediment (TSS) and total dissolved solids (TDS). These values will then be averaged and a salinity/sediment ratio calculated.

Then, by measuring the sediment retention volumes (described in earlier sections of this appendix) and multiplying this value by the average salinity/sediment ratio, the volume of salt delivered to the ponding dikes can be estimated.

$$\underset{\text{(tons)}}{\text{Sediment retained}} \times \left(\frac{\bar{x}\ \text{salinity ppm}}{1\ \text{ppm sediment}}\right) = \text{Tons of salt delivered to ponding dikes}$$

Note: The error source, which is the sampled salt/sediment ratio, will be quantified and replicated so confidence bands can be put on the total tons of salt delivered to the ponding dikes.

C. Long-Term Salt Trapping Efficiency of Project

In FY 1995, ten years post project construction, a systematic sampling procedure will be used to collect samples of both deposited sediment and substrate material in the ponding dikes. These samples will be analyzed for salinity concentrations. Then, by subtracting out the pre-runoff substrate salinity (see Section A of this appendix) and comparing the amount of salt trapped by the ponding dikes, using the sampling procedure described above, to the amount delivered to the project (see Section B of this appendix), the salt-trapping efficiency can be calculated.

$$\text{Salt trapping} = \left(\frac{\text{measured salt trapped} - \text{pre-runoff substrate salinity}}{\text{measured salt delivered}}\right)$$

Eventually the procedures described in this appendix will allow a comparison to be made between the long-term sediment and salinity retention values and the original project estimates contained in the activity plan.

The salt chemistry of water in the project area can be evaluated from two water quality samples taken from snowmelt runoff on Site 1 and Site 2 (see Project File 7240).

APPENDIX II

VEGETATION COVER MONITORING

Permanent frequency quadrat transects have been established on Site 1 and Site 2 in addition to a control area (see Figure 1). The start of each transect is field-marked with a fence post. A site-specific description of each transects follows.

A. Transect A (Site 2)

The start of this transect is located on the northeast side of the first ponding dike. From the fence post, the transect extends 100 paces or approximately 500 feet in a lineal direction 234 degrees from true north. The transect extends through the ponding area on Dike 1 and partially into the area of Dike 2.

B. Transect B (Control Area)

This transect is located south of the road between Site 1 and Site 2 (see Figure 1). From the fence post, the transect extends 100 paces or approximately 500 feet in a lineal direction 48 degrees from true north. The transect roughly parallels and lies between the road and the main drainage channel.

C. Transect C (Site 1)

The start of this transect is located just below Dike 7. From the post, the transect extends 100 paces or approximately 500 feet in a lineal direction, 132 degrees from true north.

D. Methodology for Monitoring Procedures

Data collection method for each transect:

1. Pace in the direction of the transect.

2. Every pace (2 steps) when the right foot hits the ground, place the frequency quadrat frame beside the right foot.

3. Record cover (bare ground, rock, litter, live vegetation, and overstory cover if there is not a live vegetation hit below it) at the four corners and at the end of the middle tine on the quadrat frame. This will produce a total of five readings.

4. This process is repeated for 100 paces (200 steps) for a total of 500 cover readings.

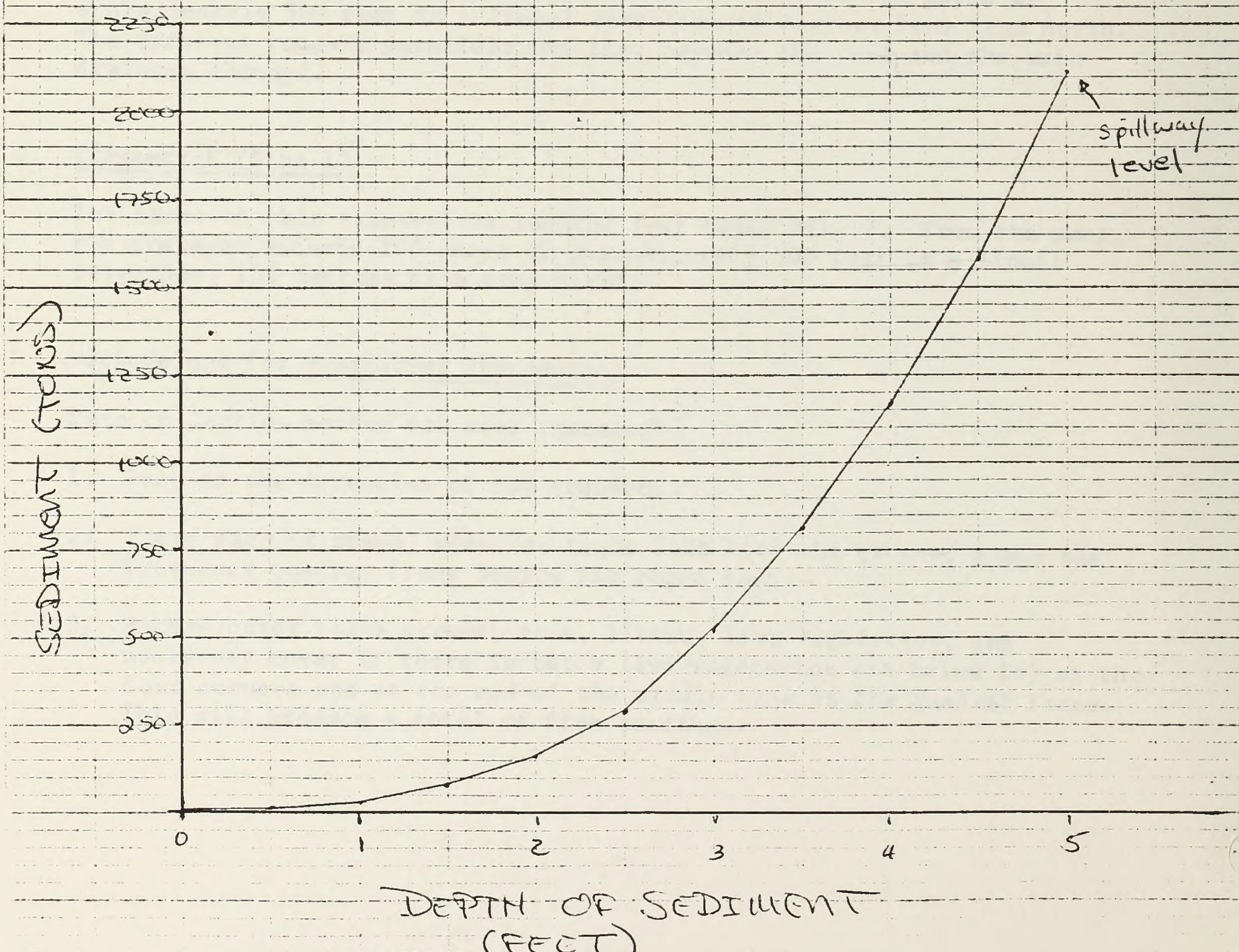
5. Percent cover is calculated by dividing the sum of the total litter and live vegetation hits by 500; this value is then multiplied by 100.

By.: Dmm
DATE: 12-85

ELEPHANT SKIN WASH

Table: 2-2 Ponding Dike 2 Site 2

DEPTH (FT.)	SURFACE AREA (FT^2)	VOLUME (FT^3)	CUMULATIVE VOLUME (FT^3)	PERCENT VOLUME	CUMULATIVE VOLUME PERCENT	SEDIMENT TONS	CUMULATIVE SEDIMENT TONS
0.0	0	0	0	0.0	0.0	0	0
0.5	400	100	100	0.2	0.2	5	5
1.0	1728	532	632	1.2	1.4	25	30
1.5	2848	1144	1776	2.6	4.0	54	84
2.0	3376	1556	3332	3.5	7.5	74	158
2.5	8240	2904	6236	6.5	14.1	138	296
3.0	10880	4780	11016	10.8	24.8	227	523
3.5	13712	6148	17164	13.9	38.7	292	815
4.0	15872	7396	24560	16.7	55.3	351	1166
4.5	20272	9036	33596	20.4	75.7	429	1595
5.0	22880	10788	44384	24.3	100.0	512	2107



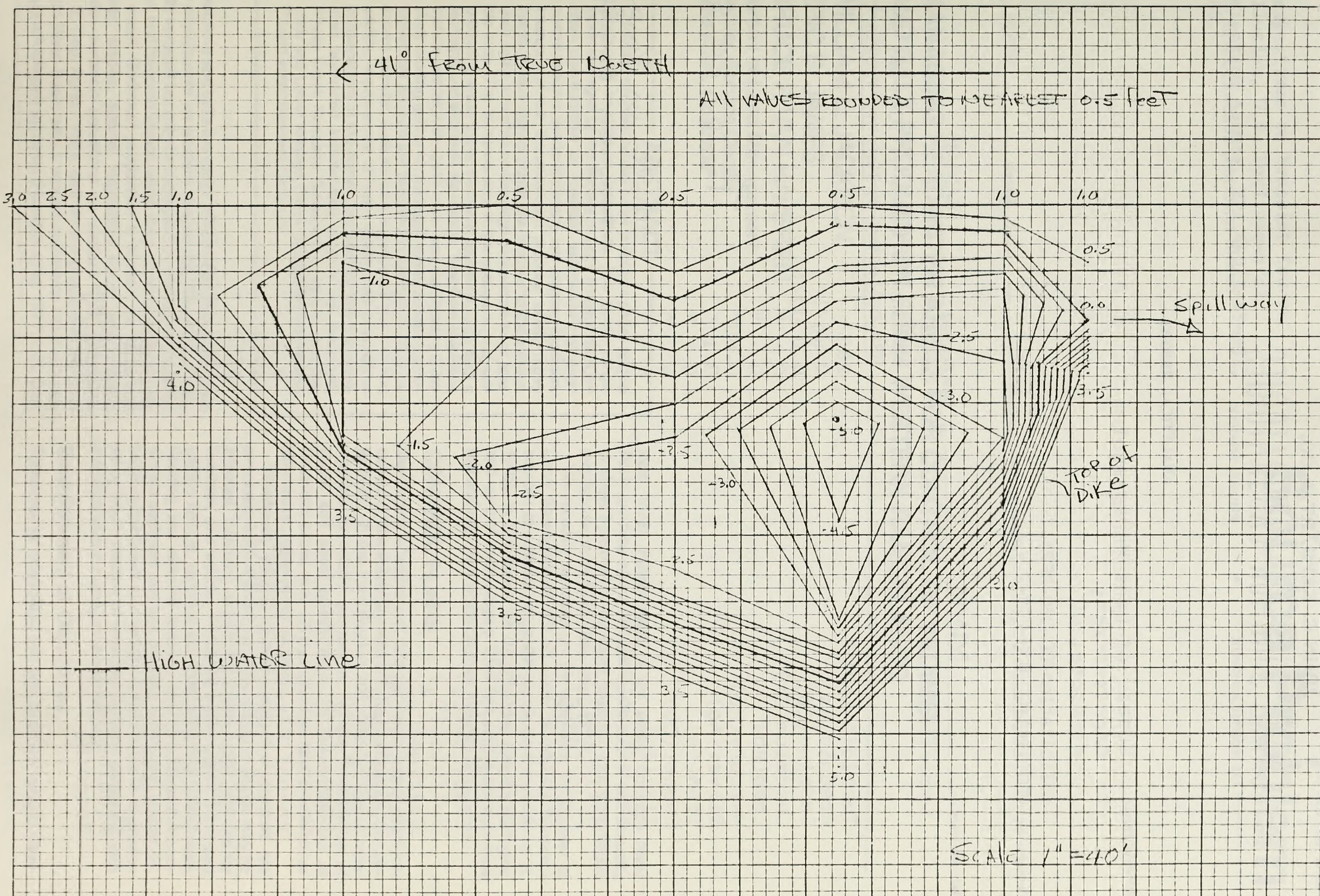


FIGURE 2-2
ELEPHANT SKIM WASH
ELEVATIONAL CONTOUR PLAN
Pumping Dike 2 Site 2 (see Activity Plan)

Squares to the Inch

JOHN C. KEPHART & CO.
GRAND JUNCTION LABORATORIES
435 NORTH AVENUE ♦ PHONE 242-7618 ♦ GRAND JUNCTION, COLORADO 81501

ANALYTICAL REPORT

Received from: Bureau of Land Management
Dennis Murphy
Montrose, CO

solicitation#CO-030-RFP5-7
Customer No. contract#CO-030-CT5-2 Laboratory No. 1415 Sample water

Date Received 5/15/85 Date Reported 6/10/85

Sample	1415 ESW Dam 2B 5/9/85 11:30AM NW¼ sec 1 T49N R9W collected by Murphy, Ypsilantis
Turbidity(NTU)	280
Arsenic(As)	0 µg/l
Cadmium(Cd)	0.0 µg/l
Chromium(Cr)	0 "
Lead(Pb)	0 "
Mercury(Hg)	0.00"
Silver(Ag)	0.1 "
Iron(Fe)	0 "
Copper(Cu)	4 "
Zinc(Zn)	6 "
Molybdenum(Mo)	13 "
Barium(Ba)	0.0 mg/l
Fluoride(F)	0.70 "
Selenium(Se)	0.000 "
Bicarbonate(HCO_3)	60.1 "
Carbonate(CO_3)	0.0 "
Nitrate(N)	36.8 "
Chloride(Cl)	79.6 "
Sulfate(SO_4)	4010 "
Calcium(Ca)	596 "
Magnesium(Mg)	83.8 "
Potassium(K)	19.1 "
Sodium(Na)	950 "
Color(Co/Pt unit)	5
Hardness($CaCO_3$)	1900 mg/l
Phenol Alkalinity($CaCO_3$)	0.0 "
Total Alkalinity($CaCO_3$)	49.7 "
Dissolved Solids	5750 "
Conductivity@25°C	5900 µmhos/cm
Manganese(Mn)	0.004 mg/l
Ammonia(N)	0.84 "
Phosphate(P)	0.00 "
pH	7.8
Aluminum(Al)	0.04 mg/l
Boron(B)	0.752 "

Temp. 20.5°C

water in Pond was snowmelt Runoff

LAB DIRECTOR: BRIAN S. BAUER

In: Perspectives on Nonpoint Source Pollution, U.S. Environmental Protection Agency, EPA 440/5-85-001, 1985.

Salinity: A Nonpoint Source Problem

MANAGING HEADWATER AREAS FOR CONTROL OF SEDIMENT AND SALT PRODUCTION FROM WESTERN RANGELANDS

WILLIAM L. JACKSON
ERIC B. JANES
BRUCE P. VAN HAVEREN
Bureau of Land Management
Denver Service Center
Lakewood, Colorado

ABSTRACT

Control of nonpoint source water pollutants poses special challenges on western rangelands. The public rangelands managed by the Bureau of Land Management are often characterized by unstable sedimentary geologic parent material, semiarid climate, and sparse vegetation. Intense summer thunderstorms produce locally heavy runoff. Where marine shales are exposed at the surface, their sediments often contain high concentrations of soluble salts. The immense size of the sediment- and salt-producing areas poses treatment problems, both from a technical and economic standpoint. Treatment objectives include retention of runoff water and stabilization of actively eroding gullies in headwater areas. Watershed improvement projects are designed to provide multiple resource benefits, such as water supplies for livestock and wildlife, improvement of water quality, and retention or enhancement of site primary productivity. Two representative watershed improvement projects are described: Sheep Creek Resource Conservation Area in southern Utah and Lower Missouri Creek Tributaries Stabilization Project in northwestern Colorado.

Sediment and salts are major nonpoint source, water quality constituents on western rangelands. They occur naturally in runoff but may be increased by management activities and become issues when they affect beneficial uses of water. Sediment production is highest on lands with steep slopes, sparse vegetation cover, and erodible soils—common conditions on western U.S. rangelands (U.S. Dep. Agric., 1980). Salinity is a problem in the Colorado River Basin where eroded sediments have naturally high soluble salt contents (Hawkins et al. 1977; U.S. Dep. Inter. 1978). Public lands in the upper Colorado River Basin produce about 650,000 metric tons of salt annually, or about 8 percent of the upper basin salt load from diffuse overland sources (U.S. Dep. Inter., 1978).

We recently reported on the approach the Bureau of Land Management (BLM) uses to identify nonpoint sources of pollution on public lands (Van Haveren et al. 1985). In this paper we describe the specific strategies and control technologies BLM has employed to reduce salt and sediment production on western rangelands.

CONTROL PLANS

Developing effective salt and sediment control plans requires: (1) the establishment of resource management objectives, (2) the identification and quantification of manageable hydrologic processes, (3) the investigation of cause and effect relationships, (4) the stratification of treatment areas, and (5) the selection and evaluation of alternative treatment techniques.

Whichever watershed management techniques are eventually implemented, multiple resource values may be affected, including forage production, water supplies for livestock and wildlife, improved water quality, enhanced wildlife habitat, reduced soil loss, control of downstream flooding and channel erosion, and reductions in downstream sediment and salt delivery. The overall goal in developing sediment and salinity control plans is to provide an optimum mixture of resource benefits consistent with overall resource management objectives.

Establishment of Objectives

Objectives for controlling salt and sediment should relate to both the processes to be influenced and the management goals to be achieved. In establishing management objectives for sediment and salinity control, corresponding objectives need to be established for related, affected resource values. This will enable a meaningful analysis of tradeoffs associated with alternative treatment techniques. If possible, objectives need to be quantified so that progress in achieving them can be effectively monitored and evaluated.

Identification and Quantification of Manageable Processes

The identification and quantification of manageable processes and variables is accomplished as part of the watershed analysis procedure (Solomon et al. 1982; Gebhardt, 1985). However, more detailed or site-specific quantification may be required for project design or for ranking individual treatment alternatives. Most sediment and salinity control projects require information on both long-term and runoff and sedimentation rates, and single-storm design values for runoff, peak flows, and sediment yield.

In quantifying manageable salt and sediment processes, it is useful to distinguish between natural and management induced problems. Generally BLM prefers to correct management induced problems rather than control natural processes.

Investigation of Cause-and-Effect Relationships

Distinguishing between causes and effects is very important when evaluating sediment and salinity problems. For example, high gully erosion rates may be the result of local or regional changes in base-level controls, or they may be caused by runoff in excess of the thresholds, the reduction of streamside vegetation, or some combination of causes. Proper identification and quantification of the causes of a problem will more likely lead to the proper selection of treatment techniques than will a simple quantification of the problem symptom (such as erosion rates). Of particular importance in investigating salinity issues is the relationship between sediment and salt. Where highly saline soils are eroding, we assume that controlling sediment will also control salt. However, other salt transport mechanisms, including interflow and ground water flow, may not be manageable by controlling runoff and erosion.

Stratification of Treatment Areas

Where large watersheds (>50 km^2) are to be treated, we recommend dividing the area into treatment units. The stratification is based on topographic considerations, including soils and vegetation, salt and sediment source areas, locations where controlling processes can be managed, and treatment potential. After identification, treatment units are ranked, based on both the sediment or salt production rating and treatability of the area. The application of this concept to the Lower Wolf Creek watershed is discussed later in this paper.

TREATMENT TECHNIQUES

Controlling salinity in surface runoff from rangelands is closely related to controlling soil erosion. Vegetation cover is usually the most important management variable influencing runoff and erosion rates on rangelands.

Therefore, vegetation management, either directly through vegetation manipulation or indirectly through the design and implementation of livestock grazing plans, is an important erosion and salinity control technique. However, on the most highly saline rangelands, maximum potential cover is usually too low to provide meaningful control of surface runoff and erosion. In these cases, or in situations where the watershed's condition is so severely degraded by past management practices that natural recovery will be inefficient, mechanical land treatments and structural alternatives may be the most effective erosion and salinity control techniques.

Vegetation Management

Vegetation cover, including canopy cover, ground cover, and litter, reduces upland soil loss by protecting soil from direct raindrop impact and by reducing surface runoff velocities. Vegetation also intercepts rainfall and enhances soil infiltration properties, thus reducing runoff volume and its erosive capacity, both on hillslopes and in stream channels.

Livestock grazing affects vegetation cover by influencing species composition, vigor, production, and forage use. Most studies have shown that runoff and erosion increase with grazing intensity (Lusby, 1979a; Gifford and Hawkins, 1978). Generalized relationships between livestock grazing and vegetation cover, however, have not been forthcoming. Common erosion estimation techniques, such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978), that require information on vegetation cover are difficult to apply given information only on livestock grazing or forage use. Thus, it is difficult to accurately predict the effects of livestock grazing systems on erosion. Nevertheless, proper land use, including well-designed grazing systems, is the preferred method of achieving watershed management objectives (Moore et al. 1979; Van Haveren et al. 1985).

The most common techniques for direct vegetation manipulation on rangelands include pinyon-juniper control and big sagebrush control. Both techniques involve eliminating pinyon-juniper or big sagebrush stands by mechanical or chemical means or burning. Either native grasses and forbs are permitted to reestablish naturally or grasses are planted. General conclusions concerning the effectiveness of vegetation conversions in reducing runoff and soil loss on rangelands are not available. However, the many discrepancies in the literature suggest that vegetation manipulations may not be reliable techniques for controlling sediment and salinity. In many cases, vegetation conversions have resulted in more desirable forage species for livestock, but have not significantly reduced runoff or soil loss (Williams et al. 1972; Gifford et al. 1970; Gifford, 1972; Gifford and Busby, 1974; Blackburn and Skau, 1974). In some cases involving sagebrush conversion to grass (Lusby, 1979b) runoff and sediment yield have been reduced significantly.

Mechanical Land Treatments

Mechanical land treatments involve soil tillage techniques such as contour furrowing, ripping and pitting. Tillage is generally applied to increase infiltration volumes. This may be accomplished by increasing infiltration capacities or depression storage (thus, the time available for infiltration), or both. When successful, runoff and erosion can be reduced. Salinity benefits will be proportional to the amount of salt in the controlled runoff and sediment. If improved soil moisture regimes improve vegetation cover, benefits derived from mechanical land treatments may be sustained indefinitely, given compatible subsequent land use management. If improved cover is not achieved or maintained, benefits from mechanical land treatments may be short-lived.

Contour furrows are usually constructed within a reseeding and grazing management program, primarily to increase depression storage and the time available for infiltration. Furrows are not recommended on slopes greater than 10 percent, and are most effective in medium to fine textured soils. Furrows have finite lives (Branson et al. 1966) that are a function of their storage capacity in relation to runoff and erosion at the site. When functioning properly, they eliminate most runoff from a site.

Ripping, unlike furrowing, generally influences depression storage very slightly; the main benefits must be achieved by increasing soil infiltration capacities. This is most effective on severely compacted soils such as on roads or reclaimed mined lands, or on soils where a shallow pan layer restricts downward water movement. In most rangelands, ripping either has not significantly improved infiltration or cover (Branson et al. 1966; Dortignac, 1963), or has produced very short-lived benefits (Aldon and Garcia, 1972). However, Griffith et al. (1985) found ripping to be effective in increasing herbage production on shortgrass prairie in southeastern Wyoming.

Land treatment techniques must be carefully tailored to the site, with topography and soil characteristics dictating treatment types and design.

Structural Techniques

Common structural techniques used in managing runoff, sediment, and salt yields include rangeland dikes, retention plugs, retention and detention reservoirs, and gully plugs. Retention and detention structures trap runoff and sediment volumes in accordance with their design capacities. Generally, total runoff retention is required for a structure to effectively control salinity. Gully plugs usually have small retention capacities, but provide salt and sediment control by reducing erosion in active gully systems.

In addition to effectively controlling downstream impacts associated with runoff, erosion, and salinity processes, retention/detention structures may provide localized onsite benefits. Reservoirs provide water for livestock and wildlife. Even after filling with sediment they may provide a riparian-like habitat. Gully plugs, when properly located, can cause overincised channels to aggrade and, if conditions are adequate, result in the creation or restoration of streamside riparian zones (Heede, 1981). Dikes and widely spaced furrows (>5 m) usually do not increase vegetation production (Branson et al. 1966) unless they are constructed as part of a water-spreading system (Miller et al. 1969).

To control salinity, reservoirs must be designed with sufficient storage to trap all incoming runoff. While a retention structure will cease to function for salinity control after it is filled with sediments in excess of its design capacity, a proper spillway will keep the structure from failing and becoming a future source of salt and sediment. Maintenance of retention structures—either by excavating stored sediments or by increasing their height—will allow the structures to function beyond their original design life.

In highly saline areas, retention structures are usually the only practical management alternative. The feasibility of constructing these types of structures depends upon identifying secondary benefits, such as flood control, water supply, and wildlife habitat. In less saline areas, onsite benefits to water supply, vegetation production, and riparian enhancement associated with retention structures often will be greater than in highly saline areas, but mechanical treatments and vegetation management also may be feasible treatment strategies, depending upon the management objectives.

CASE STUDIES

Two BLM watershed improvement projects, both in the Colorado River Basin, are described here. Both are examples of well-planned, properly designed sediment- and salt-control projects.

Sheep Creek, Utah

Sheep Creek is a tributary to the Paria River, one of the highest sediment-producing watersheds in the Colorado Basin. Chosen in the 1950's for an intergovernmental resource conservation project, Sheep Creek is an exemplary watershed improvement project because of good interagency cooperation, primarily at the field level, and because of a well-planned mix of properly designed watershed treatments.

The Sheep Creek project area, 50.1 km^2 in size, drains mid-elevation, pinyon-juniper badlands and sagebrush on the south boundary of Bryce Canyon National Park in southern Utah. Land ownership is mixed and includes public lands managed by the BLM, Forest Service, and National Park Service, and private lands. Treatments included a concrete barrier dam on Sheep Creek at the downstream end of the project area, detention dams and dike water spreader systems on the sagebrush flats, pinyon-juniper to grass vegetation conversions, and gully checks and reseedings in the upper end of the watershed.

The barrier dam was constructed in 1961 by the Bureau of Reclamation to provide base-level control for the project area. As of April 1984, 43.9 ha–m of sediment had been trapped behind this structure and 915 m of the main Sheep Creek channel were stabilized.

BLM constructed two earthen detention dams on Sheep Creek Flat, a large sagebrush flat in the upper Sheep Creek watershed. These dams have accumulated large sediment deposits and have also been successful water control structures because their capacities are large in relation to their contributing areas.

One of the most successful treatments included a series of several hundred small gully checks constructed at the extreme upper end of Sheep Creek. These checks were installed at a very high density and successfully planted to western wheatgrass. They trapped large quantities of sediment and stabilized a downstream gully system.

Benefits realized from the Sheep Creek watershed proejcts include the following: (1) an estimated 125 ha–m of sediment trapped behind erosion and water control structures, (2) an estimated 1,000 m of main channel aggradation, (3) an estimated 6 ha of riparian vegetation established behind the Sheep Creek Barrier Dam, increasing both cover and diversity for wildlife habitat, (4) an estimated 10 km of gullies healed, (5) improved watershed cover on an estimated 200 ha, (6) reduction of flood peaks, (7) establishment of perennial flow at the Sheep Creek Barrier Dam, and (8) improved forage production (unable to quantify).

In addition, dissolved solids in Sheep Creek may have decreased in concert with the sediment reductions.

Lower Wolf Creek, Colorado

The Lower Wolf Creek project area covers 319 km^2 and represents 58 percent of the entire Wolf Creek drainage, which is tributary to the White River in northwestern Colorado. Salinity reduction was one of the management objectives for Lower Wolf Creek (U.S. Dep. Inter., 1982). Because of its large size, the Lower Wolf Creek project area was stratified into treatment units (Table 1). Treatment techniques were designed to trap and retain runoff and sediment from saline soils.

The Lower Wolf Creek project is in its third year of implementation. Initial treatments included large reservoir repair and maintenance, pit reservoirs, gully checks, and earthen retention dams. These initial treatments have been applied to the high-priority treatment units. As a step

In determining the cost effectiveness of the project, benefit/cost ratios were determined for each structural treatment type, using salinity control as the primary benefit (Table 2). This information was used in the project planning to ensure that the overall mix of treatments had a positive benefit/cost ratio.

We do not have any results from the Lower Wolf Creek project at this time, as it will be several more years before the project is fully implemented. We feel this project is an excellent example of how to approach sediment and salt control in a large watershed.

SUMMARY AND CONCLUSIONS

The development of plans for salt and sediment control on western rangelands requires: (1) the establishment of resource management objectives, (2) the identification and quantification of manageable hydrologic processes, (3) the investigation of cause and effect relationships, (4) the stratification of treatment areas, and (5) the selection and evaluation of alternative treatment techniques. BLM prefers to incorporate salt and sediment control objectives as part of management plans for grazing, wildlife management, and other resource activities. When objectives cannot be met this way, techniques including vegetation management and mechanical and structural treatments may be used to control salt and sediment problems. Almost all salt and sediment control techniques influence multiple resource values. Because of the location of public lands in the significant sediment- and salt-producing river basins, BLM concentrates its control efforts in small headwater streams. Watershed projects at Sheep Creek, Utah, and Lower Wolf Creek, Colorado, are specific examples of successful salt and sediment control programs.

REFERENCES

Aldon, E.F., and G. Garcia. 1982. Vegetation change as a result of soil ripping on the Rio Puerco in New Mexico. J. Range Manage. 25(5): 381–3.

Blackburn, W.H., and C.M. Skau. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. J. Range Manage. 27: 476–80.

Branson, F.A., R.F. Miller, and I.S. McQueen. 1966. Contour furrowing, pitting, and ripping on rangelands in the western United States. J. Range Manage. 19(4): 182–90.

Dortignac, E.J. 1963. Surface runoff and erosion as affected by soil ripping. U.S. Dep. Agric. Misc. Publ. 970: 156–65.

Gebhardt, K.A. 1985. Erosion, productivity, and rangeland watershed planning. Pages 175–82 *in* E.B. Jones and T.J. Ward, eds. Watershed Management in the Eighties. Am. Soc. Civil Engin. New York.

Gifford, G.F. 1972. Infiltration rate and sediment production trends on a plowed big sagebrush site. J. Range Manage. 26: 440–3.

Gifford, G.F., and F.E. Busby. 1974. Intensive infiltrometer studies on an plowed big sagebrush site. J. Hydrology 21: 81–90.

Gifford, G.F., and R.H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: A critical review. Water Resour. Res. 14(2): 305–13.

Gifford, G.F., G. Williams, and G.B. Coltharp. 1970. Infiltration and erosion studies on pinyon-juniper conversion sites in southern Utah. J. Range Manage. 23: 402–6.

Griffith, L.W., G.E. Schuman, F. Rauzi, and R.E. Baumgartner. 1985. Mechanical renovation of shortgrass prairie for increased herbage production. J. Range Manage. 38(1): 7-10.

Hawkins, R.H., G.F. Gifford, and J.H. Jurinak. 1977. Effects of Land Processes on the Salinity of the Upper Colorado River Basin. U.S. Dep. Inter. Bur. Land Manage. Final proj. rep. Contract 52500-CT5-16, Denver, CO.

Heede, B.H. 1981. Rehabilitation of disturbed watersheds through vegetation treatment and physical structures. Pages

Table 1.—Lower Wolf Creek watershed treatment units.

Treatment unit	% of Watershed	Description	Treatments recommended	Salt production	Priority
Mancos shale uplands	42	Mancos shale ridges, gentle to moderate slopes, sparse vegetation, and shallow soil	gully plugs, contour furrows, grassed waterways, pit reservoirs, vegetation manipulation, spreader dikes	High	1
Mancos alluvial	24	small drainages and dissected benches and fans at the base of Mancos shale outcrops and grassed waterways	reservoirs, spreader dikes, vegetation manipulations	high	2
Gullied alluvium	4	major gullied bottomlands	large detention reservoirs and riparian planting	low to moderate	3
Sagebrush uplands	7	upland big sagebrush sites on sandstone around perimeter of watershed	vegetation manipulation and small check dams and pit reservoirs	low	4
Pinyon-juniper woodland steep slopes	23	steep, inaccessible slopes and shallow, heavy-textured soil	none	moderate to high	5

Table 2.—Benefit/cost data by watershed treatment.

Treatment	Cost	Structures per km²	Life of project in years	Sediment storage capacity	Salt retention	Retention benefit	B/C ratio
Contour furrow	$2,350/km²	10′ spacing	10	8,520 tonne/km²	256 tonne/km²	$15,972/km²	6.80
Gully plug	$1,770/km²	865	15	6,050 tonne/km²	181 tonne/km²	$11,293/km²	6.38
Pit reservoir	$1,000 ea.	3	25	.03 ha–m	11.0 tonne	$686	.69
Check dam	$1,550 ea.	3	25	.01 ha–m	4.4 tonne	$274	.18
Retention dam	$5,000 ea.	2	25	.41 ha–m	147 tonne	$9,171	1.83
Detention dam	$60,000 ea.	0.1	50	5 ha–m	1,758 tonne	$109,682	1.83

Assumptions:
Conversion Factors:
One hectare–meter of sediment weighs 11,878 tonne
3% sediment from Mancos Shale equals the weight of salt
1 tonne of salt retained equals $62.39 benefit downstream

257–68 *In* D.M. Baumgartner, ed., Proc. Interior West Watershed Manage. Symp., Washington State Univ., Pullman, WA.

Lusby, G.C. 1979a. Effects of grazing on runoff and sediment yield from desert rangeland at Badger Wash in Western Colorado, 1953–73. U.S. Geolog. Surv. Water-Supply Pap. 1532-I.

Lusby, G.C. 1979b. Effects of converting sagebrush cover to grass on the hydrology of small watersheds at Boco Mountain, Colorado. U.S.Geolog. Surv. Water-Supply Pap. 1532-J.

Miller, R.F. et al. 1969. An evaluation of range floodwater spreaders. J. Range Manage. 22(4): 246–57.

Moore, E. et al. 1979. Livestock grazing management and water quality protection. EPA 910/9-79-67. U.S. Environ. Prot. Agency, Washington, DC.

Solomon, R.M., J.R. Maxwell, and L.J. Schmidt. 1982. Determining watershed conditions and treatment priorities. *In* Proc. 1982 Arizona–Nevada Acad. Sci. Hydrology Section (Vol. 12).

U.S. Department of Agriculture. 1980. Soil and Water Resources Conservation Act: 1980. Resour. Conserv. Act Coordinating Comm. Appraisal. Rev. draft. Part I.

U.S. Department of the Interior. 1978. The effects of surface disturbance on the salinity of public lands in the Upper Colorado River Basin. (status report). Bur. Land Manage. U.S. Dep. Inter., Denver, CO.

Van Haveren, B.P., E.B. Janes, and W.L. Jackson. 1985. Nonpoint pollution control on public lands. J. Soil Water Conserv. 40(1): 92–4.

Williams, G., G.F. Gifford, and G.B. Coltharp. 1972. Factors influencing infiltration and erosion on chained pinyon-juniper sites in Utah. J. Range Manage. 25(3): 201–5.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses. U.S. Dep. Agric. Handbook 537. Washington, DC.

WATER RESOURCES BULLETIN
VOL. 18, NO. 1 AMERICAN WATER RESOURCES ASSOCIATION FEBRUARY 1982

SOLUBLE MINERAL CONTENT IN SURFICIAL ALLUVIUM AND ASSOCIATED MANCOS SHALE[1]

Jonathan B. Laronne and Stanley A. Schumm[2]

ABSTRACT: The Mancos Shale area of the Upper Colorado River basin produces large quantities of solutes. In order to develop an understanding of the mechanism of salt production and to determine the source of salinity, a study of the soluble mineral content (SMC) of Mancos Shale and associated alluvium was undertaken. SMC is highly variable in alluvium and associated surficial Mancos Shale. However, lithomorphological units can be identified in terms of their SMC. [redacted] The crusts are saline, sometimes efflorescent, in shale bedrock channels or where channels abutt against the shale. [redacted]

(KEY TERMS: salt content; salinity; Colorado River basin.)

INTRODUCTION

High salt content in soils and high solute concentrations in runoff are a major problem in most semiarid and arid regions. Management techniques used to reduce the salinity hazard in such areas should be cost effective and, therefore, based on sound knowledge of salt accumulation and solute loads. [redacted] and its spatial temporal variations (Riley, *et al.*, 1979). Recent studies have dealt with the kinetics of dissolution of saline surficial materials in the laboratory (Jurinak, *et al.*, 1977; Laronne, 1980) and in the field (Shen, *et al.*, 1981; The role of sediment in nonpoint source salt loading within the Upper Colorado River basin, Completion Report No. 107, Colorado Water Resources Research Institute, 213 pp.). [redacted]

The Mancos Shale terrain, which comprises a large part of central and lower portion of the Upper Colorado River basin, is a source of considerable solute contribution to the Colorado River (U.S. Environmental Protection Agency, 1972). [redacted] These alluvial channels are incised or gullied and produce very high sediment and solute yields (e.g., Iorns, *et al.*, 1965; Lusby, *et al.*, 1971). Moreover, channel incision into both Mancos Shale and associated alluvium, a process which may have started at the end of the 19th century (Schumm and Hadley, 1957), is continuing at present. The proximity of the alluvial deposits to Mancos Shale and their derivation from the Dakota sandstone and Green River shales, as well as from the Mancos Shale proper suggest that they may contain a high SMC. [redacted]

The objective of this study was to determine the spatial variability of SMC in weathered Mancos Shale and particularly in Mancos Shale derived alluvium. As the study was carried out in areas experiencing minimal anthropogenic effects such as irrigation, grazing, or coal mining, the identification of this spatial variability will aid in the location of the natural point and diffuse source areas of high solute yields. Also, it established trends in SMC, which is essential for the development of mathematical models and land management programs in areas experiencing salinity problems. For example, if the alluvium produces appreciable quantities of solutes then standard channel control techniques could be used to reduce both solute and sediment contribution to the Colorado River.

SPATIAL VARIABILITY

The variability of SMC in surficial Mancos Shale is known to be very high (Ponce, S. L., 1975. Examination of a nonpoint source loading function for the Mancos Shale wildlands of the Price River Basin, Utah. Unpublished Ph.D. dissertation, Utah State University, 177 pp.). [redacted] Becket and Webster (1971) reviewed the literature on soil variability and stated that because

[1]Paper No. 80134 of the *Water Resources Bulletin*. Discussions are open until October 1, 1982.
[2]Respectively, Lecturer, Dept. of Geography, Ben Gurion University of the Negev, Beer-Sheva, Israel; and Full Professor, Dept. of Earth Resources, Colorado State University, Fort Collins, Colorado 80523.

the required collection and analysis of a large number of samples is laborious and not very glamorous, little information is available on how much variability is present in soils. They (Becket and Webster, 1971) did, however, conclusively show that variability increases with increased area, and they maintained that this increase is due to the inherent variability in parent materials (e.g., localized mineralization), microclimate (e.g., shelter in depressions), topography (e.g., aspect and formation of catenas), within soil processes (e.g., leaching), and biological activity (e.g., burrowing animals). They concluded that as much as half of the variability (expressed by the coefficient of variation) present within 1 ha is already present within a few m^2.

Parametric statistical tests can be utilized to determine whether significant differences among sample means exist, but these tests demand knowledge of or an assumption concerning the probability distribution function of the tested variate. Many physical soil properties are normally distributed about the mean, although the distribution functions of most hydraulic characteristics are lognormal (McIntyre and Tanner, 1959; Nielsen, *et al.*, 1973; Cassel and Bauer, 1975; Van De Pol, *et al.*, 1977). Little information is available on the distribution function of chemical properties, and different functions defining the increase in variability with increase in area have been reported (Becket and Webster, 1971).

DESCRIPTION OF STUDY AREAS

The study areas, all in Mancos Shale terrain, were selected to meet the requirements of having no irrigation or other prominent man induced effects. In this manner, the natural salt contribution from diffuse source areas could be investigated. Sampling was undertaken in channel reaches that represent the three types of channels which drain Mancos Shale outcrops within the Upper Colorado River basin (Table 1). Soils and surficial sediments were sampled from the following areas: 1) the Price River Basin, Utah, from an unnamed northern branch of Miller Creek (herein called North Miller Creek) with a drainage area (A_d) of 10.5 km^2; 2) West Salt Creek (A_d = 435 km^2) in the Grand Valley, Colorado; and 3) the unnamed 'Mesa Creek' (A_d = 11.4 km^2), a tributary of McElmo Creek near Mesa Verde National Park, Colorado (Figure 1). These sites are located in the High Plateaus and Canyonlands sections of the Colorado Plateau Physiographic Province (Fenneman, 1931).

TABLE 1. Characteristics of Channels and Their Alluvium in the Study Areas.

		Alluvium		
Study Area	Channels	Depth	Geometry	Proximity to Saturated Shale Bedrock
N. Miller Creek	bedrock	shallow	high alluvial terraces	near
Mesa Creek	alluvial	shallow	complete valley fill	near
West Salt Creek	alluvial	deep	complete valley fill	far

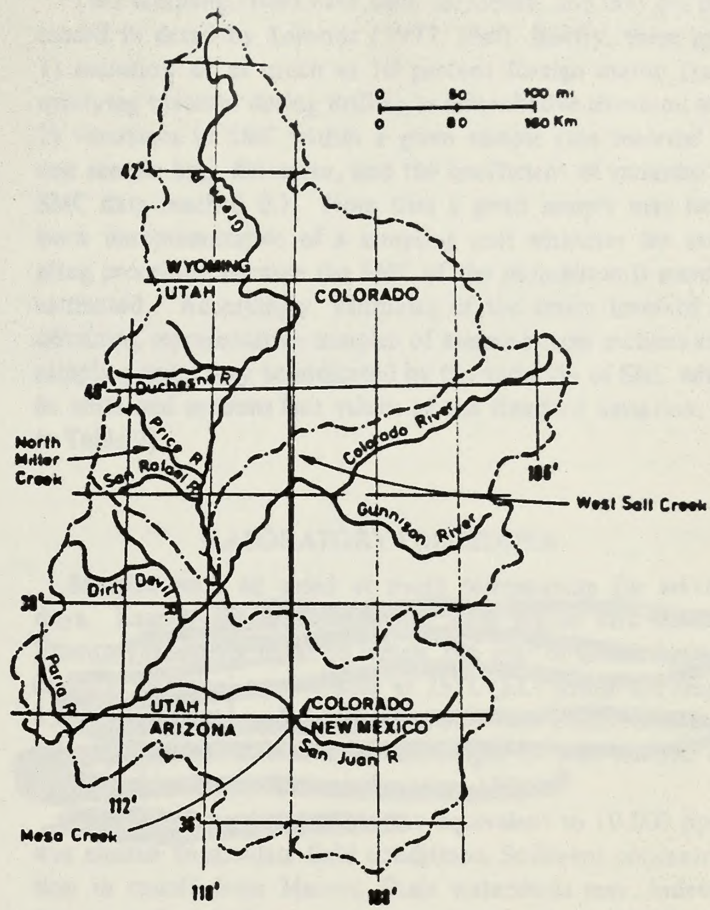


Figure 1. Map of the Upper Colorado River Basin Showing Location of Study Sites.

The characteristics of Mancos Shale, which may reach a thickness of 1000 m naturally, vary throughout the stratigraphic column (Stokes and Cohenour, 1956; Fisher, *et al.*, 1960). The shale is known to contain medium to high contents of soluble minerals which may occur as veinlets of gypsum and calcite; it is consequently a major source of solutes to the Colorado River. The variation of SMC in Mancos Shale within a given watershed, as studied in detail by Ponce (1975, *ibid*) is not as relevant to this study as is the shale-alluvium interaction. The SMC in the shale may, indeed, differ between and within study areas, although the two small watersheds and part of the studied reach within West Salt Creek lie in the same stratigraphic location.

The upper reach of North Miller Creek is deeply cut into Mancos Shale bedrock, and it is bounded by unstable vertical walls of bedrock, which may reach 15 m in height. The channel bed is presently downcutting and bedrock is exposed throughout the studied reach. Most of the alluvial deposits in the vicinity cover large elongated pediments at various levels, and closer to the channel the deposits form high (2-15 m) terraces. The alluvium, primarily comprised of gravel and sands, together with the erodible unstable shaley bedrock, supply much sediment as they erode from the gully walls.

Figure 1. Map of the Upper Colorado River Basin Showing Location of Study Sites.

the required collection and analysis of a large number of samples is laborious and not very glamorous, little information is available on how much variability is present in soils. They (Beckett and Webster, 1971) did, however, conclusively show that variability increases with increased area, and they maintained that this increase is due to the inherent variability in parent materials (e.g., localized mineralization), microclimate (e.g., shelter in depressions), topography (e.g., aspect and formation of catenas), within soil processes (e.g., leaching), and biological activity (e.g., burrowing animals). They concluded that as much as half of the variability (expressed by the coefficient of variation) present within 1 ha is already present within a few m².

Parametric statistical tests can be utilized to determine whether significant differences among sample parameters exist, but these tests demand knowledge of or an assumption concerning the probability distribution function of the tested variables. Many physical soil properties are normally distributed about the mean, although the distribution functions of most hydraulic characteristics are lognormal (Baldwin and Sumner, 1959; Nielsen, et al., 1973; Cassel and Bauer, 1975; Van De Pol, et al., 1977). Little information is available on the distribution functions of chemical properties, and different functions defining the increase in variability with increase in area have been reported (Beckett and Webster, 1971).

DESCRIPTION OF STUDY AREAS

Three study areas, all in Mancos Shale terrain, were selected to meet the requirements of having no irrigation or other prominent man-induced effects. In this manner, the surface and contribution from diffuse source areas could be investigated. Sampling was undertaken in channel reaches that represent the three types of channels which drain Mancos Shale outcrops within the Upper Colorado River basin (Table 1). Soils and surficial sediments were sampled from the following areas: 1) the Price River Basin, Utah, from an unnamed northern branch of Miller Creek (herein named North Miller Creek) with a drainage area (A_d) of 10.5 km²; 2) West Salt Creek (A_d = 436 km²) in the Grand Valley, Colorado; and 3) the unnamed 'Mine Creek' (A_d = 114 km²), a tributary of McElmo Creek near Mesa Verde National Park, Colorado (Figure 1). These sites are located in the High Plateaus and Canyonlands sections of the Colorado Plateau Physiographic Province (Fenneman, 1931).

The characteristics of Mancos Shale, which may reach a thickness of 1500 m in thickness, vary throughout the stratigraphic column (Cobban and Reeside, 1952; Fisher, et al., 1960). The shale is known to contain medium to high contents of soluble minerals, which may occur as residuals of gypsum and calcite; it is consequently a major source of salinity to the Colorado River. The variation of TDS in Mancos Shale within a given watershed, as studied in detail by Evans (1975, 1980) is not as relevant to this study as is the shale-alluvium interaction. The TDS in the shale may, indeed, differ between and within study areas, although the two small watersheds and part of the gauged reach within West Salt Creek lie in the same stratigraphic horizon.

The upper reach of North Miller Creek is deeply cut into Mancos Shale bedrock, and it is bounded by unstable vertical walls of bedrock, which may reach 12 m in height. The channel bed is presently downcutting and bedrock is exposed throughout the studied reach. Most of the alluvial deposits in the vicinity cover large elongated sediments at various levels, and above in the channel the deposits form high (2-12 m) terraces. The alluvium, primarily comprised of gravel and sands, together with the modern bedrock shaley bedrock, supply much sediment as they erode from the gully walls.

TABLE 1. Characteristics of Channels and Their Alluvium in the Study Areas.

Study Area	Channels	Alluvium		Proximity to Exposed Shale Bedrock
		Depth	Geometry	
N. Miller Creek	bedrock	shallow	high alluvial terraces	near
Mine Creek	alluvial	shallow	aggrading valley fill	near
West Salt Creek	alluvial	deep	canyon/valley fill	far

Within West Salt Creek bedrock samples were collected from Mesa Verde Group (cliff forming sandstone with interbedded shales overlying Mancos Shale) and Mancos Shale outcrops in the channel as well as from the alluvium proper. Depth of alluvium increases downstream, and it approaches a thickness of 150 m at the lowest sampling site near a U.S. Geological Survey electrical conductance monitoring and gaging station. The main channel is incised throughout its length to a depth of 5-10 m below the upper terrace, which constitutes the valley floor.

Alluvium and bedrock were also sampled in Mesa Creek. This incised channel drains a watershed as small as that of North Miller Creek, and, similarly, it is entrenched in or abutts against Mancos Shale in the upper part of the basin. The samples analyzed in this study originate from a channel reach in the central part of the Mesa Creek basin. Although the entire valley within this reach is filled with alluvium, the fill is rather shallow (~ 4m).

SAMPLING TECHNIQUE

The sampling design consists of systematic point (i.e., volume) sampling along systematic traverses chosen within several definable channel reaches in each of the study areas. The channel reaches in West Salt Creek are located upstream of the gaging station wherever the road leading to Baxter Pass is close to the channel or crosses it. A long channel reach in each of the other two basins, rather than several reaches, was chosen for logistic reasons. Each traverse, the location and description of which is given elsewhere (Laronne, J. B., 1977; Dissolution potential of surficial Mancos Shale and alluvium. Unpublished Ph.D. dissertation, Colorado State University, 128 pp.), consists of a cross section of the channel. It includes the banks and gully walls or hillslope against which the channel abutts, the channel bed proper, foreign (i.e., mass wasted) matter resting on it, as well as the nearby terrace into which the channel is incised. Each of these cross sectional parts (a morphological unit) is referred to herein as a sampling unit; it was separately sampled at varying depths because the coarse texture of the alluvium made it impractical to sample cores at given depths. In most cases several holes were drilled within a sampling unit to decrease the error arising from the large inherent variability of SMC that persists even in small areas (Ponce, 1975, *ibid*; see also Figure 3a). Weathered bedrock was sampled wherever exposed in the cross sections on banks, gully walls, and adjacent hillslopes.

Samples were collected as cores perpendicular to the surface with a 10 cm diameter bucket type auger, but salt efflorescence and surface crusts were collected by hand. Particular attention was directed in sampling the surface layer because it comes in direct contact with surface flow. Surface crusts normally form in semiarid regions and slightly cohesive crusts were present at most sampling sites except on sandy surfaces and on channel beds lacking silt and clay particles. Because crust thickness (0.1-10 cm) may vary with the sediment size distribution, mineralogy, organic content, and antecedent moisture conditions, all crusts were collected in their entirety. Samples were stored in plastic bags.

Two sampling errors have been identified, and they are discussed in detail by Laronne (1977, *ibid*). Briefly, these are: 1) inclusion of as much as 10 percent foreign matter from overlying material during drilling in noncohesive alluvium; and 2) variations in SMC within a given sample (the material in one sample bag) did occur, and the coefficient of variation of SMC data reached 0.1. Note that a given sample may have been unrepresentative of a sampling unit whatever the sampling procedure because the SMC of the *population* is merely estimated. Accordingly, estimates of the errors involved in obtaining representative samples of selected cross sections and sampling units may be indicated by the variation of SMC within units and sections (see values of the standard deviation, $\hat{\sigma}$, in Table 2).

LABORATORY PROCEDURE

Samples were air dried at room temperature for several days. [redacted]e equivalent to 10,000 ppm was chosen to simulate field conditions. Sediment concentration in runoff from Mancos Shale watersheds may, indeed, rise to such a high concentration (Ioms, *et al.*, 1965) but rarely exceeds it. [redacted]ith concommitant saturation with respect to gypsum would lead to an underestimation of SMC. 1:999 sediment:water mixtures are similar to those reported herein except for a somewhat naturally higher relative abundance of calcium and bicarbonate in solutions derived from most of the dilute mixtures (Laronne, 1977; *ibid*).

$\Sigma(C^{z+} + C^{z-})$, the sum of cationic and anionic concentrations in mg l^{-1} and equivalent to the misnomer total dissolved solids (TDS), is related to SMC. For a 1:99 sediment: water ratio, the SMC (weight per weight, in percent) is equal to $0.99\ (C^{z+} + C^{z-})$. SMC was determined in this study from EC measurements (Lectro Mho Meter, Lab Line Instruments Inc.) and from the relationship between analytically determined solute concentrations and EC (Figure 2). Although it is realized that the EC of an aqueous solution is determined by the concentration of specific ion species, our regression has a high correlation coefficient with a slope greater than unity due to common ion effects.

Chemical analyses were performed according to standard methods (U.S. Department of Agriculture, 1954). For the large majority of the analyses, $100|\Sigma(C_i^{z-} - C_i^{z+})|/\Sigma C_i^{z-} < 0.1$.

RESULTS

The mean SMC in bed crusts in North Miller Creek is 10.10 percent compared to 0.94 percent in the bed proper (Table 2). Although crusts of the lower and upper Mancos Shale gully

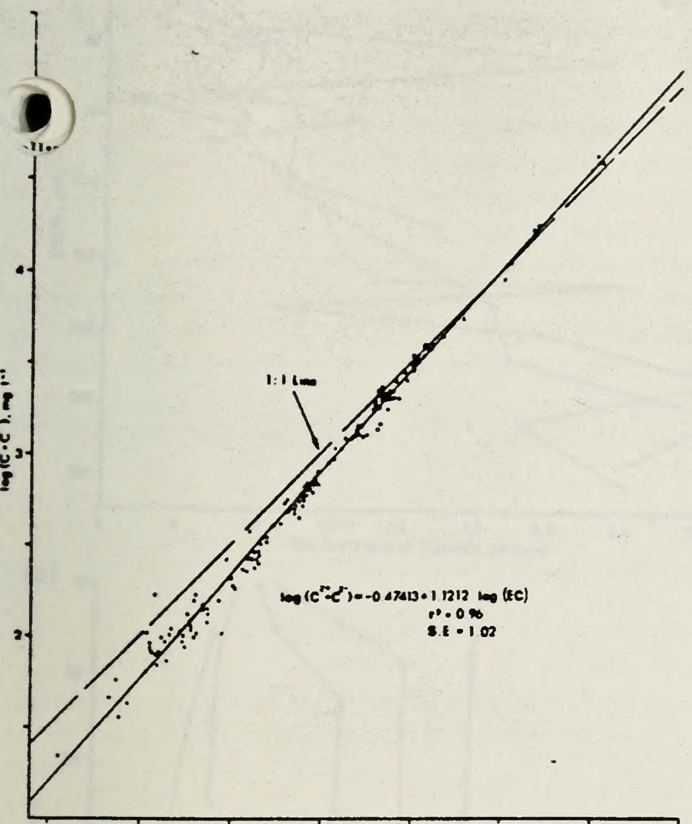


Figure 2. Variation of Total Stoichiometric Solute Concentration With Electrical Conductance.

walls of North Miller Creek contain 1.07 and 0.76 percent soluble minerals, respectively, which was more than material further removed from the surface, this difference between the lower and upper walls is not statistically significant.

Analysis of variance of the SMC in channel bed alluvium and its crust shows no significant difference. A difference was found to be significant ($\alpha < 0.05$, wherein α denotes the significance, or the maximum probability for a type 1 error) between the more saline crust and material immediately underlying it for the bed of Mesa Creek. [redacted]

The variation in SMC with depth in bed materials of Mesa Creek is shown in Figure 3a. Mean SMC for 6, 15, and 50 cm depths are 1.13, 0.91, and 1.46 percent, respectively; these means are all significantly different ($\alpha < 0.025$). [redacted] (Figure 3d) although the mean salt content of the surface crust is higher than that at any other depth. Similarly, no consistent trend of SMC with distance from the surface takes place in the terrace and gully walls of Mesa Creek (Figure 3e), in the gully walls of North Miller Creek (Figure 3c) nor in the leached terraces of West Salt and North Miller Creeks (Figure 3b).

Differences in SMC between sampling units are masked by the general large inherent variability in SMC. The extent of

TABLE 2. Summary of Mean Soluble Mineral Content ($\bar{X}$), its Standard Deviation ($\hat{\sigma}$), and the Number of Samples (n) of Sampling Units in North Miller, West Salt, and Mesa Creeks.

NORTH MILLER CREEK

	CT	T	CUMW	UMW	CAM	A	CLMW	LMW	EB[c]	B	CMS[d]	MS[d]
$\bar{X}$	0.186	0.620	0.760	0.690	1.037	1.118	1.067	0.974	10.098	0.936	0.703	1.987
$\hat{\sigma}$	0.066	0.778	0.275	0.445	0.954	1.020	0.699	0.634	14.884	0.525	0.030	0.301
n	7	22	12	7	3	9	10	13	13	21	3	9

WEST SALT CREEK

	CT	T	CW	W[e]	A	CB	B[f]
$\bar{X}$	0.141	0.296	0.323	1.009	1.335	0.509	0.665
$\hat{\sigma}$	0.043	0.196	0.292	1.606	1.562	0.544	0.813
n	7	26	4	24	13	21	60

MESA CREEK

	T	W	UB	B
[illegible]	1.690	1.734	1.130	2.081
$\hat{\sigma}$	0.622	0.509	0.430	1.630
n	14	8	9	55

[a] [illegible] expressed as weight of dissolved components per total weight, in percent.
[b] [illegible]t; T=terrace; U=upper; L=lower; M=Mancos Shale; S=hillslope; W=gully wall; A=mass wasted material; B=bed material; E=efflorescence or salt [illegible]
[c] Without one value the mean and standard deviation change to 6.281 and 4,090, respectively.
[d] From North Miller and Mesa Creeks.
[e] These wall samples include two Mancos Shale-affected sites; excluding these, the $\bar{X}$, σ, and n are 0.314, 0.284, and 17, respectively.
[f] These bed samples include five shale-affected sites; excluding these, the $\bar{X}$, σ, and n are 0.13, 0.14, and 34, respectively.

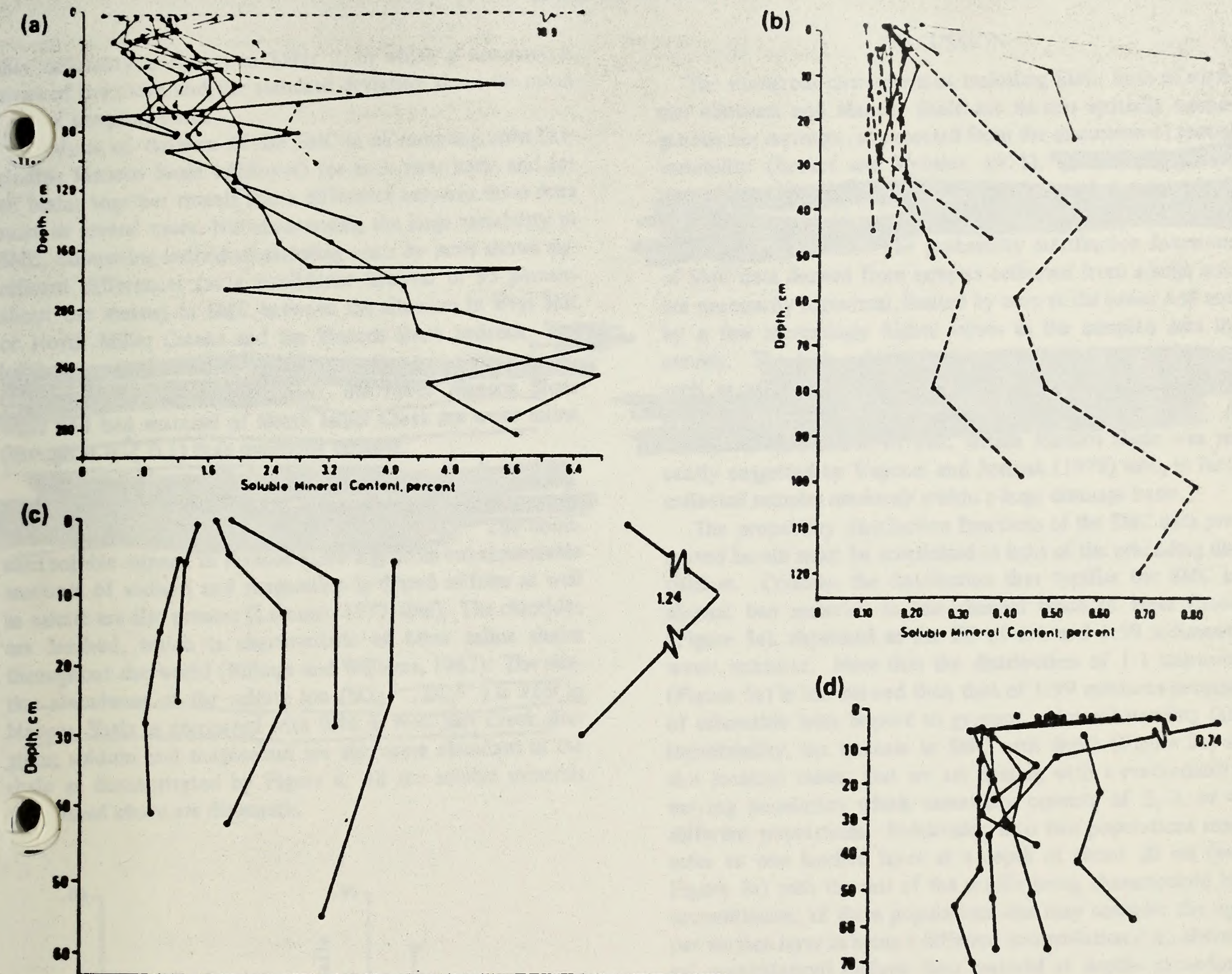


Figure 3. Variation of SMC With Depth (a) in the Bed of Mesa Creek; (b) in Terraces of West Salt and North Miller Creeks (dashed and solid lines, respectively); (c) Variation of SMC With Distance From the Surface in Gully Walls of North Miller Creek; (d) in the Bed of West Salt Creek; and (e) in the Terrace (solid lines) and Gully Walls (dashed lines) of Mesa Creek.

this variability is shown in Table 2, in which a summary is given of the mean and the standard deviation about the mean of sampling units.

Analysis of variance of the SMC in *all* sampling units (excluding Mancos Shale hillslopes) for each river basin and for all basins together reveals that a difference between them does exist in several cases. Notwithstanding the large variability in SMC, comparing individual sampling units *by pairs* shows significant differences (at a confidence interval of 95 percent about the means) in SMC between the alluvium in West Salt or North Miller Creeks and the Mancos Shale bedrock. [redacted] Also, the lower Mancos Shale walls and bed material of North Miller Creek are more saline (though at $\alpha \lesssim 0.1$) than overlying terraces.

[redacted] The dominant soluble mineral in Mancos Shale is gypsum but appreciable amounts of sodium and magnesium hydrated sulfates as well as calcite are also present (Laronne, 1977; *ibid*). The chlorides are leached, which is characteristic of other saline shales throughout the world (Billings and Williams, 1967). The relative abundance of the sulfate ion ($SO_4^{2-}/\Sigma C_i^{z-}$) is 3.09 in Mancos Shale as compared with 0.46 in West Salt Creek alluvium; soidum and magnesium are also more abundant in the shale as demonstrated by Figure 4. All the soluble minerals mentioned above are diagenetic.

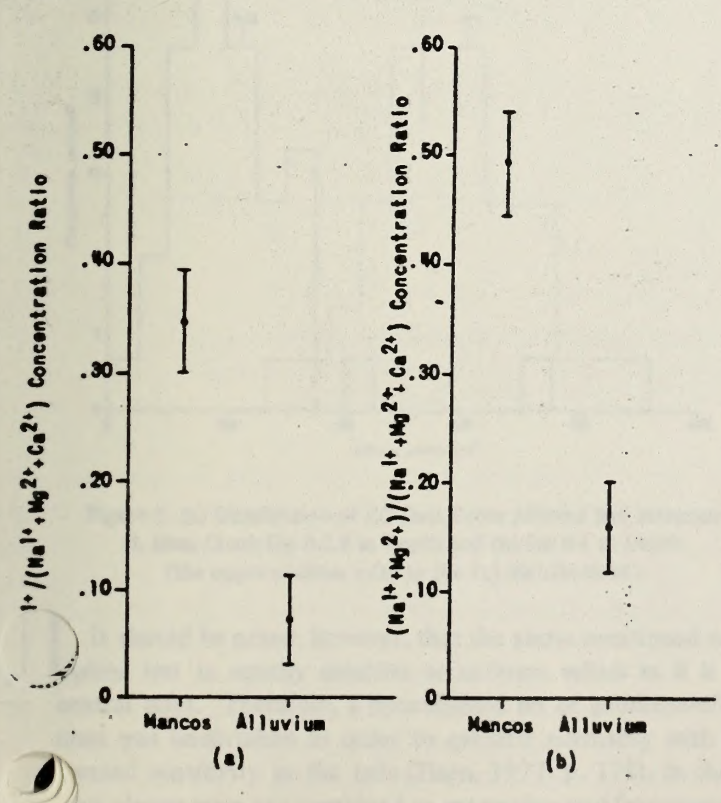


Figure 4. Means and 95 Percent Confidence Intervals About the Means of Na^{1+} (a) and $[Na^{1+} + Mg^{2+}]$ (b) Abundance Ratios From 1:99 Sediment:Water Mixtures of Mancos Shale and Alluvium.

DISCUSSION

The numerous characteristics including SMC, both of surficial alluvium and Mancos Shale are neither spatially homogenous nor isotropic, as expected from the discussion of spatial variability (Becket and Webster, 1971). [redacted] The probability distribution functions of SMC data derived from samples collected from a large area are necessarily lognormal, limited by zero at the lower end and by a few increasingly higher values as the sampled area increases. [redacted]. A [redacted] within Mancos Shale was recently suggested by Wagenet and Jurinak (1978) who, in fact, collected samples *randomly* within a large drainage basin.

The probability distribution functions of the SMC data presented herein must be scrutinized in light of the preceding discussion. Consider the distribution that typifies the SMC in alluvial bed materials in one channel reach of Mesa Creek (Figure 5a), expressed as the EC of 1:1 and 1:99 sediment: water mixtures. Note that the distribution of 1:1 mixtures (Figure 5a) is less skewed than that of 1:99 mixtures because of saturation with respect to gypsum. Notwithstanding this lognormality, the increase in SMC with depth (Figure 3a) at this location means that we are dealing with a methodically varying population which essentially consists of 2, 3, or 4 different populations. Subdivision into two populations may refer to one leached layer at a depth of about 20 cm (see Figure 3a) with the rest of the profile being characterized by accumulation; of three populations one may consider the upper surface layer as being a different accumulation (i.e., chemical precipitation) horizon than material at depths exceeding 40 cm; also, four populations may refer to the above mentioned three with an [redacted] upwards [redacted]. The data presented in Figure 3a may also be envisaged as two populations but with a different causal basis than the leaching *vs.* accumulation subdivision. In fact, the upper 1 m, for which most of the data is available, may represent a population where both upward and downward solute transport occur, and underlying material may represent primarily downward (although also downchannel and some vertically upward) solute transport and accumulation in more saline alluvium.

The distribution of SMC in the upper population (0-1 m) is apparently a normal distribution function (Figure 5b). Similarly, the distribution of SMC in Mancos Shale, as adapted from Ponce and Hawkins (1978), is also not a 'hot spot' distribution. Rather, it (Figure 6) is bimodal with a minor leached segment and the rest is approximately normally distributed about a higher value

Unlike the qualitative evaluation of distribution functions based on their similarity in form to a gaussian distribution (e.g., Figure 5b and Figure 6), normality may be quantitatively

DISCUSSION

The numerical characteristics including SMC, both of earth and alluvium and Mancos Shale are neither spatially homogeneous nor isotropic, as expected from the discussion of spatial variability (Borden and Schumm, 1971). [illegible]

[illegible] by probability distribution functions of SMC data derived from samples collected from a large area are statistically lognormal, limited by zero at the lower end and by a few increasingly higher values in the sampled area [illegible] [illegible]

[illegible] which was recently suggested by Wagenet and Jurinak (1978) who, in fact, indicated salinity variations within a large drainage basin.

The probability distribution functions of the SMC data presented herein must be considered in light of the preceding discussion. Consider the distribution that typifies the SMC in alluvial bed materials in the channel reach of Sand Creek (Figure 5a), expressed as the EC of 1:1 and 1:99 sediment-water mixtures. Note that the distribution of 1:1 mixtures (Figure 5a) is less skewed than that of 1:99 mixtures because of saturation with respect to gypsum. Notwithstanding this nonuniformity, the increase in SMC with depth (Figure 5a) at this location means that we are dealing with a stochastically varying population which apparently consists of 2, 3, or 4 different populations. [illegible]

[illegible] The data presented in Figure 5a may also be envisaged as two populations but with a different causal basis than the leaching vs. nonleaching of sediments. In fact, the upper 1 m, for which most of the data is available, may represent a population where both upward and downward water transport occur, and underlying material may represent primarily downward (although also downward) and more normally upward water transport and accumulation in more saline alluvium.

The distribution of SMC in the upper population (0-1 m) is apparently a normal distribution function (Figure 5b). Similarly, the distribution of SMC in Mancos Shale, as adapted from Ponce and Hawkins (1978), is also not a 'text book' distribution. Rather, it (Figure 6) is bimodal with a minor bimodal segment and the rest is approximately normally distributed about a higher value.

Unlike the qualitative evaluation of distributions here done based on their similarity in form to a gaussian distribution (e.g., Figure 5b and Figure 6), normality may be quantitatively

this variability is shown in Table 2, in which a summary is given of the mean and the standard deviation about the mean of sampling units.

[illegible] of variance of the SMC in all sampling units (excluding Mancos Shale bedrock) for each river basin and for all basins together reveals that a difference between them does exist in several cases. Notwithstanding the large variability in SMC, comparing individual sampling units by pairs shows significant differences (at a significance interval of 95 percent about the means) in SMC between the alluvium in West Salt or North Miller Creeks and the Mancos Shale bedrock. [illegible] Also, the exact Mancos Shale and bed material in North Miller Creek are more saline [illegible] sampling sections.

[illegible] The composition of [illegible] but appreciable amounts of sodium and magnesium hydrated sulfates as well as halides are also present (Lawson, 1977 ibid). The chemistry [illegible] which is characteristic of other saline shales throughout the world (Phillips and Williams, 1967). The relative abundance of the cations Na^+ [illegible] $(Ca^{2+} + Mg^{2+})$ in Mancos Shale is compared with that in West Salt Creek alluvium. Sodium and magnesium are also more abundant in the shale as demonstrated by Figure 4. As the results indicated above are diagnostic.

Figure 4. Means and 95 Percent Confidence Intervals About the Means of Na^+ (a) and $(Ca^{2+} + Mg^{2+})$ (b) Abundance Ratios From 1:99 Sediment-Water Extractions of Mancos Shale and Alluvium.

evaluated by determining the linearity of cumulative distributions on probability paper as depicted in Figure 7. The probability distribution functions of SMC in the more rigorously sampled morphological units within West Salt and North Miller Creeks (Figure 7) are indeed not far removed from normality. Neither high correlations characterize the regressions of cumulative probability *vs.* TDS (i.e., they are roughly linear) although only one sampling unit, the leached bed materials of West Salt Creek, exhibits an unequivocal linear relationship and several others are bimodal.

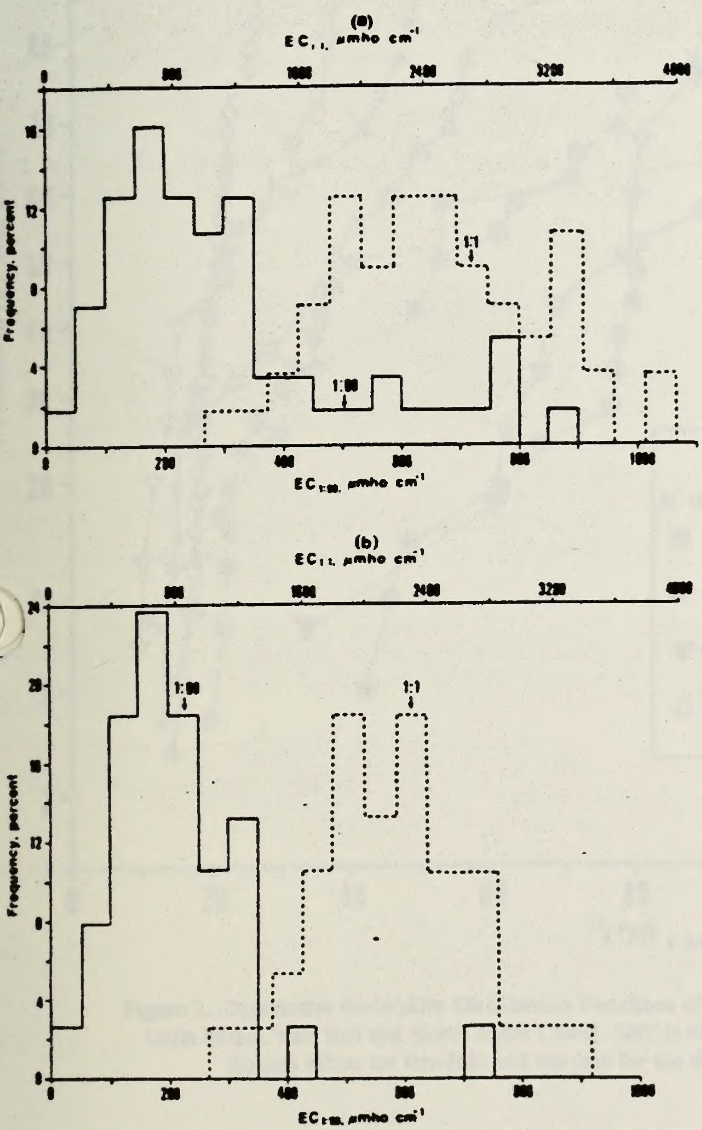


Figure 5. (a) Distribution of EC Data From Alluvial Bed Materials in Mesa Creek for 0-2.8 m Depth and (b) for 0-1 m Depth (the upper abcissas refer to the 1:1 distributions).

It should be noted, however, that the above mentioned normality test is equally sensitive to extreme values as it is to central ones. Therefore, a nonstandard set of goodness-of-fit tests was undertaken in order to evaluate normality with increased sensitivity in the tails (Haan, 1977, p. 178). In these tests classes were not combined to get an observed frequency of 3 or 5 as outlined in general statistics books (e.g., Walpole and Myers, 1978, p. 266). These goodness-of-fit tests, the results of which are summarized in Table 3, were used to determine whether the data may be adequately represented by a gaussian distribution with a given (α) confidence level. All but one of the distributions are, in fact, normal as is evidence by α values equal to or greater than 0.025. Note that whereas opinion varies concerning which critical confidence level proves a good fit (usually $\alpha = 0.05$), the fit always *increases* as α increases.

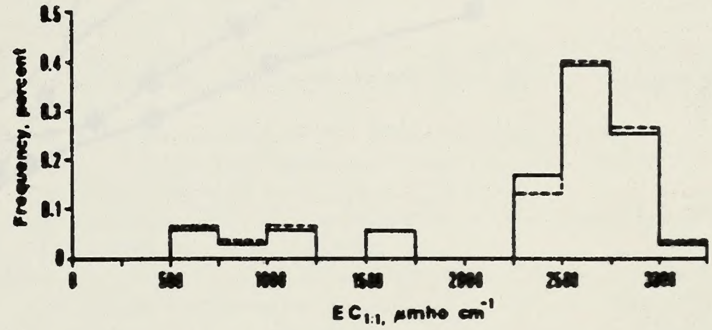


Figure 6. Distribution of SMC, Expressed as EC of 1:1 Mixtures, of Mancos Shale From Three Lumped Microgrids, each 27.6 m^2 and Represented by 12 Samples (solid lines) and one Macrogrid, 1620 m^2 with 30 Samples (dashed lines). Adapted from Ponce and Hawkins (1978).

The results presented in Figures 5, 6, and 7 and Table 3 prove that the distribution of SMC within sampling units is approximately normal; this, in turn, indicates that mean values are representative of these sampling units and that units may be compared on the basis of SMC using standard parametric techniques. Therefore, part of the data of Table 2 may be used to delineate spatial trends in SMC (see Figure 8). The following is a discussion of these trends.

[redacted] which the channel abutts. This 'sterility' is due to the coarse texture of the alluvium which favors the rapid downward percolation of water and due to the absence of nearby sources containing a high SMC. [redacted]. Such an enrichment is illustrated by the increase in SMC with depth (Figure 3a), a trend which is nonexistent in the upper part of deep fills (Figure 3d).

[redacted] deep alluvial fills are covered with crusts. This is expected because of the leaching effectiveness of the downward movement of water in highly permeable coarse sediments. However, the downward flux of water and solutes is restricted where permeability is lower and moisture content higher, so that salt precipitation ensues as soon as water evaporates. [redacted] covers saline alluvium (note the decrease in SMC at 15-20 cm depth, Figure 3a).

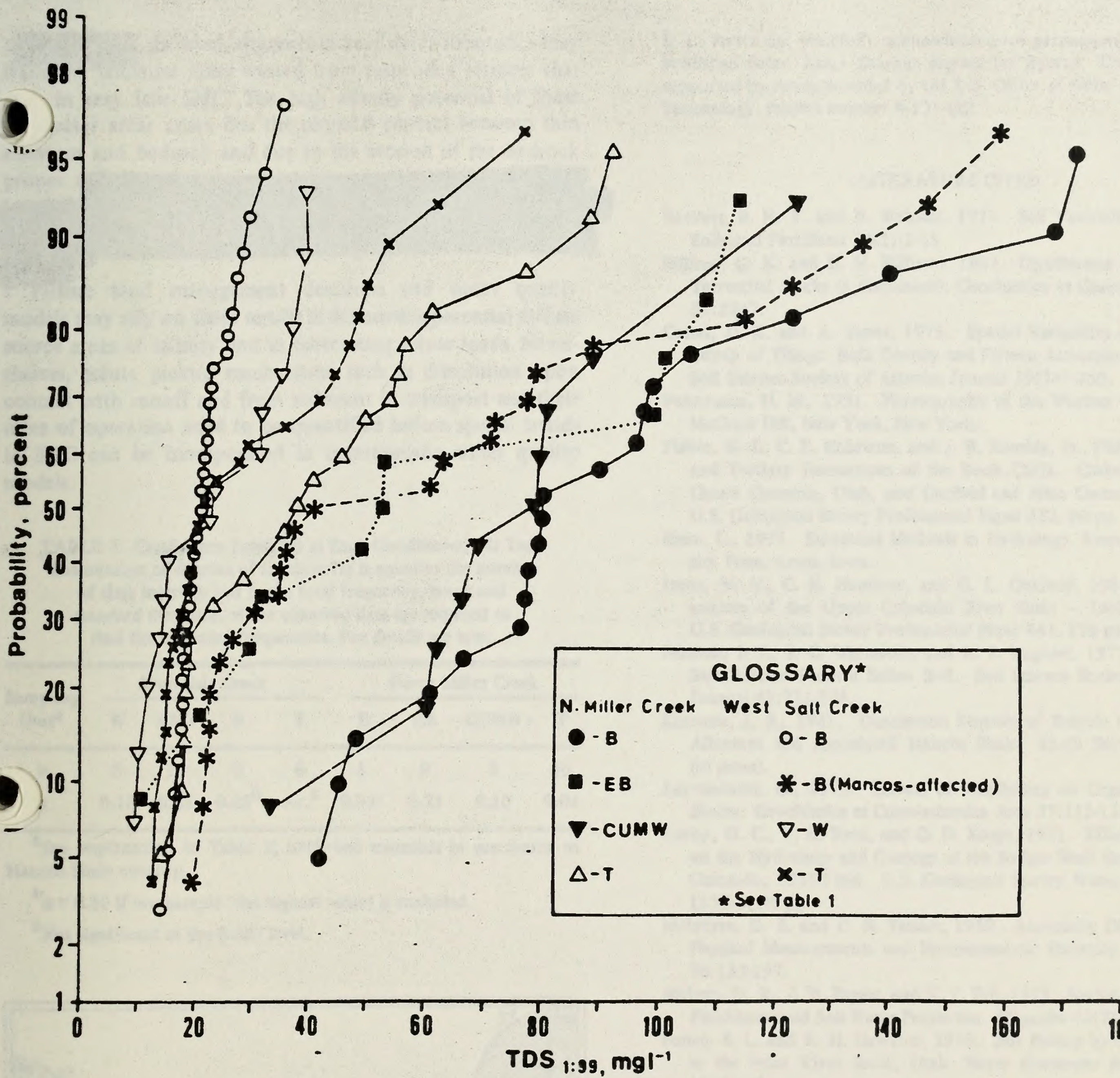


Figure 7. Cumulative Probability Distribution Functions of SMC for the More Rigorously Sampled Morphological Units Within West Salt and North Miller Creeks. SMC is expressed as the TDS of 1:99 sediment:water mixtures. Abcissa values are two-fold and ten-fold for the dashed and dotted distributions, respectively.

Surficial Mancos Shale sampled from hillslopes is on the average more saline than the limited number of crust samples (Table 2). This also applies to Mancos Shale sampled at other locations (Shen, *et al.*, 1981; *ibid*). Wagenet and Jurinak (1978) sampled Mancos Shale in the Price River basin and showed that although the mean and median SMC increased with depth, the mode behaved in the opposite manner. Their results agree with ours because the increase of the mode with depth is due to the strong positive skewness (lognormality) and a trend of the standard deviation of SMC in their data to increase with depth.

The EC of 14 pairs of Mancos Shale samples (Ponce, 1975; *ibid*) was analyzed and it also shows leaching of the crust; the uppermost samples (0-2.5 cm) are on the average half as saline as the friable underlying (15-30 cm) material. Leythaeuser (1973) also provides data showing that the upper layer is leached in Mancos Shale.

CONCLUSIONS

An important conclusion stemming from the results presented in this study is [redacted]

t[redacted] Bedrock channels in headwater tributaries may trans[redacted]vium mass wasted from suspended terraces that ...in very low SMC. The high salinity potential of these ...water areas arises due the physical contact between thin alluvium and bedrock and due to the erosion of the bedrock proper. [redacted]

Future land management decisions and water quality models may rely on these results in delineating potential diffuse source areas of salinity and in forecasting solute loads. Nevertheless, solute pickup mechanisms such as dissolution upon contact with runoff and from sediment in transport and their rates of operation need to be quantified before spatial trends in SMC can be incorporated in deterministic water quality models.

TABLE 3. Confidence Level (α) in Each Goodness-of-Fit Test. The number of degrees of freedom (ν) is equal to the number of class intervals less 3; the total frequency, mean and standard deviation of the observed data are required to find the expected frequencies. For details see text.

Sampling Unit[a]	West Salt Creek				North Miller Creek			
	W	BMS	B	T	B	EB	CUMW	T
ν	5	13	9	6	5	9	3	10
α	0.10	0.25	0.05[b]	n.s.[c]	0.025	0.25	0.10	0.05

[a]See explanation in Table 2; BMS=bed materials in proximity to Mancos Shale outcrop.

[b]α = 0.10 if one sample (the highest value) is excluded.

[c]Not significant at the 0.025 level.

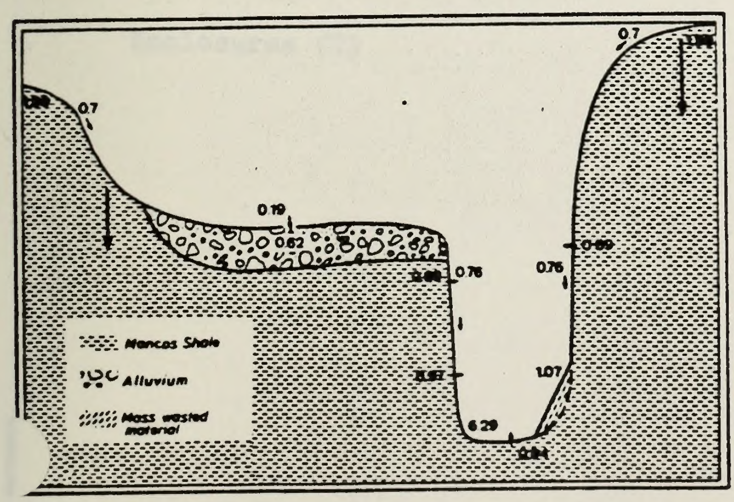


Figure 8. Model of Spatial Variation of SMC in a Mancos Shale Bedrock Channel (e.g., North Miller Creek). The arrows point to the net transport direction of solutes.

ACKNOWLEDGMENTS

The authors wish to thank Prof. J. W. Biggar, University of California at Davis, for reviewing this manuscript. Prof. H. W. Shen and Prof. S. L. Ponce are gratefully acknowledged for permissions to quote unpublished data. Lazar Sharona drafted the figures. The research was supported by funds provided by the U.S. Office of Water Resources and Technology, project number B-121-CO.

LITERATURE CITED

Beckett, P. H. T. and R. Webster, 1971. Soil Variability: A Review. Soils and Fertilizers 34(1):1-15.

Billings, G. K. and H. H. Williams, 1967. Distribution of Chlorine in Terrestrial Rocks (a discussion). Geochimica et Cosmochimica Acta 31:2247.

Cassel, D. K. and A. Bauer, 1975. Spatial Variability in Soils Below Depth of Tillage: Bulk Density and Fifteen Atmosphere Percentage. Soil Science Society of America Journal 39:247-250.

Fenneman, N. M., 1931. Physiography of the Western United States. McGraw Hill, New York, New York.

Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1961. Cretaceous and Tertiary Formations of the Book Cliffs. Carbon, Emery and Grand Counties, Utah, and Garfield and Mesa Counties, Colorado. U.S. Geological Survey Professional Paper 332, 80 pp.

Haan, C., 1977. Statistical Methods in Hydrology. Iowa State University Press, Ames, Iowa.

Iorns, W. V., C. H. Hembree, and G. L. Oakland, 1965. Water Resources of the Upper Colorado River Basin – Technical Report. U.S. Geological Survey Professional Paper 441, 370 pp.

Jurinak, J. J., J. C. Whitmore, and R. J. Wagenet, 1977. Kinetics of Salt Release From a Saline Soil. Soil Science Society of America Journal 41:721-724.

Laronne, J. B., 1981. Dissolution Kinetics of Soluble Minerals From Alluvium and Associated Mancos Shale. Earth Surface Processes (in press).

Leythaeuser, D., 1973. Effects of Weathering on Organic Matter in Shales. Geochimica et Cosmochimica Acta 37:113-120.

Lusby, G. C., V. H. Reid, and O. D. Knipe, 1971. Effects of Grazing on the Hydrology and Geology of the Badger Wash Basin in Western Colorado, 1953-1966. U.S. Geological Survey Water Supply Paper 1532-D, 90 pp.

McIntyre, D. S. and C. B. Tanner, 1959. Anormally Distributed Soil Physical Measurements and Nonparametric Statistics. Soil Science 88:133-137.

Nielsen, D. R., J. W. Biggar, and K. T. Erh, 1973. Spatial Variability of Field-Measured Soil-Water Properties. Hilgardia 42(7):215-259.

Ponce, S. L. and R. H. Hawkins, 1978. Salt Pickup by Overland Flow in the Price River Basin, Utah. *Water Resources Bulletin* 14(5): 1187-1200.

Riley, J. P., *et al.*, 1979. Preliminary Identification of Price River Basin Salt Pick-up and Transport Processes. *Water Resources Bulletin* 15(4):984-995.

Schumm, S. A. and R. F. Hadley, 1957. Arroyos and the Semiarid Cycle of Erosion. American Journal of Science 255:161-174.

Stokes, W. L. and R. E. Cohenour, 1956. Geologic Atlas of Utah. Utah Geological and Mineralogical Survey Bulletin 52, 92 pp.

U.S. Department of Agriculture, 1954. Diagnosis of Saline and Alkali Soils. U.S. Agricultural Handbook No. 60, 160 pp.

U.S. Environmental Protection Agency, 1972. Proceedings of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries, 7th Session, Las Vegas, Nevada, Vol. 1.

Van De Pol, R. M., P. J. Wierenga, and D. R. Nielsen, 1977. Solute Movement in a Field Soil. Soil Science Society of America Journal 41:10-13.

Wagenet, R. J. and J. J. Jurinak, 1978. Spatial Variability of Soluble Salt Content in a Mancos Shale Watershed. Soil Science 126(6): 342-349.

Walpole, R. E. and R. H. Myers, 1978. Probability and Statistics for Engineers and Scientists, 2nd edition. MacMillan, New York, New York.

[illegible]. Bedrock channels in headwater tributaries may [illegible] alluvium mass wasted from suspended terraces that [illegible] very low SMC. The high salinity potential of these [illegible] areas shows that the physical contact between thin alluvium and bedrock and that in the erosion of the bedrock proper [illegible]

Future land management decisions and water quality models may rely on these results in delineating potential diffuse source areas of salinity and in forecasting saline loads. Nevertheless, solute pickup mechanisms such as dissolution upon contact with runoff and from sediment in transport and their rates of operation need to be quantified before spatial trends in SMC can be incorporated in deterministic water quality models.

TABLE 3. Confidence Limit (a) in Each Greenberg-Wilk Test. The number of degrees of freedom for a equal to the number of mass sampling less 3, the total frequency, mean and standard deviation of the observed data are required to find the expected frequencies. For details see text.

Sampling Unit[a]	Main Salt Creek				North Miller Creek				
	W	SMD	B	T	B	SB	COMP	T	
N	3	11	3	8	5	9	3	10	
a	0.10	0.25	0.05^b	$n.s.^c$	0.025	0.25	0.10	0.50	

[a]See explanation in Table 2; SMD-bed materials in proximity to bedrock; Shale outcrops.

[b]a = 0.10 if one sample (the highest value) is excluded.

[c]Not significant at the 0.50 level.

Figure 6. Model of Spatial Variation of SMC in a Mancos Shale Bedrock Channel (e.g., North Miller Creek). The arrows point to the net transport direction of salines.

ACKNOWLEDGMENTS

The authors wish to thank Prof. J. R. Biggar, University of California at Davis, for reviewing this manuscript. Prof. M. W. Gass and Prof. A. E. Potter are gratefully acknowledged for permission to quote unpublished data. Linda Shannon drafted the figures. The research was supported by funds provided by the U.S. Office of Water Resources and Technology, project number B-122-UT.

LITERATURE CITED

Bennett, J. H. T. and R. Wheaton. 1971. Soil Variability: A Review. Soils and Fertilizers 34(1):1-13.
Billings, G. K. and H. H. Williams. 1967. Distribution of Chlorine in Terrestrial Rocks (a discussion). Geochimica et Cosmochimica Acta 31:2247.
Cassel, D. K. and A. Bauer. 1975. Spatial Variability in Soils Below Depth of Tillage: Bulk Density and Fifteen Atmosphere Percentage. Soil Science Society of America Journal 39:247-250.
Fenneman, N. M. 1931. Physiography of the Western United States. McGraw-Hill, New York, New York.
Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr. 1960. Cretaceous and Tertiary Formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa Counties, Colorado. U.S. Geological Survey Professional Paper 332, 80 pp.
Hahn, G. 1977. Statistical Methods in Hydrology. Iowa State University Press, Ames, Iowa.
Iorns, W. V., C. H. Hembree, and G. L. Oakland. 1965. Water Resources of the Upper Colorado River Basin — Technical Report. U.S. Geological Survey Professional Paper 441, 370 pp.
Jackson, J. J., J. C. Whitmore, and R. J. Wagenet. 1977. Leaching of Salt Residues From a Saline Soil. Soil Science Society of America Journal 41:153-154.
Laronne, J. B. 1981. Dissolution Kinetics of Soluble Minerals From Alluvium and Associated Mancos Shale. Earth Surface Processes (in press).
Löffelmann, G. 1972. Effects of Weathering on Organic Matter in Shales. Geochimica et Cosmochimica Acta 37:115-126.
Lusby, G. C., V. H. Reid, and O. D. Knipe. 1971. Effects of Grazing on the Hydrology and Geology of the Badger Wash Basin in Western Colorado, 1953-1966. U.S. Geological Survey Water Supply Paper 1532-D, 90 pp.
McIntyre, D. S. and C. B. Tanner. 1959. Anormally Distributed Soil Physical Measurements and Nonparametric Statistics. Soil Science 88:133-137.
Nielsen, D. R., J. W. Biggar, and K. T. Erh. 1973. Spatial Variability of Field-Measured Soil-Water Properties. Hilgardia 42(7):215-259.
Ponce, S. L. and R. H. Hawkins. 1978. Salt Pickup by Overland Flow in the Price River Basin, Utah. Water Resources Bulletin 14(5): 1187-1200.
Riley, J. P. et al. 1979. Preliminary Identification of Price River Basin Salt Pick-up and Transport Processes. Water Resources Bulletin 15(4):984-995.
Schumm, S. A. and R. F. Hadley. 1957. Arroyos and the Semiarid Cycle of Erosion. American Journal of Science 255:161-174.
Stokes, W. L. and D. E. Cohenour. 1956. Geologic Atlas of Utah, Utah Geological and Mineralogical Survey Bulletin 52, 92 pp.
U.S. Department of Agriculture. 1954. Diagnosis of Saline and Alkali Soils. U.S. Agricultural Handbook No. 60, 160 pp.
U.S. Environmental Protection Agency. 1972. Proceedings of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and its Tributaries, 7th Session, Las Vegas, Nevada. Vol. 1.
Van De Pol, R. M., P. J. Wierenga, and D. R. Nielsen. 1977. Solute Movement in a Field Soil. Soil Science Society of America Journal 41:10-13.
Wagenet, R. J. and J. J. Jurinak. 1978. Spatial Variability of Soluble Salt Content in a Mancos Shale Watershed. Soil Science 126(6): 342-349.
Wagner, R. E. and R. H. Brown. 1978. Probability and Statistics for Engineers and Scientists. 2nd edition. Macmillan, New York, New York.

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
1037 20th STREET
DENVER, CO 80202

IN REPLY REFER TO:
CO-933
4120

August 7, 1984

Instruction Memorandum No. CO-84-402
Expires: 9/30/85

To: District Managers

From: State Director, Colorado

Subject: Worksheet #3 - Rangeland Investment Ranking for FY '85 AWP

Forthcoming annual work plan directives will require completion of Worksheet #3. A blank and a sample copy are enclosed for your use. Completion of Worksheet #3 is in response to the Office of Management and Budget requirement that we prepare a special analysis of range investment.

We are sending you this information prior to AWP preparation so that you have enough time available to gather the required data for timely AWP submission.

Any questions should be addressed to Hans Hess (CO-933) at 844-3264 or FTS 564-3264.

Kannon Richard

Enclosures (2)

State *Arizona* Resource Area *Gila*

District *Safford* Preparer *Smith*

WORKSHEET #3

Rangeland Investment Ranking For FY AWP

Page *1*

Date Prepared *9-9-84*

Group	INVESTMENT ANALYSIS: Allotment	Mgmt. Cat.	B/C Ratio	IROR	RPS Rank	User Coop.	Dist. Adv. Bd. Rank	Area Mgr. AWP Rank	Dist. Mgr. Rank	PROJECT WORK SCHEDULE: PROJECT No.	PROJECT Name	CONSTR. UNITS No.	CONSTR. UNITS Type	Sub-Activity	Job Code	CONSTR. Type	Est. Costs BLM	Est. Costs Contr.	Comments
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Maint.	Logo #4520	M				—	1	1		50 12	Diablo Pipeline	10	mi.	7120	4457	F		500	12 stocktanks on this pipeline
										25 61	Study Excl. #1	1	ea	4322	4462	F	100		Range study comparison area
	Bruno #4960					—	1	1		1/2 10	Big Reservoir	1	ea.	4322	4457	C	200		Multiple use reservoir, used
														4350	5557		200		by lvst., waterfowl, and flood
														4340	5257		200		and sediment control.
2 Old Plans	Wabash #4600	I	1.6/1	12.0	5	A	2	2		9 50 1	Dunn Seeding	500	ac.	8100	4455	C	10,000		Tame spring pasture will
														4350	5355		5,000		allow deferred turn-out on native rng
3 New plans	Bryce #4608	I	4.3/1	44.8	7	A	4	3		16 00	Hot Spr. Catchment	1	ea	8100	4457	F	7,200	6,200	Materials contributed by permittee
										50 19	B.P. Pipeline Ext.	1.7	mi.	8200	4457	C	9,000	1,700	labor contributed by permittee
	Whitetail #5150	I	.5/1	-1.9	—	D	3	4		60 11	Whitetail Pipeline	3.0	mi.	7120	4457	C		3,368	Contributions deposited
										50 18	Whitetail Tank	1	ea.	8100	4457	F	1,500		
4 Addit. Project Needs	Tollgate #5033	I	1.4/1	11.2	10	A	6	5		52 18	Yellowstone Pipeline	.4	mi.	8100	4457	F	1300		
										50 20	Yellowstone Tank	1	ea.	8100	4457	F	3700		
	Slickrock #5113	I	.5/1	-2.3	11	O	5	6		50 16	Sliderock Tank	1	ea.	8100	4457	F	3,500		SCS Ranch Plan

Group Projects and separate with with a heavy horizontal line:

1. all maintenance projects
2. projects needed to fully implement a plan (column 6) already cleared for funding
3. projects needed to implement new plans
4. additional projects (25% above cost target) next in line for implementation should extra funds become available because of budget add-ons, contract savings, etc.

Enclosure 2

State ________ Resource Area ________

District ________ Preparer ________

WORKSHEET #3

Rangeland Investment Ranking For FY AWP

Page ________

Date Prepared ________

INVESTMENT ANALYSIS									PROJECT WORK SCHEDULE									
									PROJECT		CONSTR. UNITS				CONSTR.			
																Est. Costs		
Allotment	Mgmt. Cat.	B/C Ratio	IROR	RPS Rank	User Coop.	Dist. Adv. Bd. Rank	Area Mgr. AWP Rank	Dist. Mgr. Rank	No.	Name	No.	Type	Sub-Activity	Job Code	Type	BLM	Contr.	Comments
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Group Projects and separate with with a heavy horizontal line:

1. all maintenance projects
2. projects needed to fully implement a plan (column 6) already cleared for funding
3. projects needed to implement new plans
4. additional projects (25% above cost target) next in line for implementation should extra funds become available because of budget add ons, contract savings, etc.

Enclosure 1

[illegible] Dam Safety

Program Definition

A. Dam Programs
   1. National Dam Inspection Act 1972
      a. Defines a dam to greater than 25 ft. in hydraulic height and impounds greater than 50 ac. ft. of water
   2. DNR Program
      a. Defines a dam as greater than 6 ft. in hydraulic height, and impounds greater than 15 ac. ft. of water

B. DNR Policy
   1. DNR [illegible]
   2. Inventory of all DNR dams
   3. Inspection survey every 3 yrs
   4. Only inspect DNR-owned dams

C. Inventory
   1. All dams - 6 ft. height, 15 ac. ft. storage
   2. Location

D. Classification
   1. Size
   2. Hazard
      a. Low
      b. Medium
      c. High

E. Inspection Survey
   1. Preliminary physical inspection
   2. Verifies hazard & size classification
   3. Frequency
      a. Once every 3 yrs. for all dams
      b. Every yr. for
         (1) Classification as large
         (2) Significant, high hazard

F. Emergency Preparedness Plan
   1. Dams with all significant or high hazard
   2. Inundation maps
   3. At District Office

G. Funding
   1. Engineering - [illegible]
      a. [illegible] Survey, Emergency Plan, [illegible]
   2. [illegible]
      a. [illegible]

Water Resource Issues - Dam Safety

I. Program Definition

A. Two Programs
1. National Dam Inspection Act 1972
a. Defines a dam as greater than 25 ft. in hydraulic height and impounds greater than 50 ac. ft. of water
2. BLM Program
a. Defines a dam as greater than 6 ft. in hydraulic height, and impounds greater than 15 ac. ft. of water

B. BLM Policy
1. BLM Manual 9177
2. Inventory of all BLM dams
3. Condition survey every 3 yrs.
4. Only inspect BLM-owned dams

C. Inventory
1. All dams 6 ft. height, 15 ac. ft. storage
2. Location

D. Classification
1. Size
2. Hazard
a. Low
b. Medium
c. High

E. Condition Survey
1. Evaluates Physical Condition
2. Verifies Hazard & Size Classification
3. Frequency
a. Done every 3 yrs. for all dams
b. Every yr. for
(1) Intermediate or large
(2) Significant, high hazard

F. Emergency Preparedness Plan
1. Done for All Significant or High Hazard
2. Inundation Maps
3. At District Office

G. Funding
1. Engineering - 4714
a. Inventory, Condition Survey, Emergency Prep. Plan
2. Soil, Water, Air - 4341
a. Maintenance

Water Resource Issues - Water Rights

I. BLM Manual

A. Policy

1. States have authority over water rights in their state, except as otherwise specified by Congress.
2. Very general

B. Types of Water Rights

1. Reserved Rights
2. Appropriate Rights
3. Riparian Rights
4. Oil & Gas Conversions

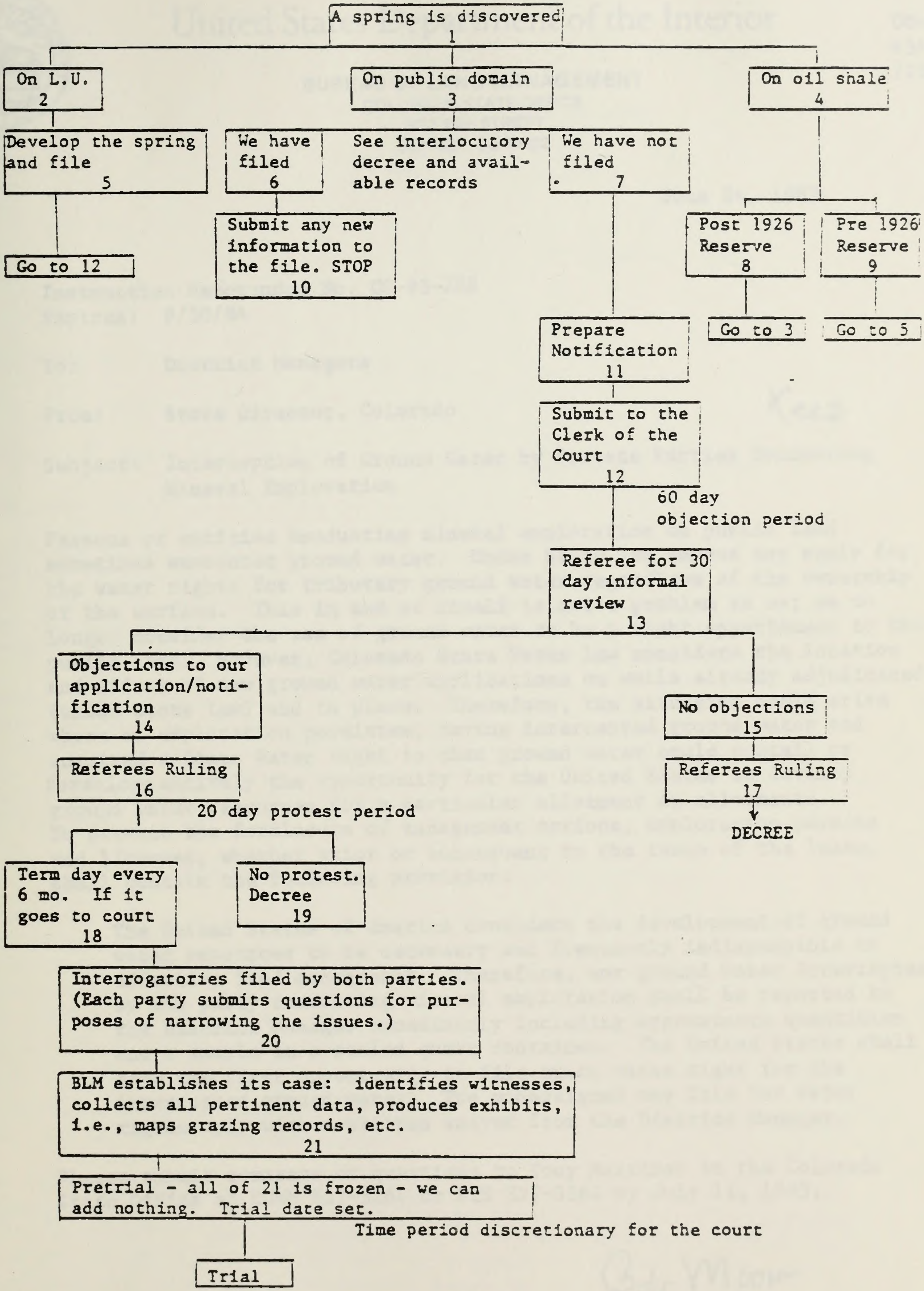
II. Steps for Filing

A. Lands Determination
B. Type of Right
C. Filing
D. Objectives

III. Issues

A. Appropriate Rights
B. Wilderness
C. Mining
D. Oil & Gas
E. Case Studies

NOTIFICATION



United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
1037 20th STREET
DENVER, CO 80202

IN REPLY REFER TO:
CO-933
4340
7250

June 24, 1983

Instruction Memorandum No. CO-83-288
Expires: 9/30/84

To: District Managers

From: State Director, Colorado

Keep

Subject: Interception of Ground Water by Private Parties Conducting Mineral Exploration

Persons or entities conducting mineral exploration on public land sometimes encounter ground water. Under State law anyone may apply for the water rights for tributary ground water regardless of the ownership of the surface. This in and of itself is not a problem to us; we no longer consider the use of ground water to be a right appurtenant to the public land. However, Colorado State Water law considers the location and effect of new ground water applications on wells already adjudicated (under State law) and in place. Therefore, the situation could arise where an exploration permittee, having intercepted ground water and acquired a State Water right to that ground water could curtail or foreclose entirely the opportunity for the United States to develop ground water resources for a particular allotment or allotments. To prevent the forclosure of management options, exploration permits and licenses, whether prior or subsequent to the issue of the lease, shall contain the following provision:

> The United States of America considers the development of ground water resources to be necessary and frequently indispensible to effective land management. Therefore, any ground water intercepted by the party conducting mineral exploration shall be reported to the District Manager immediately including approximate quantities and a sample in a sealed quart container. The United States shall have the first opportunity to file state water right for the intercepted ground water. The undersigned may file for water rights only with a written waiver from the District Manager.

Please submit comments or questions to Tony Martinez in the Colorado State Office at COMM 837-3264 or FTS 327-3264 by July 11, 1983.

Bob Moore

Associate

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
2020 ARAPAHOE STREET
DENVER, COLORADO 80205

IN REPLY REFER TO:
CO-933
7250.1

December 20, 1985

Information Bulletin No. CO-86- 52

To: District Managers

From: Deputy State Director for Lands and Renewable Resources

Subject: 84 K-2, Sierra Club vs. Block

The issue of reserved water rights in wilderness areas has been heavily debated in Congress during the last several sessions. The Colorado delegation is particularly concerned with the impact wilderness reserved water rights could have on our state water allocation system. A recent Federal District Court decision provides some insight into the question.

Judge Kane addressed three issues in his decision: " 1) whether federal reserved water rights exist with respect to the designated Colorado wilderness areas, 2) whether federal defendants have a duty to administer the wilderness areas pursuant to the public trust doctrine, and 3) whether federal defendants' failure to assert reserved water rights is arbitrary, capricious, unlawful under the APA, or violates the public trust."

Federal Reserved Rights in Wilderness Areas

A reserved water right can arise by implication when land is withdrawn from the public domain. Judge Kane considered the arguments of defendant intervenors, Mountain States Legal Foundation, Colorado Cattleman's Association, the Colorado Farm Bureau, the National Cattleman's Association, the City and County of Denver, The Colorado Water Congress (hereafter referred to as defendant intervenors), that the lands in question were withdrawn from the public domain when the national forests or parks were created. It was their contention that subsequent land dedications like wilderness designations could not be withdrawals because the land is no longer public domain.

The decision points out that there is nothing sacrosanct about the first withdrawal from the public domain. Subsequent withdrawals would certainly have the effect of creating reserved water rights, particularly when the language of the Wilderness Act and the legislative history stress the importance of maintaining the natural character of the designated wilderness area.

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
2850 YOUNGFIELD STREET
DENVER, COLORADO 80215

December [illegible], 198[illegible]

Information Bulletin No. CO-86- [illegible]

To: District Managers

From: Deputy State Director for Lands and Renewable Resources

Subject: 84 B 2, Sierra Club vs. Block

The issue of reserved water rights in wilderness areas has been heavily debated in Congress during the last several sessions. The Colorado delegation is particularly concerned with the impact wilderness reserved water rights would have on our state water allocation system. A recent Federal District Court decision provides some insight into the question.

Judge Kane addressed three issues in his decision: "1) whether federal reserved water rights exist with respect to the designated Colorado wilderness areas, 2) whether federal defendants have a duty to administer the wilderness areas pursuant to the public trust doctrine, and 3) whether federal defendants' failure to assert reserved water rights is arbitrary, capricious, unlawful under the APA, or violates the public trust."

Federal Reserved Rights in Wilderness Areas

A reserved water right can arise by implication when land is withdrawn from the public domain. Judge Kane considered the arguments of defendant intervenors, Mountain States Legal Foundation, Colorado Cattlemen's Association, the Colorado Farm Bureau, the National Cattlemen's Association, the City and County of Denver, the Colorado Water Congress (hereafter referred to as defendant intervenors), that the lands in question were withdrawn from the public domain when the national forests or parks were created. It was their contention that subsequent land designations like wilderness designations could not be withdrawals because the land is no longer public domain.

The decision points out that there is nothing [illegible] about the first withdrawal from the public domain. Subsequent withdrawals would certainly have the effect of creating reserved water rights, particularly when the language of the Wilderness Act and the legislative history stress the importance of maintaining the natural character of the designated wilderness area.

In concluding that Congress did intend to withdraw the land for a specific public purpose the Court states: "Wilderness is not simply a land management status. Rather, wilderness areas are federal reservations whose status, as concerns the implied-reservation-of-water doctrine, is equal to that of other federal reservations such as national forests, parks, and monuments."

Public Trust Doctrine

The Court points out that the public trust doctrine does not apply to situations where Congressional direction is very specific. Under 1133(b), "each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character..... wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use" 16 U.S.C. S 1133 (b).

In concluding that the public trust doctrine is inapplicable, the Court finds the language in the Wilderness Act sufficiently specific.

Must the Federal Agencies Assert Reserved Water Rights?

Judge Kane found:

> To begin with, the Wilderness Act unequivocally imposes certain duties on the part of agencies and officials administering the wilderness areas. Sections 1131(a) and 1133(b) require that the wilderness character of these areas be protected and preserved. Further, Congress stated that these areas shall be administered "for the use and enjoyment of the American people in such a manner as will leave them unimpaired for future use and enjoyment as wilderness...." 16 U.S.C. S 1131(a). Finally, S 1133(b) mandates that the "wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use" and that the agencies charged with administering the wilderness areas shall administer the areas for these purposes.
>
> These mandates evince Congress' intent to impose a duty on the administering agencies to protect and preserve all wilderness resources, including water. Thus, there is a general duty under the Wilderness Act to protect and preserve wilderness water resources. There is, however, no specific statutory duty to claim reserved water rights in the wilderness areas even though Congress impliedly reserved such rights in order to effectuate the purposes of the Act, as discussed above.

Judge Kane ordered the Federal defendants to submit a memorandum explaining how they plan to protect reserved water rights in compliance with the Wilderness Act.

In concluding that Congress did intend to withdraw the land for a specific public purpose the Court states: "Wilderness is not simply a land management status. Rather, wilderness areas are federal reservations whose status, as concerns the implied-reservation-of-water doctrine, is equal to that of other federal reservations such as national forests, parks, and monuments."

Public Trust Doctrine

The Court points out that the public trust doctrine does not apply in situations where Congressional direction is very specific. Under 1133(b), "each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character.... Wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use" 16 U.S.C. § 1133 (b).

In concluding that the public trust doctrine is inapplicable, the Court finds the language in the Wilderness Act sufficiently specific.

Must the Federal Agencies Assert Reserved Water Rights?

Judge Kane Ruled:

To begin with, the Wilderness Act unquestionably imposes certain duties on the part of agencies and officials administering the wilderness areas. Sections 1131(a) and 1133(b) require that the wilderness character of these areas be protected and preserved. Further, Congress stated that these areas shall be administered "for the use and enjoyment of the American people in such a manner as will leave them unimpaired for future use and enjoyment as wilderness ...." 16 U.S.C. § 1131(a). Finally, § 1133(b) mandates that the "wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use" and that the agencies charged with administering the wilderness areas shall administer the areas for these purposes.

These mandates reflect Congress' intent to impose a duty on the administering agencies to protect and preserve all wilderness resources, including water. Thus, there is a general duty under the Wilderness Act to protect and preserve wilderness water resources. There is, however, no specific statutory duty to claim reserved water rights in the wilderness areas when though Congress impliedly reserved such rights in order to effectuate the purposes of the Act, as discussed above.

Judge Kane ordered the Federal Defendants to submit a memorandum explaining how they plan to protect reserved water rights in compliance with the Wilderness Act.

Significance to the BLM in Colorado

This decision will further delay the Congressional designation of BLM wilderness areas in Colorado. The contention of the opponents of wilderness designation is that designation would result in the creation of reserved water rights. According to this Court, they were correct.

Representative Mike Strang was recently quoted in the Rocky Mountain News calling for an appeal of the decision. The decision was rendered on November 25. Any appeal must be filed within 60 days. The appeal process will probably take years. If there is no compromise on the issue reached out of court, any designation of BLM wilderness areas in Colorado will be delayed indefinitely.

We do not have to respond to the court on how we will protect wilderness values, because we have no wilderness areas. Forest Service and Park Service will be required to respond to the Court.

Copies of the decision may be obtained by contacting Tony Martinez at 303/294-7116 or FTS 564-7116.

WATER RESOURCES RESEARCH, VOL. 21, NO. 11, PAGES 1749–1750, NOVEMBER 1985

The Contemporary Setting for Water Management in the West: An Overview

RONALD G. CUMMINGS

University of New Mexico, Albuquerque

The socioeconomic, legal, and institutional settings for water resources management and use in the United States have undergone dramatic changes over recent years. The resulting confusion and uncertainties in terms of the structure of water rights, the prerogatives of sovereign states, and the limitations of state-federal interfaces provide the raison d'être for the collection of papers in this special section of *Water Resources Research.*

This special issue is intended to serve several purposes: to inform, to provoke, and to invite. Thus many readers may find new and informative *Tarlock*'s [this issue] overview of the evolution of groundwater law from English Common Law to laws based on notions of "reasonable use" and "sharing"; of particular importance is the readers appreciation of the changes and uncertainties in water law associated with the 1982 decision in Sporhase and in the later El Paso case. These cases, marking an end of the "immunity theory" wherein states were immune, in cases involving resources use, from challenges under the Commerce Clause, give rise to Tarlock's concern with the question, Might current conditions give rise to federal control of groundwater?

It is hoped that the reader will find provocative the solutions and alternatives for dealing with post-Sporhase water management and planning problems offered by our other authors. Thus referring to the environment for interstate competition for water resources introduced by Sporhase, *Utton* [this issue] focuses on inconsistencies in water law. The "Equitable Apportionment" doctrine is applied to interstate disputes concerning surface waters: each state is apportioned a "fair" share of the river and, most importantly, it can deny use of its apportioned water to non-residents of the state. The "Commerce Clause" doctrine is applied (beginning with Sporhase in 1982) to interstate groundwater, however. As an article in commerce, the state cannot claim a "fair" share to groundwater in transboundary aquifers; neither therefore can the state deny out-of-staters access to groundwater supplies, even when such supplies are within its boundaries. Utton then poses two particularly provocative questions. First, how is it that an acre-foot (1 ac ft) of water in an aquifer is a "commodity" in commerce to which principles of "fair apportionment" do not apply when the same acre-foot of water in a stream is not? Second, and as an extension to the preceding question, what does one do about water in a tributary aquifer wherein water taken from the aquifer must, at some point in time, result in withdrawals from the stream? Utton's concern with inconsistencies is particularly sharp with respect to this latter question. The court, in El Paso, has applied the Commerce Clause doctrine to the tributary aquifer; Utton argues that consistency requires the application of the Equitable Apportionment doctrine.

Paper number 5W0480.
0043-1397/85/005W-0480$05.00

Suppose, however, that the courts continue to apply Commerce Clause principles to groundwater in transboundary aquifers that are tributary; a relevant question concerns the long-run implications of such judicial treatment of water for efforts by states to engage in rational water planning. This is the issue addressed by *DuMars* [this issue]. DuMars focuses on two classes of judicial decisions involving efforts by states to control their natural resources: cases involving the state as a regulator of socioeconomic activity and cases involving the state as a participant in the market. As a regulator, the state cannot control access to resources within its boundaries under the Commerce Clause; as a market participant, however, the state can buy or sell resources from or to whomever it chooses. However, this choice leave the states with few viable alternative courses of action. First, if the state wishes to exert control, vis-a-vis out-of-staters, over its resources, it might appropriate and then sell the resources. Second, the state might attempt to impose "public welfare" criteria on rules for water allocation, an option which introduces the potential for substantial mischief and distortions as seen in a recent New Mexico case. DuMars argues that the uncertainties and confusion following from recent court decisions reflects a Supreme Court which tries to do too much. Thus interstate water issues of the type discussed above involve state actions that are "··· subtle, complex, politically charged and difficult to assess under traditional commerce clause analysis." The way out, Dumars argues, is for the Court to follow its earlier precedents wherein such issues are sorted out in a forum better suited to treat them: the U.S. Congress.

In still another area of potential conflict, between states and the federal government, *Brookshire et al.* [this issue] consider the highly controversial issue of federal reserved rights, particularly, the rights to water reserved to Indian reservations by the 1906 Winters case. In Winters, the Supreme Court exempted tribes from "prior appropriation" criteria relevant for non-Indians in their efforts to establish water rights, holding that Congress, in establishing the reservations, had reserved to the tribes those resources (water) necessary to accomplish the intended purposes of the reservation. In the 1956 Arizona versus California case, however, the court responded to efforts on the part of Western States to obtain a quantification of those rights to water "reserved" to the tribes. In Arizona versus California the court seemingly traded one vague, ill-defined notion (reserved rights) for another which was equally ill-defined: "practicably irrigable acreage" as a means for quantifying reserved rights.

Brookshire et al. [this issue] offer interesting insights into the many complexities of the reserved rights doctrine. A notable example is their discussion of the implications of how "purposes" of a federal reservation are defined. A broad interpretation of Congress' intended purposes for a specific reservation (e.g., a tribal homeland) may give rise to larger quantities of reserved water rights than a more narrow interpretation (e.g., the establishment of farming).

Brookshire et al.'s [this issue] arguments are particularly provocative in their analyses of, and recommended changes in, the current standard for quantifying water rights reserved to Indian tribes, namely, the "practicably irrigable acerage" (PIA) criterion. They argue that the major conceptual difficulty with the PIA criterion is the legal fiction that rights exist independently of off-reservation developments. Thus for example, for a 10,000-acre reservation created in 1870, only 100 acres might have been irrigable in 1870 (the priority date for a water right under current judicial interpretations). New irrigation-related technologies, center pivot irrigation systems, more efficient pumps, etc., have become available since 1870, and such changes may well have resulted in, for example, all of the reservations land now being "practicably irrigable." Brookshire et al.'s "legal fiction" problem then seemingly arises due to the fact that the new technologies were not developed by the Indians per se (one must wonder if they know that an Indian was not involved in the development of any of these technologies): they were "off-reservation" developments. As a method for treating this issue, Brookshire et al. suggest that priority dates for water rights be linked to dates at which technologies become available that give rise to practicable irrigation.

In terms of provocativeness, one finds a delightful contrast between *Brookshire et al.*'s [this issue] paper and the paper by *Deloria* [this issue]. Deloria's thesis is a fascinating one: "... an important current in the development of the legal system has been to define Indian rights and then develop an orderly process for taking them away." Thus Deloria sees in contemporary legal battles concerning Indian water rights, first, efforts to provide "scope" for such rights (priority dates, quantities, uses, etc.) so that second, "rights" now become "claims" which can then, third, be narrowed by the legal system. As claims are "narrowed," Deloria argues, society can then tell itself that it is defining the Indians' water rights, not taking them away (one cannot "take away" property, a water right, without compensation). Some part of this process implied in Brookshire et al.'s description of Deputy Solicitor General Claiborne's legal devices designed to "soften" the impact of the PIA standard on non-Indian water users. (See also *Brookshire et al.*'s [this issue, section 2.1] "... most important issue(s) regarding reserved rights..." which is "... the selection of appropriate standards for determining their nature and quantity.")

Finally, the issues, questions, and controversies set out in the papers in this special section will hopefully be viewed by you, our readers, as an invitation: an invitation to offer to *Water Resources Research* readership your ideas, your insights, and your expertise as they relate to these issues. Read the papers. Enjoy. I'll look forward to receiving your manuscript.

REFERENCES

Brookshire, D., G. Watts, and J. Merrill, Current issues in the quantification of federal reserved water rights, *Water Resour. Res.*, this issue.

Deloria, S., A Native American view of western water development, *Water Resour. Res.*, this issue.

DuMars, C., The state as a participant in water markets: Appropriate roles for Congress and the courts, *Water Resour. Res.*, this issue.

Tarlock, A. D., An overview of the law of groundwater management, *Water Resour. Res.*, this issue.

Utton, A. E., Alternatives and uncertainties in interstate groundwater law, *Water Resour. Res.*, this issue.

R. G. Cummings, Department of Economics, University of New Mexico, 1915 Roma N.E., Albuquerque, NM 87131.

WATER RESOURCES RESEARCH, VOL. 21, NO. 11, PAGES 1777-1784, NOVEMBER 1985

Current Issues in the Quantification of Federal Reserved Water Rights

DAVID S. BROOKSHIRE

Department of Economics, University of Wyoming, Laramie

GARY L. WATTS

Western Research Corporation, Laramie, Wyoming

JAMES L. MERRILL

U.S. Environmental Protection Agency, Seattle, Washington

This paper examines the quantification of federal reserved water rights from legal, institutional, and economic perspectives. Special attention is directed toward Indian reserved water rights and the concept of practicably irrigable acreage. We conclude by examining current trends and exploring alternative approaches to the dilemma of quantifying Indian reserved water rights.

1. INTRODUCTION

Federal reserved water rights stem from the United States Supreme Court's 1908 decision *Winters versus United States* [1908]. Winters involved rights to water from the Milk River, which formed the northern boundary of the Fort Belknap Indian Reservation in Montana. Settlers had been diverting water pursuant to Montana law for irrigation purposes. On behalf of the Indians, the United States sued to stop the diversions, claiming that the water diverted by the settlers was needed for an irrigation project on the reservation. The Supreme Court agreed. In effect, the Court held that water appropriated by settlers under Montana law was needed (and could be taken without compensation) to convert the Tribe into a "pastoral and civilized" people [*Winters versus United States*, 1908, p. 576].

That decision marked the beginning of the "Winters doctrine" as it is commonly known. The doctrine has spawned much literature (see, for example, *Patterson* [1946], *Sondheim and Alexander* [1960], *Clyde* [1967], *Morreale* [1967], *Bloom* [1971], *Veeder* [1971], *Dellwo* [1971], *Price* [1973], and *Ranquist* [1975]). Also, *Ranquist* [1975] reviews the Winters doctrine's development. Court decisions after Winters have not only affirmed the doctrine, but extended it to other federal reservations, including national forests, monuments, and parks. An important tenet of the Winters doctrine is that federal action reserving land for a particular purpose may have also implicitly reserved enough water to accomplish that purpose, thus giving rise to the nomenclature "federal reserved water rights" [*Cappaert versus United States*, 1976, p. 138].

Their vast land holdings in the West place the federal government and Indian tribes in a prime role concerning control of western water, a role that concerns many western states and appropriators. One reason for concern is that many claims to reserved water rights have not been resolved. The resulting uncertainty tends to obstruct water planning and complicates individual states' efforts to manage their water development. Another reason for concern is that the courts have consistently held that reserved water rights are to be administered with a priority date as of the date the underlying reservation of land was established [*Cappaert versus United States*, 1976, p. 138]. Since many tracts were reserved in the late 1800's, any reserved rights they may have are consequently of senior priority to most water rights established under state law by later settlers. Further, federal reserved rights are not subject to forfeiture due to nonuse. Thus failure by the federal government or Indian tribes to use water in the past has not (in theory at least) affected the priority dates or availability of that water to satisfy a reserved right.

Early western water development proceeded independently of federal water rights. Congress specified that most federal water projects operate pursuant to state water law. As a result, little consideration was given to federal reserved water rights for decades; individual appropriators used water without hearing of or understanding the reserved rights doctrine. In more recent years, states have entered into interstate water compacts, with Congressional approval, which acknowledge the existence of reserved rights without quantifying them. Typical is the language of the *Yellowstone River Compact* [1951, Article VI, p. 663], which provides in part "Nothing contained in this compact shall be construed or interpreted as to affect adversely any rights to the use of the water of the Yellowstone River and its tributaries owned by or for Indians, Indian tribes and their reservations."

The early establishment dates of many federal reservations, along with the characteristic that reserved rights are not foregone through lack of use, means that much western water already allocated pursuant to state law and compacts may be found to have been reserved under federal law for other users and uses. One report estimates that Indian reserved rights claims might total roughly 45 million ac-ft annually in 16 western states, more than 3 times the average annual virgin flow of the Colorado River [*Western States Water Council*, 1984]. While that figure is probably an upper bound upon the amount of water that may eventually be awarded, it underscores the importance of unquantified federal reserved rights.

The following sections of this paper examine some major contours of the reserved rights doctrine and focus on a contro-

Paper number 5W0478.
0043-1397/85/005W-0478$05.00

versial concept associated with most Indian water claims: practicably irrigable acreage. Practicably irrigable acreage (PIA) is an empirical standard created by the judiciary for quantifying Indian reserved water rights. Procedures utilized for measuring PIA generally have followed economic efficiency criteria. However, the quantification process inherently involves issues of equity as well as economic efficiency. Conflicts between these concepts have led to problems in the quantification of reserved water rights.

2. Reserved Rights Issues

In the past, reserved rights settlements have been reached through court decisions and negotiations supported by federal legislation [*Folk-Williams*, 1982]. The potential for future negotiated settlements is uncertain, however, due to the many unresolved legal issues involved and the potential magnitude of certain claims. Litigation will undoubtedly remain an important tool for resolving reserved rights issues. At the present time there are approximately 40 cases pending, being adjudicated or awaiting final resolution in western states that pertain to the quantification of federal reserved water rights. For a brief summary of each case (see the work by *Folk-Williams* [1982]).

The following discussion focuses on some of the legal issues that determine the potential magnitude of reserved rights claims. First, the dimensions of reserved rights claims are examined by exploring purposes for which land may have been reserved. Second, a variety of procedures that have been used to quantify reserved rights are discussed. Finally, limitations and restrictions that have been associated with reserved rights claims, including the issue of transferability.

2.1. *Purposes*

One of the fundamental inquiries underlying the quantification of reserved rights concerns the purposes for which various federal Indian and non-Indian reservations were established. Generally speaking, courts have held that reserved rights exist to fulfill the primary purposes of a reservation: the more purposes a reservation has (i.e., a forest), the more extensive its reserved rights may be. The courts have also held that different types of reservations were created for different purposes. For example, in *State of Arizona versus State of California* [1963] the Court held that the Indian Reservations in question were created primarily for the purpose of encouraging agricultural endeavors. Other Indian reservations in the Pacific Northwest may have been intended primarily to preserve ancestral hunting and fishing grounds for certain tribes [*United States versus Adair*, 1979]. Other federal reservations have been created for purposes different from those of Indian reservations, such as recreation and wildlife habitat preservation.

Judicial attempts to resolve the "purposes" issue have focused on the concept of federal intent: What was the major objective in creating a reservation? In determining intent, one must refer to the documents creating a federal reservation. However, the congressional acts, treaties, and executive orders are open to interpretation because they rarely mention water rights expressly. How these documents are construed has significant implications for the quantification of reserved rights.

For example, the treaty creating the Wind River Indian Reservation in Wyoming contains references to "agriculture" and "farming," as well as references to "a permanent homeland" for the Shoshone Tribe [*Treaty of July 3, 1868*, 1868, Articles VI, VII, II, and IV]. A narrow interpretation of the treaty might conclude that the primary purpose of the Reservation was to encourage the Tribe to farm, implying that a reserved right exists for agricultural purposes. A broader interpretation would find that the purpose of the Reservation was to create a permanent homeland, suggesting in turn that a reserved right might exist for any purpose consistent with use of the Reservation as a homeland, including hunting and fishing, recreation, and mineral and industrial development as well as irrigated agriculture. In this example the broad interpretation adopted by the Special Master resulted in a larger award than would have resulted from a narrow interpretation [*Special Master*, 1982, pp. 327–344].

It appears that the current Supreme Court favors narrow interpretations of purposes. The Court affirmed its narrow view in *United States versus State of New Mexico* [1978], which addressed reserved water rights for the Gila National Forest in New Mexico. The Court found that the primary purposes of the Gila National Forest were to furnish a continuous supply of timber and insure favorable conditions of water flow. The Court further suggested that a reserved right does not exist for secondary purposes established under the Multiple-Use Sustained-Yield Act of 1960, such as stock grazing, fish and wildlife habitat, or aesthetics. The Court opined that Congress intended for water for such secondary purposes be obtained pursuant to New Mexico state law.

The principles enunciated in *United States versus State of New Mexico* [1978] have been held applicable to an Indian Reservation in the State of Washington. In *Colville Confederated Tribes versus Walton* [1979] the United States Court of Appeals for the Ninth Circuit found that the principal purposes of the reservation consisted of agricultural pursuits and fishing. More recent cases, such as Wyoming's Big Horn Adjudication, may again test the Supreme Court's interpretation of the purposes arguments. In the interim, it is fair to assume that the Court will be consistent with its past rulings and interpret purposes relatively narrowly.

2.2. *Quantification Standards*

One of the most important issues regarding reserved rights involves the selection of appropriate standards for determining their nature and quantity. For reserved water rights the quantification process involves determining how much water is required to fulfill a specific purpose. A partial list of some quantification standards that have been used in the past for Indian reservations is given in Table 1.

The Supreme Court's *Winters versus United States* [1908] decision established the legal basis for the existence of reserved rights without specifying a quantification methodology. From 1908 through 1963, several court cases upheld the Winters doctrine, but provided only fleeting glimpses into how these rights were to be quantified. For example, in *United States versus Walker River Irrigation District* [1939, p. 340] a federal court held that the amount of water an Indian Tribe needed for irrigation " ... could only be demonstrated by experience." In an earlier case, the same court had held that the appropriate standard was "ultimate need" encompassing past, present, and future uses [*Conrad Investment Company versus United States*, 1908, p. 832].

In *State of Arizona versus State of California* [1963] the reserved rights of five Indian tribes along the lower Colorado River were quantified. In its 1963 opinion the Court held that a reserved right existed to serve the "practicably irrigable acreage" on the reservations; the Court later awarded the right to divert approximately 900,000 ac-ft of water annually as a

TABLE 1. A Sample of Standards Accepted by the Courts for Quantification of Indian Reserved Rights

Case and Citation	Standard for Quantification
United States versus Walker River Irrigation District [1939]	Past and present uses as demonstrated by experience
United States versus Alexander [1942]	"So much water as may be required to irrigate such lands."
Conrad Investment Company versus United States [1908]	"Whatever water ... may be reasonably necessary, not only for present uses but for future requirements...."
State of Arizona versus State of California [1963]	The amount of water needed to irrigate the practicably irrigable acreage as determined by then-current (1960) standards
Colville Confederated Tribes versus Walton [1981]	Quantity necessary to (1) permit irrigation of all practicably irrigable acreage on the reservation and (2) support the development and maintenance of replacement fishing grounds
United States versus Adair [1979]	"As much water on the Reservation lands as they need to protect their hunting and fishing rights."
Special Master [1982]	Quantity based upon the amount of water needed to irrigate the practicably irrigable acreage
State of Arizona versus State of California [1982, 1983]	Quantity based upon the amount of water needed to irrigate the practicably irrigable acreage added to the reservations by boundary determinations and adjustments

quantification of that reserved right. In more recent court cases, the PIA standard has continued to be used for the quantification of agricultural reserved rights on Indian reservations. Although there is a continuing debate concerning what constitutes "practicably irrigable acreage," a consensus view seems to be emerging that it implies suitability for irrigation from the engineering, soils, water supply, and economic perspectives [*Special Master*, 1982]. The courts have been careful, however, not to imply that PIA is the only acceptable standard for quantifying Indian agricultural reserved rights. The Supreme Court recently suggested that given an appropriate case, it might modify the natural resource based PIA standard it initially embraced in *State of Arizona versus State of California* [1963].

The Supreme Court has also placed limits on the quantification of reserved rights in specific situations not involving Indian claims. One example is the *Cappaert versus United States* [1976] case, which involved an express reservation of water for the Devil's Hole National Monument in Nevada. The Court held that the federal reservation was created to preserve natural habitat and that the amount of water reserved to preserve that habitat would be defined by " ... minimal need" [*Cappaert versus United States*, 1976, p. 141]. In a more recent case the Supreme Court limited the scope of a reserved right for the Gila National Forest in New Mexico to the amount such that " ... without the water the purposes of the reservation would be entirely defeated" [*United States versus State of New Mexico*, 1978, p. 700]. In another recent case involving tribal fishing rights in Washington the court held that the amount of fisheries reserved was the amount required to maintain a "moderate standard of living" [*State of Washington versus Washington Commercial Passenger Fishing Vessel Association*, 1979, p. 686].

Although none of these latter cases involved reserved water rights for Indian reservations, the change in emphasis from the Court's 1963 decision to these more recent decisions is striking. It is unclear whether the change stems from the fact that different types of situations were involved, or whether they reflect a changing judicial attitude toward quantification.

2.3. *Other Reserved Rights Characteristics*

One important limitation on federal reserved rights is that thus far, they have been restricted to surface water supplies. An opportunity for the Court to extend reserved rights to groundwater arose in *Cappaert versus United States* [1976]. In Cappaert the federal government sought a reserved right for a pool of water hidden in a limestone cavern in the Devil's Hole National Monument to protect the breeding grounds of the Devil's Hole Pupfish. The pumping of several nearby irrigation wells, pursuant to Nevada state law, was lowering the water level of the cavern to a level that made it impossible for the pupfish to breed. The irrigation wells postdated the creation of the Monument. The Court, while finding an express reserved water right in the pool, was careful not to extend the reserved right to underground water. Noting that "no cases of this Court have applied the doctrine of implied reservation of water rights to underground water," [*Cappaert versus United States*, 1976, p. 2071], the Court stated that the water in the pool was surface water and as such could be protected from subsequent diversions of surface water and groundwater.

Another potential limitation on federal reserved rights involves the issue of their transferability: that is, whether reserved water must be put to the specific purpose for which it was reserved, or whether it may be put to other on-reservation purposes or even brokered for off-reservation uses. It appears that with respect to Indian reservations, water reserved for one specific purpose such as agriculture can be used for other reservation purposes such as industrial development [*State of Arizona versus State of California*, p. 422, 1979].

The question is of less import for other types of federal reservations. Since claims for national parks, forests, and monuments for the most part seek minimum stream flows, there is little consumptive use to transfer from one purpose to another. Questions may theoretically arise concerning whether public drinking water in a national park can be taken from that park's reserved right allotment, but, as a practical matter, the magnitude of such uses is probably too small to elicit controversy. Of far more concern are the potential effects of such senior instream flows on upstream diversions.

Perhaps the most controversial question concerning transferability is whether water allotted to Indian reservations under the reserved rights doctrine can be leased or sold for off-reservation use. According to some legal observers, Indians do not have the right to utilize their reserved rights for development of off-reservation resources, nor can their reserved rights be sold or leased without congressional consent [*Palma*, 1978; *Clyde*, 1982]. This interpretation is based upon restrictions placed upon the sale of Indian resources by the Non-Intercourse Act of 1796 [*U. S. Congress*, 1796*a*, *b*]. Such restrictions are currently being challenged in court, however [*Special Master*, 1982].

If the courts uphold restrictions on the sale or lease of Indian rights, the result could be economically inefficient allocations of water in fully appropriated river basins. This situation could result because the Court has not historically considered economic tradeoffs with off-reservation uses in quantifying Indian reserved rights. To the extent that reserved rights can be bartered, however, the implications could be quite different. The sale or lease of Indian reserved water rights for nonreservation uses could improve the economic efficiency of water allocation, and at least some Indian tribes seem interested in such transfers [*Ute Indian Compact*, 1980]. The implications of such transfers for interstate compacts may become a topic of dispute, however, concerning whether the transferred water should be charged against the allocated share of the state of origin or the state of ultimate use [*Clyde*, 1985].

A related issue involves the extent to which the courts should consider potential impacts upon other users in the quantification of federal reserved rights. If considered, these potential impacts could represent a significant limitation on reserved rights in some situations. In *State of Arizona versus State of California* [1963] the quantification of reserved rights for five Indian reservations was resolved without express consideration of competing uses.

In Wyoming's Big Horn Adjudication, the *Special Master* [1982, p. 342] granted extensive agricultural reserved rights to the Arapahoe and Shoshone tribes, but imposed a restriction that water could be put to beneficial use only gradually over a 100 year period. This limitation was apparently intended to allow time for the development of storage facilities to buffer the impacts new reserved rights would have upon junior appropriators. The District Court later modified this restriction to an outright requirement that storage facilities be built before water was appropriated for new irrigation projects on the reservation. That restriction was later removed by yet another court and the case is now on appeal.

In one non-Indian case, the Supreme Court unanimously held that the quantification of federal reserved rights must be sensitive to such impacts [*United States versus State of New Mexico*, 1978]. It is not clear to what extent and in what situations the "sensitivity" criterion are to be applied.

The ultimate outcome of the issues involving limitations and restrictions will rest largely with the Supreme Court as more cases proceed through the appeals process. It is apparent that there is much to clarify about the nature of federal reserved rights before their ultimate impact upon western water resources can be assessed.

3. Indian Reserved Rights Claims

3.1. *The Centerpiece of Tribal Claims: PIA*

The preceding section explored some general aspects of federal reserved water rights. In this section we examine some implications of using the practicably irrigable acreage standard to quantify reserved water rights for Indian reservations. As a starting point, it is useful to review the Supreme Court's rationale for adopting PIA in *State of Arizona versus State of California*, vol. 373, p. 600–01, 1963].
The Court stated

> We agree with the Master's conclusion as to the quantity of water intended to be reserved. He found that the water was intended to satisfy the future as well as the present needs of the Indian reservations and ruled that enough water was reserved to irrigate all the practicably irrigable acreage on the reservations. Arizona, on the other hand, contends that the quantity of water reserved should be measured by the Indians' "reasonably foreseeable needs," which in fact means, by the number of Indians. How many Indians there will be and what their future needs can only be guessed. We have concluded, as did the Master, that the only feasible and fair way by which reserved water for the reservations can be measured is irrigable acreage.

At the time (1963) the Court believed that a resource-based standard such as PIA would ensure water for future tribal needs without entertaining the complexities of what those needs might be. Although Justices Harlan and Stewart supported the Court's decision in *State of Arizona versus State of California*, vol. 373, p. 603, 1983], they did so "... not without some misgivings regarding the amounts of water allocated to the Indian reservations." As a whole, however, the Court may not have anticipated the magnitude of future claims that would be forthcoming using the PIA standard on other reservations.

More recent opinions suggest that the Supreme Court may not be comfortable with the PIA standard as adopted in *State of Arizona versus State of California* [1963]. As is discussed in section 2 above, the Court adopted the concept of "... minimal need" in *Cappaert versus United States* [1976] to quantify a reserved right for a national monument. It also involved the concept of "... moderate standard of living" to help define Indian reserved fishing rights in *State of Washington versus Washington Commercial Passenger Fishing Vessel Association* [1976].

Also indicative of the Court's thinking was its refusal, in 1983, to expand the reserved rights award in the original *State of Arizona versus State of California* [1963] case to include lands omitted from the prior proceedings. The Court stated that to reopen the case would require reconsideration of whether application of the PIA standard itself was appropriate; the Court intimated that revisiting the issue might not be as beneficial to the interests of the Indian reservations as PIA has been [*State of Arizona versus State of California*, 1963].

The U.S. Department of Justice recently gave indications that changes are coming in the adjudication of reserved water rights. In a presentation to the Conference on the Federal Impact on State Water Rights in 1984, Deputy Solicitor General Louis F. Claiborne [*Claiborne*, 1984, p. 6] predicted that "Quantification standards or procedures will be adjusted so as to avoid adjudicating to the Indians all the available waters to the detriment of actual beneficial use by non-Indian neighbors." *Claiborne* [1984, pp. 6–7] went on to state

> The devices invoked for holding down Indian water claims where they might otherwise exhaust the available waters and require non-Indians to relinguish [sic] existing uses predictably will include some or all of the following:
> 1. According finality to old judgments or contracts which favor non-Indians and understate the trible entitlement;
> 2. Allowing State courts, in future [sic], to quantify Indian water rights, subject only to U.S. Supreme Court discretionary review in cases of manifest error;
> 3. Applying a modified *New Mexico* test to quantify Reservation entitlement, limited to the amount necessary to satisfy the primary purposes of the Reservation, as contemplated at the time of its creation;
> 4. Restricting change of use to those contemplated at the date the Reservation was established and the water was reserved;
> 5. Invoking the *Fishing Vessel* "moderate living" standard as a ceiling to Indian water claims;
> 6. Limiting transferability of water rights, at least for off-Reservation use by non-Indians;
> 7. Imposing a rule of loss of right through non-use if there is no actual beneficial use on the Reservation within some reasonable time; and, finally,
> 8. Qualifying the doctrine of implied reservation by presuming that the United States would not have ... to reserve all available waters for an Indian Reservation where the consequence of so doing was to condemn to perpetually useless desert neighboring federal lands—especially those acquired from the Indians with a view to sale to homesteaders.

On the basis of Claiborne's statements and the more recent court decisions, it appears that there are a number of legal devices that could be used to soften the impact of the PIA standard in future adjudications. The extent to which any or all of these devices are adopted in future adjudications probably depends in large measure on how the PIA standard is applied. In the following sections we examine some issues raised by past PIA quantifications and offer some thoughts on how the PIA standard could be applied more equitably in the future.

3.2. *Problems with Implementing PIA*

The biggest practical problem with the PIA standard involves determining what land is practicably irrigable and what land is not. In a previous paper, we suggested that [*Brookshire et al.*, 1983, p. 753] "... at a minimum, determinations of arability, engineering feasibility, water supply, and economic feasibility are prerequisite to a finding that lands are practicably irrigable." These criteria are similar to those used by federal and state agencies for evaluating water development projects, and the determination of PIA has often hinged on the outcome of benefit cost-analyses. As Special Master Tuttle stated in *State of Arizona versus State of California* [1963], "for present purposes, a finding that annual benefits exceed costs will suffice for a finding of practicable irrigability." One problem with this approach is that standards for assessing benefits and costs change over time. Thus when the quantification process begins is an important determinant of the outcome. Changing standards for benefit-cost analyses are illustrated by the continuum of federal cookbooks such as *U.S. Bureau of the Budget* [1952], Circular A-47, *U.S. Congress Senate* [1962], Document 97, culminating in the Principles and Standards series of the *U.S. Water Resources Council* [1979, 1983]. *Burness et al.* [1979] summarize how these standards have changed historically.

Changing standards for benefit-cost analyses have led to disagreements concerning which standards are appropriate for determining PIA. In the Big Horn Adjudication, one witness opined that then current standards for benefit-cost analysis were inappropriate for determining PIA because they were less favorable to development than standards used prior to 1973 [*Cummings*, 1981]. The witness suggested that as a consequence, the Tribes were penalized for not having their reserved rights quantified at an earlier date. The witness failed to point out, however, that an earlier quantification would not have been able to take advantage of more recent irrigation technology and could well result in a smaller reserved right even though past economic criteria were more lenient. The practical problem is simple yet complex: What is the appropriate mix of economic standards and technology given that these factors are always changing? Is it appropriate to use 1950s benefit-cost methods and 1980s technology to award a reserved water right with an 1870 priority date for land that was not irrigable then?

Another problem with PIA is that benefit-cost analyses for irrigation projects involve many assumptions concerning technical matters for which there is no objective standard. For example, what types of yields can be expected from irrigated crops on land that has never been farmed before? What effects will increased crop production have on regional crop prices? Unfortunately, the amount of PIA on a given reservation is highly sensitive to such assumptions, as well as to considerations of technology and economic standards.

This point is illustrated by the benefit cost ratios in Table 2, submitted by the contesting parties in the Wyoming's Big Horn Adjudication. The differences in the benefit-cost ratios represent both different standards as well as different internal assumptions. The primary differences are attributable to (1) differences in assumptions concerning appropriate farm size and farm equipment use and (2) differences concerning what factors constitute appropriate measures of benefits. Table 2 demonstrates the sensitivity of the results to these factors, with prices and technology being held constant.

The State of Wyoming and United States' (Table 2, columns 1 and 2) estimates are consistent with the then current Water Resources Council standards for water project evaluation. The United States' estimates differ from the State of Wyoming's principally in assumptions relating to farm size and how efficiently farm equipment could be used; note the wide range in values resulting from these technical disagreements. The Shoshone and Arapahoe Tribes presented two different conceptual measures. In column 3 the procedures are essentially those followed by the State of Wyoming and the United States, with different assumptions regarding on-farm and water delivery systems costs. Columns 1 through 3 illustrate the range of benefit-cost ratios that can result from alternative assumptions as to the appropriate measures of farm size, farm equipment use, and water delivery systems costs.

Column 4 moves beyond simple variation in technical assumptions to broader interpretation of what constitutes a legitimate benefit. *Cummings* [1981] argued that the column 4 results were appropriate because they reflect the standards employed to justify the bulk of federally financed western water projects prior to 1970 and thus (out of fairness) should be used to quantify Indian reserved water rights. Thus all else being constant (e.g., commodity prices, water delivery system costs, technology), changing standards can also yield widely ranging benefit-cost ratios. Since this variation occurs both above and below unity (1), widely ranging quantifications of the reserved water right could result.

TABLE 2. Benefit-Cost Ratios for New Irrigation Projects in the Wyoming Big Horn Adjudication

	State of Wyoming*	United States†	Shoshone and Arapahoe Tribes‡	
Designed Areas on the Wind River Reservation	Based Upon National Economic Development Benefit-Cost Concepts (Assumptions Vary From Other Parties)	Based Upon National Economic Development Benefit-Cost Concepts (Assumptions Vary From Other Parties)	Based Upon National Economic Development Benefit-Cost Concepts (Assumptions Vary From Other Parties)	Based Upon National Economic Development Concepts and Secondary Benefits
North Crowhart	0.33	1.47	1.72–2.28	2.52–3.29
Big Horn Flats	0.32	1.07	1.13–1.64	1.70–2.40
South Crowhart	0.42	1.29	1.48–1.92	2.22–2.82
Arapahoe	0.46	1.53	1.77–2.21	2.57–3.18
Riverton East	0.47	1.25	1.46–2.01	2.21–2.97

All estimates utilized a 4% real discount rate. This rate was chosen to illustrate the alternative estimates because it is the only rate that all parties utilized.
*Data from *Jacobs* [1981, p. 13, Table II-7].
†Data from *Dornbusch* [1982].
‡Data from *Cummings* [1981, p. 12, Table 2]. The range is a result of utilizing different water delivery cost estimates.

In this particular case, the Special Master accepted the United States' analysis and recommended the award of a reserved right for most of the lands proposed by the United States for new irrigation projects [*Special Master*, 1982]. It is apparent, however, that the quantification of reserved rights using PIA can lead to strikingly different results depending upon what assumptions and what set of standards are chosen for the analysis.

3.3. *PIA and Technological Change*

A problem similar to changing standards is that of changing technological feasibility. The results in Table 2 are all based upon current (late 1970's) technology. It is obvious that far more lands were irrigable in the 1970's than were irrigable when the Wind River Indian Reservation was established, partially because some lands high above water supplies are now irrigable using new pumping technology. New sprinkler configurations and drip irrigation also have increased the potential amount of acreage that may be irrigable. This situation is important because of two somewhat contradictory stances taken by the courts: (1) federal reserved water rights are to be administered with a priority date as of the date the reservation was created [*Cappaert versus United States*, vol. 426] and (2) the amount of PIA on a reservation is to be determined using contemporary standards and technology as of the time the reserved right is quantified.

An example based upon the recent adjudication of the Big Horn River in Wyoming will illustrate the potential problem inherent in mixing early priority dates with modern technology. The Wind River Indian Reservation was created by a Treaty between the United States and the Shoshone Tribe in 1868. Quantification of reserved rights for the reservation was undertaken as a part of a state-instigated adjudication of water rights on the river. During that adjudication the Special Master proposed to grant extensive reserved water rights to the Indian tribes [*Special Master*, 1982]. If exercised to their fullest, these rights would effectively nullify the rights of many non-Indian appropriators in the Big Horn River basin. Perhaps the most substantial right was one granted to bring under irrigation approximately 48,520 acres of range land located primarily on bluffs high above the Wind River. These lands could only be irrigated using modern pumping technology with center pivot and side-roll sprinkler systems.

The problem with this award can best be illustrated hypothetically. Suppose, for instance, that the virgin flow of the Big Horn River in 1868 was more than sufficient to irrigate all of the Indian and non-Indian lands that could practically be irrigated using flood techniques. Assuming no technological changes had taken place between 1868 and today, there might still have been more than adequate water in the Big Horn River to irrigate all the "practically irrigable acreage" in the river basin. In fact, however, it is now possible to bring enough new land under irrigation to more than exhaust the virgin flow of the river. It is in this situation that the conceptual difficulty with the PIA concept lies. The courts have held that PIA is to be determined using the legal fiction that the right exists independently of off-reservation development. This fiction ignores the obvious fact that the technology used to quantify the water right is a direct result of off-reservation development.

To carry the argument to the extreme, it could be argued that society would have been better off delaying the production of electrical pumps and center pivot sprinklers until such time as all reserved rights had been quantified. An equally extreme posture from the Indian position would be that it would be to their benefit to delay the quantification of their reserved rights indefinitely, based upon the premise that at some distant date the technology would exist to practically irrigate almost every acre on every reservation in the West. Thus through time, the potential amount of practicable irrigable acreage is increasing.

Others have discussed the problem of appropriate assumptions concerning technology. *Clyde* [1975, p. 47] rhetorically raised the question, "Should the courts use the acreage susceptible of irrigation when the reservation was created, or at the time of the litigation, or speculate on the future." Clyde appears to argue that to the extent that technology would increase the amount of water in a quantification procedure, then the decision should rest on whether unappropriated water exists. Thus Clyde does not appear to directly address which level of technological development is appropriate. On the other hand, *Price and Weatherford* [1976, p. 107] argue that "what is practicable is a function both of technology and cost ... " and thus " ... the United States must be free to develop and apply its water technology to Indian reservations without judicial limitation on congressional appropriation."

The issue was addressed in *State of Arizona versus State of California* [1983, vol. 456, p. 98] by Special Master Tuttle who stated he was " ... convinced that ... practicable irrigability should be based on present standards. Reference to past standards would introduce an additional complication in an already complex case." It could be argued that the complexity of the issue is not a particularly satisfying justification for avoiding the inquiry. Other PIA components (such as determining what types of soils are arable) are also technically complex. A liberal view of PIA gives rise to the possibility of pumping water long distances to irrigate significant blocks of land that could not have been irrigated without modern pumping technology. Since this water might have a very early priority date, potentially significant reallocations of existing uses can result in fully appropriated river basins.

3.4. *Suggestions*

Several solutions to this impasse are available. One class of reserved rights for agricultural purposes could be based upon technology existing at the time a reservation was established. Priority dates for water or land that could not have been feasibly put under irrigation until a later date, could receive later priority dates. Since the technology available to put these latter lands under irrigation could only be acquired through tribal interactions with society, the effects on society (other interactions) of using that water for irrigation should also be considered. For example, the opportunity cost of taking water from non-Indian users (if any) to irrigate Indian lands should also be considered.

These proposals would separate the quantification of agricultural reserved rights into two phases. The first phase would establish a reserved water right in perpetuity based upon irrigation technology available at the time reservation was established. The second phase would allocate the remaining water (if any) between Indian and non-Indian users based upon modern technology and the impacts on society of that allocation. Appropriate analyses, such as efficiency studies of water allocations, could be incorporated into these studies. This approach would mitigate many of the problems inherent in the blind application of legal precedent.

The exact extent to which changing technology keeps expanding the potential PIA base is difficult to ascertain. However, it is clear that the benefit-cost analyses used to estimate PIA can have highly variable results. In light of this potential variability, we suggest that the PIA standard must be used judiciously, keeping in mind that the quantification of Indian water rights involves equity considerations for Indians and non-Indians alike.

Acknowledgments. We thank R. Cummings, C. Hermann, and M. Turner for comments on earlier drafts. The views expressed are solely those of the authors.

REFERENCES

Bloom, P. L., Indian 'Paramount' rights to water use, in *Rocky Mountain Mineral Law Institute: Proceedings of the Sixteenth Annual Institute (July 9–11, 1970)*, pp. 669–693, Matthew Bender, New York, 1971.

Brookshire, D. S., J. L. Merrill, and G. L. Watts, Economics and the determination of Indian reserved water rights, *Nat. Resour. J.*, *23*, 749–765, 1983.

Burness, H., R. Cummings, W. Gorman, and R. Lansford, The formulation and implementation of U.S. reclamation policy: A historical and empirical review, report prepared for the Bureau of Indian Affairs and Office of the U.S. Attorney General, 1979.

Cappaert versus United States, no. 426, (U.S. 128, 96 S.Ct. 2062), 1976.

Claiborne, L. F., Indian water rights in the Supreme Court: A review and preview, paper presented at the Conference on The Federal Impact on State Water Rights, Nat. Resour. Law Cent., Univ. of Colo. Sch. of Law, Boulder, June 1984.

Clyde, E. W., Indian water rights, in *Water and Water Rights: A Treatise on the Law of Water and Allied Problems*, edited by R. E. Clark, vol. 2, pp. 373–399, The Allen Smith Company, Indianapolis, Ind., 1967.

Clyde, E. W., Special considerations involving indian rights, *Nat. Resour. Law*, *8*(2), 237–252, 1975.

Clyde, E. W., Allocation of water for Resource Development XIV, *Nat. Resour. Law*, *14*(3), 519–540, 1982.

Clyde, S. E., Legal and institutional barriers to transfers and reallocation of water resources, *S. D. Law Rev.*, *29*, 232–257, 1985.

Colville Confederated Tribes versus Walton, no. 460, (F.Supp. 1320 (E.D. Wash.)), 1979; *reversed on reh'g* 647 F.2d 42, 1981; cert. denied, 102 S. Ct. 657), 1982.

Conrad Investment Company versus United States, no. 161, (F. 829, (9th Cir.)), 1908.

Cummings, R., A critical review of economic criteria for demonstrating practicably irrigable acreage with application to the Wind River Indian reservation, report prepared for the Shoshone and Arapahoe Tribes, 1981.

Dellwo, R. D., Indian water rights—The Winters Doctrine updated, *Gonzaga Law Rev.*, *6*(2), 215–240, 1971.

Dornbusch, D., Economic feasibility of irrigated agriculture development on the Wind River Indian Reservation, introduced and admitted into evidence as U.S. Exhibit WRIR C-268 in Special Master, 1982.

Folk-Williams, J. A., What Indian water means to the West, vol. 1, in *Water in the West*, pp. 1–153, Western Network, Santa Fe, N. M., 1982.

Jacobs, J., An analysis of practicably irrigable acreage on the WRIR with discount rate of four percent, report prepared for the State of Wyoming, October 1981.

Morreale, E. H., Federal-state rights and relations, in *Water and Water Rights: A Treatise on the Law of Water and Allied Problems*, edited by R. E. Clark, vol. 10, pp. 59–61, The Allen Smith Company, Indianapolis, Ind., 1967.

Multiple-Use Sustained-Yield Act of 1960, 70 Stat. 215, 16 U.S.C. §528 et seq., 1960.

Palma, J. D., II, Indian water rights: A state perspective after Akin, *Nebr. Law Rev.*, *57*(2), 295–318, 1978.

Patterson, J., Extent of Indian water rights on reservations in the west, *Rocky Mt. Law Rev.*, *18*(4), 427–430, 1946.

Price, M. E., *Law and the American Indian: Readings, Notes and Cases*, pp. 310–329, Bobbs-Merrill Company, New York, 1973.

Price, M. E., and G. D. Weatherford, Indian water rights in theory and practice: Navajo experience in the Colorado River, *Law Contemp. Prob.*, *40*(1), 97–131, 1976.

Ranquist, H. A., The Winters Doctrine and how it grew: Federal reservation of rights to the use of water, *Brigham Young Univ. Law Rev.*, 639–724, 1975 (3).

Sondheim, H. B., and J. R. Alexander, Federal indian water rights: A retrogression to quasi-Ripariansim, *South. Calif. Law Rev.*, *34*(1), 1–61, 1960.

Special Master, In Re: The general adjudication of all rights to use water in the Big Horn River system and all other sources, state of Wyoming, no. 4993, Report of the Special Master (District Court of the Fifth Judicial District, State of Wyoming), December 15, 1982.

State of Arizona versus State of California, no. 373 U.S. 546, 1963; decree 376 U.S. 340, 1964; amended 383 U.S. 268, 1966; supplemental decree 439 U.S. 419, 1979; per curiam 456 U.S. 912, 1983.

State of Washington versus Washington Commercial Passenger Fishing Vessel Association, no. 443 U.S. 658, 1979.

Treaty of July 3, 1868, 15 Stat. 673, 1868.

U. S. Bureau of the Budget, Reports and budget estimates relating to federal programs and projects for conservation, development and use of water and related land resources, *Circ. A-47*, U. S. Bur. of the Budget, Washington, D. C., 1952.

U. S. Congress, An act to regulate trade and intercourse with the Indian tribes, and to preserve peace on the frontiers, vol. 1, chapt. 30, pp. 469–474, 1st session, 1796*a*.

U. S. Congress, An act making further provision for the expenses attending the intercourse of the United States with foreign nations, vol. 1, chapt. 41, 1st session, pp. 487–488, 1796*b*.

U. S. Congress, Policies, Standards and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources, *Senate Doc. 97*, 87th Congress, 2nd Session, Washington, D. C., 1962.

United States versus Adair, no. 478, (F.Supp. 336, 345 (D. Ore.)), 1979.

United States versus Alexander, no. 131, (F.2d 359, (9th Cir.)), 1942.

United States versus State of New Mexico, no. 438, (U.S. 696, 705, 718), 1978.

United States versus Walker River Irrigation District, no. 104, (F.2d 334, (9th Cir.)), 1939.

U. S. Water Resources Council, Procedures for evaluation of national economic development benefits and costs in water resources planning, *Fed. Reg., 44*(242), 72892–72976, 1979.

U. S. Water Resources Council, *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*, U. S. Government Printing Office, Washington, D. C., 1983.

Ute Indian Compact, Art. III, UTAH CODE ANN. 73-21-2, 1980.

Veeder, W. H., Indian prior and paramount rights to the use of water, in *Rocky Mountain Mineral Law Institute: Proceedings of the Sixteenth Annual Institute (July 9–11, 1970)*, pp. 631–668, Matthew Bender, New York, 1971.

Western States Water Council, *Indian Water Rights in the West*, report prepared for the Western Governors Association, May 1984.

Winters versus United States, no. 207, (U.S. 564), 1908.

Yellowstone River Compact, 65 Stat. 663, 1951.

D. S. Brookshire, Department of Economics, University of Wyoming, Laramie, WY 82070.

J. L. Merrill, U. S. Environmental Agency, Seattle, WA.

G. L. Watts, Western Research Corporation, Laramie, WY.

(Received February 28, 1985;
revised May 16, 1985;
accepted May 30, 1985.)

WATER RESOURCES RESEARCH, VOL. 21, NO. 11, PAGES 1751–1766, NOVEMBER 1985

An Overview of the Law of Groundwater Management

A. Dan Tarlock

Chicago-Kent College of Law in the Illinois Institute of Technology

Groundwater management law has evolved in this century from a simple rule of capture to a variety of rules that require sharing among claimants, both within and outside of groundwater basins. Courts and legislatures have modified the law of groundwater in response to aquifer depletion. Most of the change has occurred in the Far West, but eastern states are now modifying their law as shortages and use conflicts intensify. Arizona, Colorado, and New Mexico have developed the most sophisticated conservation regimes that attempt to limit groundwater use to improve methods of extraction and to move water to higher valued uses. Other large groundwater using states are also implementing or considering similar conservation regimes. Groundwater conservation is encouraged by a recent Supreme Court decision that holds that groundwater is subject to the negative commerce clause. The decision has the effect of forcing states to justify conservation regimes that block out-of-state and perhaps in-state access to the resource.

1. Introduction

Groundwater, water within the earth's zone of saturation, constitutes about 22% of the nation's water supply, and consumption of this resource is expected to increase in the future [*Library of Congress*, 1980]. It is widely available throughout the country and incentives to use it are high in areas where adequate surface supplies do not exist, where supplies are fully allocated and where the costs of surface diversion are high. Polluted surface supplies also create incentives to shift to groundwater, although many aquifers may face the risk of contamination from toxic chemicals [*Epstein et al.*, 1982].

Groundwater can be either a renewable or nonrenewable resource. In the humid areas of the country, withdrawals from an aquifer seldom exceed the short-run rate of recharge. Large-scale pumping can dewater shallow wells and create spot shortages, but the long-run productivity of the aquifer is not impaired. In coastal areas, sustained pumping may, however, lower water tables and increase the rate of salt water intrusion thus permanently impairing the resource. However, it is in the High Plains and Far West where groundwater is likely to be classified as a nonrenewable resource because the rate of extraction far exceeds the rate of recharge. Groundwater use has increased in the west because there is a high demand for water in areas such as California'a San Joaquin Valley and the Los Angeles basin, Central Arizona, and the Ogallala Formation in the High Plains where surface supplies are limited [*Christensen et al.*, 1982]. As a result, significant reductions in total groundwater availability by the year 2000 and shifts in regional water consumption patterns are projected [*Aiken*, 1982]:

> Annual ground water withdrawals for irrigation are projected to decrease by nine percent by 2020. Most of the decrease will occur in Texas and Kansas, with an increase occuring in Nebraska. Annual grounds water withdrawals in Texas are projected to decrease from eight maf to 4.8 maf, a forty percent reduction. Annual ground water withdrawals in Kansas are projected to decrease from three maf to 0.3 maf, a ninety percent reduction. Annual ground water withdrawals in Nebraska are projected to increase from eight maf to thirteen maf, a sixty percent increase. The corresponding losses of irrigated areas in Texas and Kansas will be more than balanced by the increase in irrigation in Nebraska. Texas and Kansas are also likely to lose livestock feeding operations to Nebraska. Approximately six million acres will revert to dryland production, while additional acres will be only partially irrigated.

In many areas of the country, groundwater use is therefore a problem that requires management [*Corker*, 1979]. That is, someone must determine who may use groundwater at what rate and under what conditions. A necessary condition for the implementation of any long-run management program is the assignment of property rights in groundwater. Management programs start with existing property rights assignments and either refine, supplement, or supplant these rights. Economists are generally agreed that property rights must be well-defined, enforceable, and transferable [*Anderson et al.*, 1983]. Only if these three conditions are met will there be proper incentives for groundwater users to balance present versus future values of the resource and to consider the substitution of resources such as alternative supplies or more efficient water use systems. With respect to groundwater, definition is the most difficult problem because rights in common pool resources are reciprocal. One pumper's right must be defined with respect to all other pumpers' rights; a groundwater basin cannot be sliced so neatly as a coal reserve.

The legal system has been assigning rights to groundwater for centuries, but until very recently the consequences of the property rules recognized were not great because supplies were abundant; this is no longer true. In the west and in some areas of the east the assignment of groundwater rights has become extremely important and controversial as competition for scarce supplies has increased. Historically, water rights were almost exclusively determined by the courts, and this too is no longer true. Judicial assignments are still very important, but legislatures have asserted their constitutional power to redefine common law property rights. Some states such as Arizona, Colorado, and New Mexico have ambitious administrative programs that redefine property rights to conserve available supplies by putting ceilings on the amount of permissible consumption. In 1 year, Arizona switched from a permissive common law-based regime to the most sophisticated and ambitious regulatory program in the country. Eastern states have put in place some emergency as well as permanent management programs to respond to spot and more chronic shortages that are likely to increase as farmers turn to groundwater for supplemental irrigation and cities increase their claims on the supply.

Paper number 5W0483.
0043-1397/85/005W-0483$05.00

This article surveys the evolution of the law of groundwater property rights. Section 2 sketches the relevant policy considerations in groundwater management. Section 3 traces the common law rules from their English antecedents to contemporary attempts to modify the common law to promote genuine sharing among competitors. Management programs in the eastern states are also discussed. Section 4 traces the rejection of the common law in the West and attempts to place groundwater rights within the law of prior appropriation as well other not strictly appropriation management programs. Section 5 analyzes a recent Supreme Court decision holding that groundwater allocation is subject to the negative commerce clause and speculates about the impact of this decision on state management programs.

2. Policy Framework

Groundwater resources are either renewable or nonrenewable. In both cases, society's objective should be to use these resources efficiently and equitably. Society benefits when resources are allocated efficiently. The allocation of resources to their highest value contributes to the nation's wealth and is also some guarantee that the benefits of the resources will be widely distributed. The promotion of allocative efficiency, however, must sometimes be tempered by equity constraints. Because it is necessary to sustain human life, there is a persistent theme in the law and legislation that access to water must be fairly distributed. For example, to decide what is the right rate of a mining a state or region must face the hard question of how it wishes to allocate its scare groundwater resources in the future. This is usually a question of whether irrigated agriculture should be supported at its present level. Several states have faced the mining issue but only Arizona has squarely decided to shift water from agricultural to municipal and industrial uses. Arizona's choice was "aided" by its explosive urban growth and the federal government's willingness to finance the importation of surface supplies to the center of the state. The major policy choices that any groundwater management program faces were well summarized by the *National Water Commission* [1973]:

> The three principal problems of ground water law, management, and administration are: (1) integrating management of surface water and ground water, (2) depletion of ground water aquifers at rates exceeding recharge (often referred to as the "mining" of ground water), and (3) impairment of ground water quality. Lesser, though important, problems are also considered: accelerating collection of ground water data together with fuller and more meaningful interpretation of it, aquifer protection, and subsidence.

2.1. *Renewable Resources*

The basic choices that society faces with respect to renewable groundwater resources are to decide how the resource is to be shared among competing claimants and the appropriate time period to balance the rate of extraction with the rate of recharge. Unlike surface streams, there is no short-term natural limit to the amount of a resource that can be extracted over time. Thus groundwater can be pumped beyond the rate of annual recharge. It is generally agreed that limiting the rate of extraction to a basin's safe annual yield may be inefficient and legislatures, and courts have struggled to define the time period beyond the rate of annual recharge during which the books should balance. Once society decides to limit groundwater extraction to the safe yield of a basin, it is generally more efficient to put the burden of making use decisions on those who benefit immediately from the resource. The issue thus becomes how property rights can be defined to achieve this objective. There are two potential components to groundwater property rights that make definition more complicated compared to surface water rights. Groundwater rights consist of a right to a fixed quantity as well as a claim to a static pressure level. This is because groundwater is usually available to meet all demands if pumping levels are increased [*Trelease*, 1970]. The issue is how higher pumping costs should be allocated.

2.2. *Nonrenewable Resources*

The basic objective of nonrenewable resources is to make an optimum intertemporal allocation [*Hotelling*, 1931]. This is easier said than done, but it focuses the issue on the real problem, What is the right rate of mining? This objective is not easy to implement because the law has put substantial constraints in the way of the alignment of groundwater rights with these objectives. First, the law, following Kinney, has subdivided the ground waters into three major arbitrary and scientifically unsound categories: artesian, percolating, and underground water courses and formulated different rules for each source. [*Kinney*, 1912]. Second, until recently, there has been comparatively little integration of surface and groundwater rights, although water lawyers have always recognized the need for an integrated law [*Weil*, 1929]. Third, the common law has led to exaggerated claims that groundwater is constitutionally immune from the state's police power.

3. Common Law of Groundwater

The common law of ground water started with a pure rule of capture that was appropriate for its time but no longer is [*Moses*, 1966]. Nineteenth-century English courts classified groundwater as part of the soil, and the exclusive right to extract, regardless of the consequences to competing users, was assigned to the overlying property owner. Groundwater rights were conceptually a corollary of the maxim cujus est solum est useque ad coelum. Ownership of land from the heavens to the depths of the earth was never taken literally in England and has undergone major modification in this country to accomodate avaiation [*Wright*, 1968]. However, the recognition of subsurface property rights to some depth is a powerful one, and groundwater cases did not require the courts to test the lower limits of the maxim [*Ball*, 1928]. Any injustice to competing users was thought to be cured by the correlative right of capture. American courts initially adopted the English rule either as a reflexive reception of the common law or because they agreed with the underlying assumptions, but they soon became uneasy with the lack of any sharing principles analogous to those found in the law of riparian rights applicable to surface waters. American courts began to deviate from the common law so that today the common law of groundwater rights runs the gambit from the English rule to riparian rights-based sharing rules. This section will examine the scientific and economic bases of the English rule and its American modifications.

3.1. *English Rule: An Efficient Response to Uncertainty?*

The English rule, which gives an overlying landowner the right of unlimited extraction regardless of the consequences to competing users, was announced in two cases between 1843–1859. Two principal reasons were given for the rule. First, the extraction of groundwater was analogized to the erection of an artificial structure on the land [*Acton versus Blundell*, 1843]. Wells therefore fell within the law of lateral and subjacent support. At common law a landowner has a right to have his land supported in its natural but not artificial state. The reason is the encouragement of land development. The same policy was applied by the English courts to groundwater use. A landowner had no right to be free from artificial interfences with his groundwater supply because he had a correlative right of self-help to do likewise. The rule was said to serve "the great interests of society" which "require the cultivation of every man's land be encouraged and its natural advantage made fully available ...." Second, groundwater hydrology was not understood and thus rights were not susceptible to easy adjudication [*Chasemore versus Richards*, 1859]. It was easy to adjudicate rights to surface streams because "running water is something visible." In contrast, a determination that there had been an interference with undergound supplies "would require the evidence of scientific men."

American courts found the English rule's prodevelopment policies apt for an expanding economy and the "hidden" nature of groundwater a compelling justification for the conclusion that it would be unfair to compel a landowner "to redress a wrong of which he cannot possibly have noticed" [*Wheatly versus Baugh*, 1855]. American cases added an additional reason for a no liability rule that fit well with the prevailing national consensus that natural resources were there for man to exploit at the fastest rate possible. Groundwater, and with oil and gas were classified as things ferae naturae, [*Westmoreland and Cambria Natural Gas Company versus Dewitt*, 1889] a Roman classification used to describe unowned resources. Under Roman law unowned resources were in the "negative community" awaiting appropriation or capture by a private party [*Pound*, 1922]. The Roman justification for capture gave it respectability, but the English rule has long been criticized and even ridiculed. Ridicule became easy after Wisconsin took the English rule to its logical limit and held that a landowner [*Huber versus Merkel*, 1903] could extract water even for the malicious purpose of injuring another landowner, although all other courts incorporated an antimalice qualification into the common law [*Greenleaf versus Francis*, 1836].

In retrospect, the English rule, with the no malicious pumping qualification, appears to be both economically rational and not terribly unjust. The rule is efficient because the costs of adjudicating a fair division of a common source of supply probably exceeded the benefits. In areas of the country where groundwater supplies are generally abundant or use levels are minimal, the English rule does not overly restrict access to life-giving water supplies. Individual pumpers will suffer injuries but they have the reasonably effective remedy of self-help, deeper wells, and any injury is likely to be temporary rather than permanent.

Just as it may have been, this defense of the English rule rests on two assumptions that have become weaker in the twentieth century. Our knowledge of groundwater hydrology has greatly increased so that sophisticated mathematical models of reservoir mechanisms have replaced the Dantian vision of water in flux. In many situations, it is efficient to allocate the aquifer among competing users. Groundwater use has increased greatly and the technology of extraction has increased. Finally, the small-scale pumper's self-help remedy against a large-scale pumper becomes more costly. In this situation the distributional considerations may call for a rule that gives all claimants some share of both the stock and flow incidents of the common pool.

The economic criticisms of the English rule are many and powerful. Perhaps, the principal indictment is that the rule leads to a potential inefficient allocation of resources. As has been amply demonstrated, when common pool users have no rights, except self-help, against other users actions, the overrapid exploitation of the resource will result. This consequence is presumptively waste because no attempt is made to value future as against present consumption. The rule of capture created great problems in the oil and gas industry until it was modified by conservation legislation. Because groundwater demand was not as acute, there was little initial pressure for the legislative modification of the rule of capture, however; groundwater rights are undergoing a similar modification. Further, the classification of groundwater as incident to property ownership makes it difficult to coordinate surface and groundwater usage, although hydrologically almost all groundwater is connected to surface flows. Surface rights are thus impaired because against other surface users, a surface right holder must share, but a groundwater user need not share the subsurface flow with a surface user. In addition to waste, the English rule can be inequitable. It is basically fair when all aquifer users use roughly equal technologies to make the same use of water, but self-help is not as fair when modest users face large-scale pumpers [*Davis*, 1972]. Smaller users have some expectation to be compensated for conditions that change customary use patterns in an area. Most states have rejected the English or absolute ownership rule, but a few states (Indiana [*Wiggins versus Brazil Coal*, 1983] and Vermont [*Drinkwine versus State*, 1970]) have recently reaffirmed the rule. A federal district judge has refused to follow the Indiana state supreme court decision in a conflict between a large-scale supplemental irrigation and prior small farmers [*Prudential Insurance Company versus Prohosky*, 1984].

3.2. *American Rule*

These criticisms of the English rule were appreciated in the late nineteenth and early twentieth centuries. Courts began to reject the English rule and in its place substituted the so-called "American or Reasonable use Rule" [*Hoffcut*, 1904]. This rule places four restrictions on overlying pumpers: (1) water can be pumped only for a reasonable use; (2) it must be used reasonably on overlying lands; (3) pumping for a malicious purpose is per se unreasonable [*Gagnon versus French Lick Springs Hotel Company*, 1904]; and (4) the export of water from overlying to nonoverlying lands is per se unreasonable.

The American or Reasonable Use merely takes the edge off of the English rule. Only a few states allowed malicious pumping under the English rule, but the English rule was still though to be inefficient because it did not inquire into the utility of the use or its situs. The American Rule places a minimal threshold on the overlying owner's use: a pumper must demonstrate that his use serves a socially useful purpose. This clearly excludes malicious uses and might also exclude cases of excessive waste that have been tolerated under the English rule. Once this threshhold is met, the overlying owner may pump unlimited amounts of water [*Finley versus Teeter Stone, Incorporated*, 1968]. Competing claimants arguments that their wells have been dewatered are met with the same response under the English rule, damnum absque injuria. There is some loose talk in the cases that the American rule prohibits waste, but it is hard to know if waste means anything more than a malicious use. A leading water lawyer has written "such a restriction against waste is inherent in the term reasonable use. Waste is unreasonable" [*Moses*, 1969].

The restriction of the use of water to overlying lands is a major difference between the English and American rules. On one level the restriction of water to overlying lands is inefficient because it prevents its movement to higher valued uses. For example, oil and gas need not be used on the overlying land. On another level, however, the restriction of rights to overlying uses can be defended as efficient. The rule allows pumpers to develop reasonable expectations about the rate of pumpings costs in an aquifer. As a result, the race to mine stimulated by the rule of capture is somewhat tempered. In the main, the principal justification for nonoverlying land rule, however, is equity [*Clayberg*, 1915]. Its beneficiaries are generally small farmers whose wells are dewatered or who suffer a decline in depth and pressure as the result of the location of a nearby municipal well field [*Volkman versus Crosby*, 1963]. These users have some expectation that they must compete with other similarly situated users but not with subsequent users whose level of use is of a different magnitude. The cases enjoining nonoverlying users are an example of the incorporation of prior appropriation concepts into the common law of water rights.

These considerations were made explicit by the courts from the start [*Forbell versus City of New York*, 1900]:

> But to fit it up with wells and pumps of such pervasive and potential reach that from their base the defendant can tap the water stored in plaintiff's land, and in all the region thereabout, and lead it to his own land, and by merchandising it prevents its return, is, however reasonable it may appear to the defendant and its customers, unreasonable as to the plaintiff and the others whose lands are thus clandestinely sapped and their value impaired.... the immunity from liability which the defendant claims violates our sense of justice. It seems to pervert just rules to unjust purposes; it does wrong unde the letter of the law in defiance of its spirit. The case is certainly unlike those which have preceded it in the court, and we may consider the rules announced in the previous cases in the light of the cases themselves. We recognize the fact that the water supply of a great city is vastly more important than the celery and water and water cresses of which plaintiff's land was so productive before defendant encroached upon his water supply, but the defendant can employ the right of eminent domain and thus provide its people with water without injustice to plaintiff.

In most states, the American or Reasonable Use rule has not resulted in substantial pumping limitations. For example, the English rule as applied by the Texas Supreme Court tolerates a great deal of waste [*City of Corpus Christi versus Pleasanton*, 1955]. Despite statements that wasteful practices are potentially unreasonable, courts have used crude categories to resolve reasonable use conflicts [*Moses*, 1969]. Although the issue was seldom raised, overlying land was assumed to mean all land overlying a defined aquifer. One exception to this generalization is Arizona, which clung to the Reasonable Use rule in face of persuasive evidence that it was unsuited to the state's climate and economic situation. In a conflict between pecan growers and a copper mine south of Tucson, the court narrowly defined overlying use [*FICO versus Bettwy Company*, 1976]. The mine owner wanted to pump water from one part of the aquifer and use it on another part several miles away, but the farmers argued that they would be injured by the pumping and thus the use was not on the land from which the water was taken. Earlier Arizona cases suggested that the term would be defined narrowly [*Jarvis versus State Land Department*, 1969], and the court agreed with the farmers, although it did not precisely define the extent of overlying land. The reaction from cities and the mining industry ultimately led to the state's present groundwater code, a subject discussed in detail in section 4.

3.3. *True Sharing Rules*

The third phase of groundwater case law development was the adoption of rules that actually proration the supply in times of shortage or, at a minimum, open up theories of liability for injury caused by pumping beyond those recognized by the American or Reasonable Use rule. The phase is still ongoing.

California led the way in 1903 with the adoption of the correlative rights rule [*Katz versus Walkinshaw*, 1903]. This rule, like the American or Reasonable Use rule, divides claimants between overlying and nonoverlying claimants, but it also equitably apportions the supply among overlying owners. Overlying owners have the first claim to the water. Subsequent rights are entitled to equal dignity with existing rights, but what constitutes overlying use has never been clearly defined [*Tehachapi-Cummings County Water District versus Armstrong*, 1975]. Some cases have equated it with use of land within the groundwater basin rather than the parcel of land beneath which the water is actually pumped. It seems clear, however, that municipalities cannot claim overlying rights to supply customers within the basin from which water is pumped. In times of shortage the court must proration the available supply among overlying users, each of which is entitled to a "fair and just portion" of the pool. Any surplus above these needs is available for appropriation outside the basin provided that the total rate of extraction does not exceed the safe yield of the basin. If the basin is in overdraft and the supply is not sufficient to satisfy the needs of overlying owners, nonoverlying rights may be curtailed. This term is still being defined in the state. The correlative rights rule is an adaption of the sharing principles of riparian surface rights to groundwater [*Kirkwood*, 1948]. The rule's originator summarized and defended his rule in a famous law review article [*Shaw*, 1922]:

> The rights of the owners difference parcels of land situated over a water supply of that character, with respect to each other, and with respect to the use of the water on the overlying land, are mutual and reciprocal. They are regarded as persons having different interests in a common estate in such waters. Each is entitled only to a reasonable use of such water on such land and may take no more than his reasonable share for that purpose. None of them can rightfully take the water and export it from the basin for use on lands not situated over the common waterbearing stratum, if such taking injures the owners of other parcels of the overylying lands. In short, the lawful rights of the several owners of such lands to the waters therein are in almost all particulars similar to the mutual and reciprocal rights of the owners of riparian land among the course of an ordinary stream in the use of its waters. This conclusion was considered necessary to the full development and use of the natural resources of the state and to the prosperity and general welfare of its people. The geological formation of the land, its topographical characteristics, and the aridity of the climate produced conditions so different from those of the countries from which our common law rules were derived, that the well-known rule that the ownership of the soil in fee gave absolute title to all beneath the surface, including such subterranean water supplies, was held unsuitable to our conditions.

California's creative rule [*Scheiber*, 1984] attracted a grea deal of national attention during the conservation era [*Bruce*, 1909], but it has been thought largely confined to the state of its origin. Modern water law scholars have, however, insufficiently appreciated the doctrine's impact in other states. This is largely because a discussion of the rule appears as dicta in decisions (usually municipality farmer conflicts) that were decided or could have been decided under the American or reasonable use rule. Arkansas [*Jones versus Oz-Ark-Val Poultry Company*, 1957] has clearly adopted it as have Nebraska [*Olson versus City of Wahoo*, 1933] and New Jersey [*Meeker versus City of East Orange*, 1909].

For a time it appeared that the California correlative rights rule might be adopted by the Colorado doctrine appropriation states [*Hutchins*, 1942]. The Colorado doctrine states adopted the law of prior appropriation for surface waters on the theory that the common law of riparian rights was never part of the common law of the state because riparian rights were unsuited to the arid climate. However, these states were reluctant to apply appropriation to groundwater because groundwater usage was so minimal when the law of prior appropriation was enshrined [*Martz*, 1958]. Idaho and Utah flirted with correlative rights before construing their statutes to apply to groundwater. Colorado held as late as 1963 that nontributary groundwater was the property of the overlying landowner [*Whitten versus Coit*, 1963]. In the intermountain west as well as in Oregon and Washington groundwater is now subject to appropriation by statute.

As the western states began to appreciate the value of groundwater, statutes were passed expressly authorizing its appropriation. These statutes began to take first the first step toward a unified surface and groundwater law. New Mexico and Oregon passed the first statutes in 1929; Utah followed in 1935, Nevada in 1939, Kansas and Washington in 1945, and Wyoming in 1947, Oklahoma in 1949, North and South Dakota in 1955, and Montana in 1961. Colorado waited until 1967 to adopt effective groundwater legislation and is still struggling with the regulation of groundwater. The largest groundwater using states in the west, Arizona, California, Nebraska, and Texas refused to adopt the rule of prior appropriation for groundwater. The difference may be more than one of form than of substance, because the appropriation states with accute shortages have often adopted a system that is prior appropriation in name only. Prior appropriation just does not work for problems such as conjunctive use, pressure level determination, and mining.

A few eastern states moved beyond the American Reasonable Use rule by adopting the basic principles of the correlative rights rule, sharing among overlying owners, but not the formal doctrine and all of its consequences. A series of decisions have adopted riparian surface rules for ground water conflicts but give little guidance as to how groundwater rights will be defined. The first case, a lower court Delaware decision, entered a Solomonic degree to resolve a contest between a shallow well pumper and an adjoining landowner who sunk a well to fill his swimming pool [*MacArtor versus Graylin Crest III Swim Club*, 1963]. With no discussion of prior case law, the court balanced the equities and enjoined defendant from pumping "on the condition that plaintiffs deepen or agree to permit defendant to cause their well to be deepened to a reasonable depth with the cost to be equally divided." Plaintiff was also given the choice of hooking up to a water line. If plaintiff rejected both options, no injunction would ensue, and if defendant failed to pay his required share of deepening costs, a permanent injunction would ensue. Arkansas also applied the domestic preference of riparian rights to prefer a domestic to commercial user. Missouri applied riparian rules to a municipal-farmer conflict that could have been decided under the American or reasonable use rule [*Higday versus Nickolaus*, 1971]. The farmers claimed injury from a municipal well field in an area where "they attributed the fertility of the soil to the continuing presence of a high subterranean water table...." The court held only that plaintiffs had a property right to the reasonable use of percolating waters underlying their lands, but they turned over to the trial judge the hard question of the relief to which plaintiffs would be entitled. All of these cases raise, but do not answer the question in groundwater law: are right holders entitled to static pressure levels that existed before the defendant's pumping or must they suffer some decline in pressure levels as defendant exercises its equal or correlative rights? They do suggest that courts may be applying one rule between new large scale and older smaller pumpers because the injuries to the prior users are foreseeable and another rule, capture, among similar-sized pumpers.

Texas is the leading groundwater use state that adheres steadfastly to the absolute ownership rule, but even there the court has begun to temper it. The state recently reaffirmed the rule but suggested that injuries caused by negligent pumping may be actionable [*Smith-Southwest Industries versus Friendswood Development Company*, 1981]. Allegations that a large well field in the Galveston Bay area caused subsidence on neighboring lands, spaced the wells in too tight a pattern and on the side of the bay that would concentrate subsidence, and pumped at a high rate stated a cause of action in negligence.

Eastern states have taken various routes to adjust the law of groundwater to changing conditions. Farmers are fairly well protected against water raids by municipalities but not from new uses such as supplemental irrigation, which is rapidly increasing in the eastern half of the country. It is too soon to tell if states must impose administered groundwater rights, but there is an immediate need to provide equity to small pumpers. Like all issues in groundwater, this is a hard one because it is hard to determine what is fair pumping expectation. Courts will be helped by the Restatement of Torts (Second) which modifies to American or Reasonable Use Rule to provide compensation where large-scale pumping on overlying and non-overlying land causes injury. Section 858 states

> (1) A proprietor of land or his grantee who withdraws ground water from the land and uses it for a beneficial purpose is not subject to liability for interference with the use of water by another, unless:
> (a) the withdrawal of ground water unreasonably causes harm to a proprietor of neighboring land through lowering the water table or reducing artesian pressure,
> (b) the withdrawal of ground water exceeds the proprietor's reasonable share of the annual supply or total store of ground water, or
> (c) the withdrawal of the groundwater has a direct and substantial effect upon a watercourse or lake and unreasonably causes harm to a person entitled to the use of its water.

The comments explain the rationale for the expansion of the common law:

> The reasonable use rule in its original form met this problem by imposing liability for interference with neighboring wells and springs by withdrawing large quantities of water and piping it to distant places for municipal and industrial use. As usually stated, the rule gave no protection against identical harm caused by a large industrial plant or apartment house built on neighboring overlying land. Recently it has been recognized, however, that the salient factor is not the place of the use but the withdrawal of water in unprecedented quantities for purposes not common to

the locality, and that it is fair and just to place the cost of improving neighboring facilities upon the person or organization whose withdrawals render them inadequate, even though the water is used on the land form which it is withdrawn. In brief, the restatement continues the common law of capture as among similarly situated pumpers but tempers capture when a large pumper injures a prior small one. The lessons of David and Golith remain strong.

Section 858 is beginning to influence the decisions. It has been adopted in Michigan, [*Maerz versus U.S. Steel Company*, 1982], Ohio [*Cline versus American Aggregates Corporation*, 1984], and Wisconsin [*State versus Michels Pipeline Company*, 1974]. Nebraska has been influenced by it [*Prather versus Eisenman*, 1978], and only Indiana [*Wiggins versus Brazil Coal and Clay Company*, 1983] seems to have rejected Section 858, although a federal district court in the state recently rendered a decision consistent with its principles [*Prohosky versus Prudential*, 1984].

3.4. *Administrative Management in the East*

Eastern states are just beginning to confront the need for groundwater management. Statuatory regulation of groundwater use is generally designed only to empower an agency to make ad hoc apportionments in times of drought, not to put permanent ceilings on the amount of water than can be extracted from a basin. Indiana [*Indiana Code*, 1983] and New Jersey [*New Jersey Statutes Annotated*, 1985] have long had statutes that allow the state to designate critical areas and to cut back on large-scale pumpers, and an Indiana statute that applies to a small area was recently invoked to limit the withdrawals of a large supplemental irrigator. Other states require withdrawal permits for groundwater but have had little management experience; Florida is an exception. The state's geology forces 92% of its residents to consume groundwater from its extensive aquifers. The aquifers have a high rate of recharge, but overrapid pumping causes salt water intrusion or other contamination. In response to the these problems, the Florida Water Resources Act of 1972 [*Florida Statutes*, 1985], based on a model code drafted by the late Frank J. Maloney [*Maloney et al.*, 1972], creates a permit system for groundwater withdrawals and creates districts with the taxing authority to engage in recharge programs. The districts must set minimum groundwater levels above which further withdrawals would be significantly harmful to the water resources of the area and may issue permits for reasonable beneficial uses [*Maloney et al.*, 1979]. In an important decision the Florida Supreme Court sustained the permit authority against a constitutional challenge that a taking of property had occured because regulation was necessary to protect the correlative rights of aquifer users [*Village of Tequesta versus Jupiter Inlet Corporation*, 1980]. Permits are issued by multifactor criteria, but the actual practice seems to be an informal prior appropriation policy. Some districts have used the permit to impose conservation conditions on the use of water. Permits may be suspended on an emergency basis. Some find this fair; others correctly conclude that the suspension of permit rights for unspecified reasons robs the permit of the necessary stability to do long-range investment planning [*Trelease*, 1974]. Florida's water management program is breaking new ground in the coordination of water supplies and land development [*Rea*, 1983], but it has been suggested that the ability to decontaminate brackish water may remove water management as a constraint on land development [*Niegro*, 1983].

Minnesota has the most extensive regulation of agricultural groundwater withdrawals in the Midwestern United States. All major agricultural withdrawals require a state permit. The state has five priorities or use preferences. Domestic use "excluding industrial and commercial uses of municipal water supply" is first and agricultural irrigation in excess of 10,000 gallons (45.450 L) per day is third. There are two classes of groundwater permits. Class A permits are for areas of the state where adequate groundwater data exists and class B permits are for all other areas. Nonetheless, extensive geological and hydrologic information including a pumping test must accompany a class B permit application. The statute speaks of irrigation appropriations, but the term does not refer precisely to the classic doctrine of prior appropriation in force in the western states for surface waters. The statute requires all well owners to construct wells in accordance with a state code. Once this is done the statute protects these well owners from interference from subsequent pumpers:

> The commissioner shall issue permits for irrigation appropriation from groundwater only where he determines that proposed soil and water conservation measures are adequate based on recommendations of the soil and water conservation districts and that water supply is available for the proposed use without reducing water levels beyond the reach of vicinity wells constructed in accordance with the water well construction code.

There is, however, no attempt to allocate supplies in times of shortage by a priorty schedule. Minnesota has done what, in effect, many western states have done to allocate groundwater. The state decides which pumpers may enter a basin but does not attempt to allocate further supplies among the pumpers once the basic entry decision is made. To date, there has been a limited need to enforce the statute because of the state's location, but it is an important management tool to have in reserve.

4. MANAGEMENT THROUGH APPROPRIATION AND BEYOND

This section analyizes in considerable detail the management institutions now in place in the West. What emerges from this survey is that the western states have kept the form but not the substance of prior appropriation or rejected prior appropriation. In areas where the resource is functionally nonrenewable such as central Arizona, the Northern High Plains and other parts of the Ogallala formation states have protected existing pumpers by severely restricting entry into basins in overdraft and set the time period for mining. [*Baker versus Ore-Ida Foods, Incorporated*, 1973]. Pumpers in the basin are allowed to withdraw equally because there is no attempt to enforce priorities inter sese. The most interesting states are those with statewide management and considerable attention is given to Arizona, Colorado, and New Mexico. Significant experiments in local management are underway in Kansas, Nebraska, and Texas, and these efforts are discussed. For different reasons, California and Oklahoma defy conventional classification and the treatment of groundwater in these states is covered. Other western states have groundwater management problems, but because conflicts are less frequent, these states are discussed only by way of example.

4.1. *Arizona*

In 1980, with the stroke of Governor Babitt's pen, Arizona abandoned the common law of groundwater supplemented by a weak regulatory scheme designed only to preserve the status quo and adopted a comprehensive state-administered regulatory program. The program is not only designed to conserve the state's groundwater resources by limiting extraction, but to shift groundwater from agricultural to municipal and industrial uses. Arizona's agriculture, especially cotton production, has long been economically irrational [*National Academy of Sciences, Water and Choice in the Colorado Basin*, 1968], but the state is perhaps the first to adopt a statewide program to move systematically water from lower to higher value uses. The decision is at one level surprising in light of the state's persistent refusal to limit its massive groundwater mining, but it is not surprising once one realizes that alternative surface supplies are controlled by the federal government who must finance the aqueduct that will make it possible for Arizona to enjoy the waters of the Colorado River given to it by Congress and confirmed by the Supreme Court. This section will examine (1) the law of groundwater and the state's problems prior to the 1980 legislation, (2) the history of the legislation which it is instructive to other states, and (3) the use restrictions imposed by the legislation as well as its constitutionality.

4.1.1. *The Prior Law: a gamble on a federal bailout.* In the 1970's, the state used 4.8 MAF of groundwater per year compared to 1 MAF of surface water [*Arizona State Water Commission*, 1977]. The rate of annual recharge amounts to only 2.6 MAF, leaving an annual deficit of 2.2 MAF. The state's first water code, The Howell Code, declared surface but not subsurface water public and thus subject to appropriation [*Howard versus Perrin*, 1904]. In 1904 the state supreme court adopted the common-law rule that groundwater was the property of the overlying owner and not subject to appropriation [*Howard versus Perrin*, 1904]. Subsurface spring water was classified as pecolating in 1918 [*McKenzie versus Moore*, 1918]. In 1926 the court gave some indication that it might subject a large portion of the state's groundwater to appropriation by formulating a definition of an underground stream which was broad enough to cover most sources of groundwater [*Pima Farmers versus Proctor*, 1926]. The suit involved major land owners in the Santa Cruz River basin, who agreed that the major source of supply was an underground stream, although the area was over 1 mile (1.609 km) in width and had no discernable channel or bank. The court applied the doctrine of prior appropriation. However, 5 years later the court affirmed the narrow common-law definition of an underground stream which requires a stream flowing in a natural channel between well-defined banks [*Maricopa County Municipal Water Conservation District versus Southwest Cotton Company*, 1931]. In 1952 the State Supreme Court attempted its major intervention in what was a volatile political issue by overruling 1904 decision adopting the common law and declaring all groundwater subject to prior appropriation [*Bristor versus Cheatham*, 1952]. (However, the doctrine was short-lived, for on rehearing the court reversed itself and readopted the common-law rule, subject only to the reasonable use modification. [*Bristor versus Cheatham*, 1953].)

In 1948 the state enacted its first groundwater code for reasons Justice McFarland later explained [*Jarvis versus State Land Development*, 1969]:

> I call attention to the fact that what was known was [sic] the Central Arizona Project was pending in the United States Congress at that time. The Bureau of Reclamation of the Department of the Interior took the position that the Arizona Water Users in Central Arizona would not be saved by the Central Arizona Project from the disaster which would result from water shortage unless there was an underground water law which would regulate and prevent an expansion of the use of water; that otherwise new land would be put into cultivation which would deplete the water supply even more than what would be gained by the importation of water from the Colorado River.

The 1948 Code attempted to preserve the status quo by preventing new irrigated land from being put into production. The Governor's objective was to buy a decade's time. He bet, correctly as it turned out, that Arizona would prevail on its Colorado River claims in the Supreme Court [*Dunbar*, 1977]. He did not, however, foresee the problems that would arise in getting the water from Yuma to Central Arizona, the state's explosive growth region. To freeze uses, the state enacted a critical areas program which limited permitted wells to lands irrigated and in cultivation within 5 years prior to 1948. The statute was held constitutional against an equal protection challenge, but a series of court decisions allowed considerable expansion. As the state's nonagricultural population continued to grow expotentially, pressure continued to mount for more effective limitations on pumping. The Supreme Court's narrow definition of overlying land in the Bettwy case discussed earlier "created a storm of protest from the strong Arizona mining lobby," heightened the fears of cities such as Tucson that they could not obtain adequate supplies and ultimately led to the formation of a Groundwater Management Commission in 1977 [*Kyl*, 1982]. Cities and the mining industry forged a strong coalition that has permanently shifted power from agricultural to urban users. The study commission put together the management concepts embodied in the statute and beat back a plan, much like Lincoln's plan to deal with the newly freed slaves, to buy out agricultural lands.

4.1.2. *Legislative history.* The need for legislation became urgent after the then Secretary of the Interior, Cecil Andrus, announced a simple federal position on the issue in October of 1979: no groundwater legislation, no Central Arizona Project (CAP). The Carter Administration came into office determined to apply a decade plus long criticism of the cost-benefit analysis process used to justify water resources projects. A "hit list" was compiled that permanently alienated the Administration from the west, but Secretary Andrus's ultimatum to Arizona, coupled with a removal of the CAP from the hit list, is an example of effective federal leverage over state water law. Secretary Andrus's position spurred the creation of a negotiating group, chaired by Governor Babbitt, which was composed of the major water interests. After 6 months of private meetings, an agreement was obtained. The most important decision that the group took was to support statewide rather than local management. This was done because [*Connell*, 1982]

> The negotiators thought that by making the director a political appointee, at least some recourse against him would be available. The Governor realized that some vagueness in the standards and a powerful director were necessary for the Act to be completed. As part of his strategy to reach a consensus, he frequently deferred consideration of difficult issues or suggested that their resolution be delegated to the director. This strategy worked in part because of the intense pressure on the group to reach agreement.

4.1.3. *The Groundwater Act.* The Groundwater Act was created to provide a foundation for groundwater conservation and use conversion.

Management authority: For the reasons previously explained, groundwater management is exercised at the state level [*Arizona Revised Statues*, 1983]. A new Department of Water Resources was created to administer the Act. The Act retains the prior concept of groundwater basins, and the entire state is divided into basins and subbasins. The major innovation however, is in a new concept, active management areas.

Geographical scope of management and basic concepts: The Act creates four active management areas (AMA's): Phoenix, Pimaal, Prescott, and Pinal and Tucson. These four areas contain 80% of the state's population and 69% of the irrigated acreage in overdraft. New areas may be created to conserve existing supplies, prevent subsidence, or to protect the water quality of an area either by the Director of the Department of Water Resources or by voter petition. A state appointed area director manages these areas assisted by a groundwater users advisory council.

The management goals for the four active management areas are revolutionary for the state and for much of the West. For the three cities the goal is no less than "safe yield" by January 1, 2025. For the Pimal area the goal is a modified preservation of the status quo:

> The management goal of the Pimal active management area is to allow development of non-irrigation uses as provided in this chapter and to preserve existing agricultural economies in the active management area for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses.

Safe annual yield is defined conservatively as a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial groundwater recharge in the active management area. The kind of optimal yield conjunctive operation policies practiced in California could not be applied in Arizona where groundwater accounts must balance every year. Only in the Pinal area does the Act have an optimal yield policy that permits yearly overdrafts to be carried over.

These goals are to be implemented by a five-tiered management planning process over a 45-year period. From 1980 to 1990, water duties for the conservation of water must be calculated to determine the quantity of water reasonably required to irrigate crops historically grown on pre-1975 acreage. Water duty represents a conservation standard that is a compromise between proration reduction schedule and compensated land retirement [*Hidgon and Thompson*, 1980]. The theory is that the farmers are entitled to a gradual phase in of conservation practices. For example, the 1990–2000 plan must establish duties that reflect "prudent long-term farm management practices within areas of similar farming conditions, considering the time required to amortize conservation investments and farming costs."

Outside of the AMA's; the state is divided into two other areas. The 1980's carries forward the 1948 Groundwater Code concept of irrigated nonexpansion areas. Two are designated in the Act and others may be created upon Director or voter petition. Groundwater use in the rest of the state is governed by the Arizona law of reasonable use.

Use of groundwater and vested rights: The revolutionary step of the 1980 Act is to make almost all groundwater use in an AMA dependent upon a statutory category or a state permit except for exempt small capacity wells and decreed appropriative rights. Basically, the Act regulates the state's three major uses, agriculture, municipal, and industrial separately. There are three classes of grandfathered irrigated rights, municipal, industrial, and agricultural. To prevent great disruption of existing use patterns, agricultural uses are given vested rights status but conversions and transfers are regulated.

Municipal use is limited to the service area of the entity which is defined as the area actually being served by the entity in 1980 or an area served as the result of an expanded distribution system. The liberal definition of service area was controversial during the 1979–1980 negotiations because of fears that unlimited municipal expansion would dry up aquifers and lower land values and because it had been agreed that an irrigated grandfather right may only be conveyed for another irrigation use. Cities insisted on this to prevent double dipping which would allow a farmer to sell the water right to one party and the land to another. They feared that the owner of the land would then use it for nonirrigation use of the land and the landowner would develop the property and demand water service from the city. Agricultural interests did impose three restrictions on service area expansion. An entity may not expand to (1) include a well field in the service area, (2) to service "disproportionately large amounts of water to an industrial or other large user unless the expansion is consistent with the AMA plan, and (3) for gerrymandering purposes. These are defined as including irrigated acres with the service area to extinguish the right to convey grandfathered rights to a nonirrigation use and for the purpose of withdrawing groundwater for irrigation purposes. The major limitation of municipal uses will probably be the conservation measures required in the 10-year AMA plans.

Industry, especially the mining industry, secured a reversal of the supreme court's Bettwy decision that virtually prohibited mining. Six classes of permits are authorized: (1) dewatering permits, (2) mineral extraction and metallurgical processing permits, (3) general industrial use permits, (4) poor quality groundwater permits, and (5) temporary permits. Groundwater that is withdrawn pursuant to a permit may be transferred "without payment of damages" within a subbasin of an active management area, and if industry purchases an irrigation grandfathered right, it may be transported outside of AMA subject to limitations.

To soften the impact of the statute, the legislature created three classes of "grandfathered rights." Type I rights benefit land developers. A Type I right is available to a landowner in an initial AMA who retired the land between 1965 and the creation of the AMA, who retained ownership of the land since it was retired and can show that a development plan for a nonirrigation use existed at the time of retirement. The landowner may withdraw or receive for the land three acre feet per year. Similar rights are available for subsequent AMA's. These rights are appurtenant to the land retired but may be leased with the land. Type II rights benefits cities and private water companies. Type II rights are available to entities in an AMA who were legally withdrawing water at the date of the designation of the AMA. The amount of the right is either the greater of the amount granted in a certificate of exemption and the maximum amount withdrawn in anyone year within 5 years preceeding the designation of the AMA or the maximum amount withdrawn in any one of the five preceeding years less any type I water. Type II rights are appurtenent. Appurtency under the Groundwater Code does not mean that right may not be transferred off the land. With some restrictions, type II rights may be conveyed and transferred. Rights may be transferred with a subbasin without payment of damages and between subbasins subject to the payment of damages. The rules for the protection of those injured by transfers are weaker than the rules of many states to protect junior appropriators injured by a change in the point of diversion of transfer. These states often put the burden on the transferor to show that no junior rights will be impaired. Under the Code neither injury nor impairment is presumed. "To succeed, plaintiff must now demonstrate the occurance of individual harm; for example, dry wells, increased pumping costs..." [*Doyle*, 1983]. Irrigators of nonretired lands in AMA's are protected by an administratively determined supply. Irrigators are entitled to an administratively determined amount of water calculated by the size of the farm unit and the duty of water which is the highest number legally irrigated acres during 1 year for 5 years prior to 1980.

The Code contains strong management tools that illustrate the close connection between water and land use controls. Subdivided lands within an AMA may be sold only after the developer has demonstrated that there is sufficient water to satisfy the needs in the subdivision for the next 100 years. A subdivider must also show that the projected water use is consistent with the management plans for the AMA, which have been established by the Director of the Department of Water. The assurance of a supply of water need be demonstrated despite the fact that the subdivision will be served by a water company, although if the subdivision is to receive Central Arizona Project water, the director may deem the water assurance requirement met.

Whenever a state switches from the common law to prior appropriation or a new management system, the constitutionality of the switch is questioned. All states that have adopted a new system of water law have preserved rights based on water applied to a beneficial use at the time of the change, but of necessity, unexercised rights have not been protected. The argument is that the change from the common law is a taking of property without due process of law. Many cases have been able to avoid the issue because no actual injury has been caused by the change. All that the legislature has done is to force a water user to trade one form of right for another. Thus unexercised rights are curtailed not merely exchanged. Arizona's act presented more difficult problems because the Act, although preserving grandfathered rights, makes it difficult to initiate new uses in AMA's. One state [*Town of Chino Valley versus City of Prescott*, 1982] and one federal district court opinion [*Cherry versus Steiner*, 1983] upheld the Act as constitutional. The first held that the legislature could allow transfers within the same subbasin because a landowner had no property right to groundwater beneath his land until he captured it. The second case was harder because landowners within an active AMA were precluded from initating a new use. The federal district court followed the state court and held that there was not taking because there had been no capture prior to 1980. In general, groundwater regulation is a comparatively easy case because the expectations of pumpers of an unlimited right to use have never been terribly firm because of physical reasons and the law of capture and because regulation is necessary to prevent harm to other correlative rights holders [*Kelly*, 1983].

4.2. *California*

California is classed as a state without statewide management of groundwater, but this is true only in the formal sense. There is a great deal of creative groundwater management in California that has occured because of a unique partnership between the courts and major pumpers in Southern California and because of water district policies in the San Joaquin Valley. This partnership is a case study in the integration of groundwater use with imported water and of the conjunctive use of groundwater basins.

California, as was previously discussed, followed the correlative rights rule until 1949 when the Supreme Court devised a creative legal solution to groundwater overdrafts in Southern California that lasted until 1975 and induced cities to supplement groundwater supplies with Colorado River water. In 1937 Pasadena brought an adjudication against a number of cities pumping from the overdrafted Raymond Basin. All pumpers were nonoverlying appropriators, and had the court followed the doctrine of correlative rights, each appropriator would have been cut back in inverse order until the overdraft was ended. The trial court instead held that each pumper was mutually acquiring prescriptive rights against the others so each had to reduce only on a proration basis. All but one pumper agreed that each would be entitled to the highest amount of water pumped over a 5-year continuous period with rights adjusted "by actual withdrawals less the proportion this use bears to the total reduction required" [*Pasadena versus Alhambra*, 1949]. Although the court did not mention the agreement, it was undoubtedly a factor in the decision for it would have been unfair to the parties to force some of them out. At first, mutual prescription created a race to mine, but it eventually set the stage, especially as basins closer to the Pacific Ocean began to experience salt water intrusion, for cooperative arrangements to restrict groundwater usage and buy imported Colorado River water that the Metropolitan Water District had but could not sell.

The legislature's role has been limited to supporting local initiatives. [*Schneider*, 1977]. Legislation was passed in 1951 to give those who had been using imported water a credit for the groundwater withdrawals which could be used in subsequent adjudications and settlements. Within the framework of the doctrine of mutual prescription and its legislative support, large pumpers in Southern California achieved a high degree of conjunctive management using imported Colorado River water [*Reis*, 1965]. Mutual prescription has been adapted to basins where there is substantial recharge to add to salt water intrusion. A settlement in the Central and West basins limited pumping to the artificial safe yield which was defined as the natural safe yield plus the amount of water that could be effectively spread within the basin. Another widely reported trial court decision held that the prescriptive period for mutual prescription began to run when salt water intrusion threatened the quality of the basin [*Moore and Snyder*, 1969].

Management of groundwater along the coast was made possible because first, the West Basin, located on the Pacific Ocean, instituted litigation and then the Central Basin, located adjacent to the West and in effect upstream, followed suit. The West Basin litigation in Los Angeles has produced the most sophisticated institutional responses to salt water intrusion, but after 16 years of litigation, reportedly costing $5 million, resulting in reductions on pumping, salt water intrusion still continued to be a problem in the Basin. As a result of the Act, the Central and West Basin Replenishment District was formed in 1959 after lengthy negotiations with the state and with the major water service organizations in the Los Angeles area (E. Ostrom, unpublished manuscript, 1968).

Under the replenishment district enabling legislation, a district may determine the amount of annual overdraft and assess pumpers for the costs of purchasing imported water. If the basin has been adjudicated, assessments may be levied only against those who extract in excess of their declared rights.

The district may also levy and valorem taxes not in excess of $0.20/$100.00 of $0.20/$100.00 of assessed valuation. Basically, the District agreed that pumping levies rather than ad valorem taxes would be used to purchase replenishment water from Metropolitan Water District; the imported water would be spread to recharge the basin and prevent salt water intrusion by the Los Angeles County Flood Control District. The Central Basin delayed adjudication, since it was able to benefit from the West Basin's pumping reductions and spreading operations. However, to continue the spreading operations under the West and Central Basin Replenishment District, it was necessary to fix withdrawal rights in order to levy the pumping tax [*Reis*, 1967]. In contrast, Orange County has avoided adjudicating groundwater rights by a five-tier system of taxes and charges to pay for spreading Colorado River replenishment water.

California's unique mutual prescription doctrine rested on a dubious legal foundation, and in 1975 the California Supreme Court refused to follow Pasadena and began a new era of judicial equitable apportionment. California law prevents the acquisition of prescriptive rights against cities, but Pasadena did not consider this statutory prohibition. The prohibition was eventually applied in favor of the City of Los Angeles in its 20-year struggle against upstream communities to control the natural flow, mainly subsurface, of the Los Angeles River as well return subsurface flows from imported Owens Valley water. A trial court decision that gave all cities pro rata rights of equal priority to native and imported water was reversed in a major case [*City of Los Angeles versus City of San Fernando*, 1975] which held (1) that Los Angeles, as successor to the Spanish and Mexican pueblo of Los Angeles, has pueblo rights which give it a preference to the natural groundwaters of the river; (2) Los Angeles had a right to recapture imported waters including return flows "equal to the net amount by which the reservoir is augmented by such deliveries"; and (3) the doctrine of mutual prescription would not be applied in the case. The city need not show a specific intent to recapture or be able to physically trace the waters. California law was relatively well settled on the first two issues, but the third holding reversed the court's great experiment with court-induced reduction agreements and merits more extended analysis.

The court criticized mutual prescription for not taking all relevant equitable factors into account as well as for stimulating a race to pump. Pasadena was also distinguished because in that case the overdraft was substantial from the time that defendants first stated pumping. In contrast, in the Los Angeles case mutual prescription was not necessary to prevent some users from being completely eliminated if the doctrine of prior appropriation were applied. The statutory immunity against municipal prescriptive rights contained in California Law was applied to water, but this immunity does not work in reverse. The court recognized the possibility that cities could obtain prescriptive rights against both overlying owners and appropriators who had notice that the basin was in overdraft for 5 consecutive years:

> Plaintiff's pueblo right and the respective imported water rights of plaintiff and each defendant city are mutually exclusive and of equal priority. All such rights are prior to rights dependent on ownership of overlying land or based solely upon appropriation of ground water from the basin. Therefore, all the rights of the private defendants are subordinate to the foregoing rights of the plaintiff and the defendant cities and all rights of the defendant cities other than their imported water rights are subordinate to the foregoing rights of plaintiff.

> On remand, the basins's safe yield should be apportioned between amounts attributable to (1) native waters produced by recipitation within the ULARA and (2) water imported form outside the ULARA. The latter amount should in turn be apportioned among the respective quantities derived from imports by plaintiff, defendant Glendale and defendant Burbank. Plaintiff should be awarded an unadjusted pumping right to the portion of the safe pumping right to the portion of the safe yield derived from native waters and from its own imports, and defendants Glendale and Burbank should each be awarded an unadjusted pumping right to the portion of the safe yield attributable to its own imports.

Conjunctive use stimulated by basin-wide adjudications has not occured in California's other major area of groundwater overdraft, the Southern San Joaquin Valley, but significant conjunctive use but not sufficient management has occured in this part of the state. Direct limitations on groundwater pumping have been strongly resisted by Southern San Joaquin water users but surface supplies from federal reservoirs and the state water project have been allocated to influence indirectly, and at a very uneven rate of success, the rate of groundwater useage. A major study of groundwater management in the Southern San Jaoquin found [*Andrews and Fairfax*, 1984]

> ... private and local district groundwater decisionmaking are closely linked with surface water availability and allocation. Surface water quantity, quality, availability, and price are the most important variable in the local groundwater equation. They determine pumping rates and provide the major impetus for undertaking management programs. Groundwater management, therefore, is not direct control over pumping control; rather, it involves the conjunctive use, both planned and unplanned, of surface water and groundwater supplies.

4.3. *Colorado and New Mexico*

These two states have developed the most advanced agricultural groundwater management institutions in the West and a study of the resulting legal institutions demonstrates that groundwater basin management requires more than the establishment of the ground rules for the acquisition of rights. If the basin is nonreplenishing one, the choice between safe-yield and mining withdrawals must be made. The issue among rights holders is usually not whether sufficient supplies are available but how the costs of drilling deeper wells will be shared between earlier and later pumpers. Finally, groundwater withdrawals must be coordinated with surface rights.

New Mexico was the first state to apply prior appropriation to groundwater and thus to take to the first step toward management by limiting withdrawals. In 1890 a large artestian aquifer was discovered in Pecos Valley around Roswell. Farmers immediately drilled wells and let them run day and night. Just as the flaring of natural gas in the early oil fields led to pressures for conservation legislation, uncapped artesian wells led to legislation to prevent waste. After the Wichita Federal Land Bank indicated that they would not loan in the Valley because of waste, civic leaders in Roswell came to the conclusion that the doctrine of prior appropriation should be applied to limit pumping [*Dunbar*, 1983]. Legislation was passed in 1927, to allow the State Engineer to designate basins within the state that would be subject to appropriation. After the Supreme Court declared the legislation unconstitutional because of technical defects in its passage, similar legislation was enacted in 1931. Landowners argued that the legislation was as unconstitutional taking of private property without due process of law, but the Supreme Court twice upheld the switch because the Desert Land Land Act of 1877 had recognized prior appropriation for both surface and groundwaters in the state [*Yeo versus Tweedy*, 1928].

New Mexico has had a long and strong management tradition. Its state engineers, especially S. E. Reynolds, have used their powers broadly to balance widespread access with conservation of the resource: basin-wide adjunciations have been instituted to define the duty of water, surface rights have been coordinated with groundwater rights, and mining has been allowed. The end result is a system that is prior appropriation in form only and emphasizes the use of physical solutions to problems, this is illustrated by the coordination of ground and surface rights. Coordination of surface and groundwater rights started when surface holders in the Roswell area avoided priority fights by drilling wells. The issue came to the court after the State Engineer denied a change of diversion application from a surface point to a well. Because the surface stream was intermittent, the surface appropriation was always in effect an appropriation of the Valley fill. The court held that a prior appropriator had the right to follow a surface stream to its subsurface sources and satisfy his prior right regardless of the effect on well drillers [*Templeton versus Pecos Valley Artesian Conservancy District*, 1958]. The state Engineer subsequently used this doctrine to deny the City of Albuquerque the right to sink wells in the underground basin that was part of the base flow of the Rio Grande River unless the city retired its existing surface rights to offset the effect of new groundwater pumping on the flow of the river [*City of Albuquerque versus Reynolds*, 1963]. The Rio Grande Underground Water Basin had been created to protect Texas' compact share of this interstate stream, and the State Engineer's exercise of his authority to protect the base flow of the river was upheld in the face arguments that the groundwater appropriation statute required that permits be issued if unappropriated water existed in the basin and that the State Engineer lacked the power to protect existing surface rights. The Rio Grande protection decision is especially important and farreaching because it sustained the power of an administrative official to use a long time horizon in measuring the impact of groundwater pumping on surface flows [*Flint*, 1968].

Since 1969, Colorado has embarked on an ambitious program of regulating groundwater pumping and integrating ground and surface rights. Unlike New Mexico, regulation in Colorado does not derive from a long and strong tradition of regulation and adjudication of water rights by an administrative agency. Colorado has had to engraft new forms of administrative regulation onto its traditional reliance on water courts to adjudicate water rights disputes. Thus Colorado has produced rather different kinds of legislation and judicial precedents from New Mexico.

Prior to 1965 groundwater pumping was virtually unregulated in Colorado. Although the state, in contradistinction to other western states, consistently held that all groundwater was presumed tributary to a natural stream, in practice, little tributary groundwater was made subject to appropriation degrees. In 1963 the Supreme Court refused to adjudicate priorities among nontributary groundwater pumpers, so deep aquifers, as well as nontributary groundwater, remained outside the scope of the presumption and hence outside the appropriation system [*Whitten versus Coit*, 1963]. Legislation was passed as early as 1957 to regulate groundwater [*Kelly*, 1969], but it was not until 1965 and 1969 that groundwater pumping was effectively subjected to the appropriation regime. In 1965 legislation extended the doctrine of prior appropriation to groundwater and created a state agency to establish critical areas. The legislation became ineffective after the state engineer shut down 36 out of 1,000 wells in Arkansas Valley without formulating any guidelines to determine which wells should be shut down, and the Supreme Court held that his action was arbitrary and a violation of the well owners' rights to equal protection. Subsequent legislation and administrative regulations established the constitutionally required standards [*Fellhauer versus People*, 1969]. More importantly, dictum in the case invalidating the standards foreshadowed a generally hospitable reception to new regulation:

> As administration of water approaches its second century the curtin is opening on the new drama of maximum utilization and how constitutionally that doctrine can be integrated into the law of vested rights. We have known for a long time that the doctrine was lurking in the backstage shadows as a result of the accepted, thought of violated, principle that the right to use water does give the right waste it.

The statute divides the state's groundwater into two major classes: tributary to a surface stream and within a designated basin and nontributary to a surface stream [*Colorado Revised Statues*, 1973]. The supreme court subsequently added a new class: nondesignated, nontributary. The core of the statute is the definition of designated groundwater:

> Designated ground water means that ground water which in its natural course would not be available to and required for the fulfillment of decreed surface rights, or ground water in areas not adjacent to a continuously flowing natural stream wherein ground water withdrawals have constituted the principal water usage for at least fifteen years preceding the date of the first hearing on the proposed designation of the basin, and which in both cases is within the geographic boundaries of a designated ground water basin.

This water is subject to appropriation. Appropriation is managed by a two-tier scheme of administrative agencies. A statewide groundwater commission hears applications, but the landowners in designated areas may form local management destricts to supplement state regulation. The legislation has been upheld against the challenge that it delegates judicial functions to a nonjudicial agency [*Danielson versus Krebs Ag. Incorporated*, 1982]. The hard question is to separate tributary groundwater from designated groundwater. This is ultimately a factual question, and the proponent of the classification has the burden of showing that it is nondesignated [*State ex. rel. Danielson versus Vickroy*, 1981]. Tributary groundwater is subject to the surface as well as groundwater priorities, defined as "that water in the unconsolidated alluvial aquifer of sand, gravel, and other sedimentary material * * * which can influence the rate or direction of movement of water in that alluvial aquifer or natural stream."

Coordination favors surface against groundwater users since surface rights will inevitably be prior. The primary defense of a junior pumper against a senior surface call is the futile call doctrine. This doctrine allows a junior to continue his diversion on the ground that a cessation of use would not benefit the senior. This doctrine is codified in the Water Right Determination and Administration Act of 1969. However, the futile call doctrine has been limited by the court which held that a call does not require a showing of a casual relationship between a well and the "calling" senior's suface flow. To implement the Groundwater Management Act, the engineer's office developed a zone plan along the South Platte River.

Wells in zone A were estimated to affect the river in 10 days, in zone B in 10–30 days, and in zone C from 30–75 days, and the court recognize that the State Engineer had the discretion to adopt a reasonable margin of safety in deciding whether a call would be futile [*Kuiper versus Well Owners Association*, 1971]. A de minimus principle has subsequently been recognized [*Kuiper versus Lundvall*, 1975]. In many cases, surface groundwater conflicts have been solved by exchanges allowed under plans for augmentation which do not require the introduction of new water into the system [*Harrison and Sandstrom*, 1971]. For example, out of priority pumping is allowed in the South Platte Basin because the State Engineer has approved a detailed plan to supply surface replacement water from sources such treated sewage effluent. Colorado does not seem to follow New Mexico's rule that a surface user has great discretion to trace his surface source to groundwater [*Hanay*, 1981]. A person who seeks a change from a surface to groundwater source in a designated basin must prove that the water is nontributary and this question may be initially decided by the groundwater commission. The statute creates a gap in the waters regulated. There is no express regulation of deep aquifers, those that are not tributary to a surface stream and not within a designated area. A crisis of sorts arose in Colorado when a single individual made substantial filings on unappropriated deep groundwater. A trial judge ruled that nontributary, nondesignated groundwater was subject to appropriation but imposed antispeculative restrictions on appropriations. The Colorado supreme court reversed on a cramped reading of the 1969 Act and threw the whole matter back to the legislature [*State versus Southwestern Colorado River Conservation District*, 1983].

Colorado and New Mexico have squarely faced the question of whether "mining" should be allowed in nonreplenishing basins and have concluded that it should be permitted. Other states withdraw groundwater from the same formation, the Ogallala, and have chosen to allow mining by default. [*Bittinger and Green*, 1980]. Colorado and New Mexico are interesting because they have decided the conditions under which mining will occur. These two states have therefore been required to address the most difficult issue in groundwater law, Is an appropriater entitled to a fixed level of static pressure in addition to a quantity of water?

In 1952 the New Mexico State Engineer calculated the amount of water in the Lea County Underground Basin, part of the Ogallala formation and decided to allow appropriation up to the point that less than one third of the water currently in storage would be left at the end of 40 years. This increased entry into the basin and along with his decision that all pumpers would have to share water table declines, effectively managed the basin on a capture rather than prior appropriation model. This decision was upheld because the administration of nonrechargable basins "compels a modification of the traditional concept of appropriation supply under the appropriation doctrine" [*Mathers versus Texaco Incorporated*, 1966]. To the protestors argument that their rights had been impaired, the court answered that higher pumping costs and lower yields were "inevitable results of the beneficial use by the public of these waters." Other depletion formulas were formulated by Colorado for the Northern High Plains area to restrict entry into the basin, and these have been upheld by the court [*Fundingsland versus Colorado Groundwater Commission*, 1970].

Once mining is allowed, static pressure levels will drop. Does a senior appropriator have a right to the pressure level at the time that the appropriation was perfected? Originally courts answered this question yes reasoning that static pressure was an integral part of the right, although an appropriator never had a right to a fixed flow level. [*Current Creek Irrigation Company versus Andrews*, 1959]. In the face of the argument that this rule was inefficient because it restricted entry into a basin, courts and legislatures began to modify the rule [*Wayman versus Murray City*, 1969]. In all states that have recently considered the issue, a senior appropriator is limited to a reasonable pumping level [*Grant*, 1981]. Consistent with the analysis, the supreme Court of Colorado recently held that surface irrigators could be limited to reasonable means of diversion, such deepened headgates, to free more undergroundwater for maximum beneficial use [*In the Matter of Rules and Regulations*, 1984].

What is a reasonable pumping level is a question that courts have been reluctant to confront and legislatures have been content to delegate the decision to administrative agencies. The result is that pumping level decisions are made on an ad hoc basis or protected through restrictions that apply to all pumpers equally and thus try and spread widely the rate of decline and the costs of reasonable level maintenance. Any relationship between optimum yield and administered pumping levels is coincidental, but perhaps this is all that can be expected, since rational solutions are both hard to formulate and costly to administer, [*Grant*, 1983]. An economic analysis of the issue must start from the premise that lift costs are reciprocal externalities imposed by one pumper on another. Thus these costs must be shared among the pumpers. Rational sharing is only possible when the total volume of the pool is allocated among the pumpers. Then, solutions are possible such as requiring that for each marginal unit extracted, other pumpers share this cost in proportion to the fraction of all other units that have actually been withdrawn [*Friedman*, 1971]. This formula would both seem to promote economic efficiency and protected the expectations of earlier pumpers. Only Oklahoma has actually allocated the total supply of groundwater basins to pumpers [*Jensen*, 1979], and little interest has been shown in rational lift pricing schemes, perhaps because the costs of information assembly exceed the benefits.

4.4. *Local Control: Kansas, Nebraska, and Texas*

Two of the major groundwater irrigation states over the Ogallala formation have resisted statewide management and have instead choosen to retain the common law rules of groundwater "ownership" with local regulation. Kansas follows the prior appropriation doctrine; Nebraska applies the doctrine of correlative rights and regulates groundwater pumping through its Natural Resources Districts. Nebraska's 1975 Groundwater Management Act gives the districts the option of establishing groundwater control areas. [*Nebraska Revised Statutes*, 1943]. Control areas must be designated by the state department of Water Resources. The standards are whether the use of groundwater has caused or is likely to cause an inadequate supply to meet present or reasonably forseeable future needs or whether there is a risk of quality degradation due to mining. Designation is a strong step in Nebraska and the Director of the department has refused to designate control areas, where the only effect of pumping is a seasonable artesian pressure reduction [*Aiken*, 1980]. Within designated areas, well spacing restrictions, pumping rotations, quantity allocations transfer restrictions, and well drilling moritoria may be imposed. Once a control area is established, a state permit is required, but it can only be denied if the well will violate a Natural Resources District condition. Nebraska has not yet chosen, as has its neighbor Colorado, to coordinate surface and groundwater rights [*Holland*, 1977]. A preliminary assessment of the 1975 Act and local implementation concludes that (1) well spacing requirements did not reduce the rate of withdrawals but did give some static level protection to existing pumpers and (2) that the first major quantity allocation regulations will reduce withdrawals below the prevailing average use patterns because; mining would be limited to 1% of the saturated thickness of the aquifer [*Aiken and Suppalla*, 1979].

Kansas authorizes the creation of local districts which may adopt management programs subject to state approval [*Kansas Statutes*, 1984]. Several districts have been created in western Kansas, and the conservation programs and regulations vary. Well spacing requirements to protect existing rights are widespread, and some districts have adopted safe yield objectives. For example, the safe yield program in the Equus Beds District is accomplished in the following manner [*Peck*, 1981]:

> The safe yield policy is found in the statement that a "balance will be maintained between recharge to the Equus Beds and total groundwater withdrawals (discharge) from the Equus Beds." To accomplish safe yield, the GMD basis its recommendation for approval or denial of an application permit on a two-mile radius formula as follows: (1) a circle with a radius of two miles is drawn around the proposed well, and with the circle all of the existing wells as shown on prior applications for permits, certificates of appropriation, or vested rights are totalled as to annual quantity; (2) that annual quantity is added to the quantity of water requested in the application; (3) if the total quantity found by the addition in (2) is less than 4025 acre-feet, approval of the application will be recommended if it meets other criteria; if the total is greater than 4025 acre-feet, denial of the application will be recommended, unless it is the quantity of the proposed well that puts the total over 4025 acre-feet, in which case the GMD may recommend a quantity that would make the withdrawals equal 4025 acre-feet.
>
> The 4025 acre-feet is the average amount of recharge within an average two mile radius circle in the GMD. This amount is calculated by assuming that out of an average rainfall of thirty inches, twenty percent or six inches returns to the aquifer as recharge.

Other districts in far western Kansas allow mining based on depletion formulae that run from calculations based on the historic depletion rate to formulas, similar to those used in Colorado, that allow a percentage depletion rate over time within a 2-mile (3.218 km) radius of a well.

Texas also regulates groundwater through local districts, but in contrast to Kansas and Nebraska, Texas districts stress education and technical conservation rather than pumping controls [*Water-Related Technologies*, 1983]. The Texas courts have repeatedly held that groundwater is the property of the overlying landowner. Courts have refused to curb waste, but they have suggested that negligent pumping is actionable. To date, this limitation applies only to pumping that causes subsidence and not to mining generally. Three districts overlying the Ogallala Aquifer have been formed since 1950, and they have conducted research programs and experimented with Playa lake recharge programs. To curb excessive groundwater use the districts currently have educational programs to try and induce irrigators to use more efficient cropping and irrigation methods. For example, the following program has been implemented by the High Plains Underground Water Conservation District No. 1 (K. Carver, unpublished manuscript, 1984):

> Center pivots are very popular in Texas, because they have many advantages over furrow irrigation. However, the early pivots were subject to high evaporation loss due to the West Texas winds. Dr. Bill Lyle, of the Texas Agricultural Extension Service, began working on eliminating the problem. He developed the Low Energy Precision Application (LEPA) system. It applies the water at the soil surface through drop tubes. The system is used with furrow dikes to hold the water in place. The farm is plowed and farmed in a circle so that each drop will always be in a furrow. The system efficiency is 95 to 98 percent instead of the 60 percent for the usual center-pivot system. Furrow dikes are a very important part of the LEPA farming method since they hold the high volume from the drops until it has time to soak into the soil. The Districts have helped promote the use of this equipment with articles, field tours, and information-exchange meetings.

5. A Look Into the Future: Federal Control of Groundwater Use?

This paper has focused exclusively on state groundwater management. Historically, this is the correct focus. The federal government seldom asserts the power to allocate directly groundwater, although it possesses the constitutional power to do so. Instead, the federal interest has been limited to the regulation of certain uses of navigable waters and to the assertion of limited proprietary rights in the west incident to the withdrawal of land from entry for a water-related use [*United States versus New Mexico*, 1978]. Federal power stems from the Commerce Power and was first limited to the protection of navigation. Today, federal Commerce Power extends to multiple-purpose river development and environmental protection, but this power has been exercised primarily with respect to surface waters. Federal reserved proprietary rights have been expressly recognized for groundwater connected to surface water [*Cappaert versus United States*, 1976] and may be claimed both by land management agencies and Indian tribes [*Griffith*, 1980]. In the main, whatever control over groundwater has been exercised has been done so indirectly. The threat to withhold Central Arizona Project funds to force Arizona to phase out irrigated agriculture is the most dramatic example of this indirect power. During the Carter Administration, noises were made that a strong federal interest in groundwater conservation would be asserted, but efforts toward a national water policy died when President Carter failed to realize that the West was different from the South.

In 1982 the Supreme Court rendered a decision that asserts a new federal interest in groundwater management and provides the theoretical base for the assertion of strong federal management interests and also ironically, many provide the basis for new challenges to state conservation programs. [*Sporhase versus Nebraska*, 1982]. Sporhase holds that the negative commerce clause applies to state groundwater law because groundwater is a commodity in interstate commerce. Specifically, the Court held that a Nebraska law that prohibited interstate groundwater transfers unless the host state had reciprocal export privileges discriminated against interstate commerce. Sporhase overruled a late 19-century case that held that state resource embargoes were immune from negative commerce clause scrutiny because the state owned the resources in trust for the public. There is little new constitutional law in the decision except its application to an area erroneously but long "thought" to be immune from judicial intervention. The immunity argument is simply an assertion of the state's inherent police power, and in a federal system, state police power is always subject to overriding federal interests. By Sporhase, the immunity theory had been so eroded that the decision came as a surprise only to the few western water lawyers who confused bald assertions of exclusive state control with modern constitutional commerce clause jurisprudence [*Williams*, 1984].

The issue now is what does Sporhase mean for state groundwater management? All state efforts to restrict access must now be evaluated by federal constitutional standards [*Dormant Commerce Clause and the Constitutionality of the Intrastate Groundwater Management Programs*, 1983]. Justice Steven's majority opinion went out of its way to stress the strength of traditional state interests in water management and suggested a "conservation" immunity from the negative commerce clause. This exception was unsuccessfully invoked by New Mexico to apply its embargo statute to the City of El Paso, Texas which wanted to sink wells in New Mexico. A district court held that New Mexico's statute was unconstitutional and rejected the argument that arid New Mexico could conserve the water for the benefit of its own citizens [*City of El Paso versus Reynolds I*, 1983]. New Mexico claimed that by 2020 the state would have a 626,000 ac-ft shortage, but the district court read Sporhase narrowly and limited Justice Stevens "me first" exception to an imminent water shortage that jeoparadizes public health. Otherwise, water is an economic good which must be shared among claimants regardless of geographic location. In short, a conservation defense is never likely to suceed if the statute expressly discriminates against interstate commerce. New Mexico was handicapped in its conservation argument because it lacked "clean-hands." The court was not convinced that the embargo would achieve the proffered conservation objective because the state did not have adequate in-state conservation measures. New Mexico subsequently enacted a statute that sallows the interstate export of water subject to conservation and public welfare restrictions but it has been held that this statute violates the negative commerce clause because it fails to place equal restrictions on in-state permit applications and thus the regulation is not "evenhanded." [*City of El Paso versus Reynolds II*, 1984].

The immediate effect of Sporhase is to force states to develop more sophisticated water management and conservation programs. States must now bear a higher burden of justification if an alleged interference with interstate commerce is shown. For example, New Mexico has begun to ask some hard questions about the value of different uses of its water and to debate a more active state role in water resources allocation [*Dumars*, 1984]. It is unlikely that federal courts will become superwater masters, and in the end the net effect of Sporhase should be positive. The more comprehensive and scientifically based the conservation regulation, the more burdens on interstate commerce are likely to be classified as incidental and thus immune from judicial invalidation. It is unlikely that courts will scrutinize intensively nonfacially discriminatory management programs that further traditional state water conservation objectives even if they have a theoretically distorting effect on interstate groundwater allocation.

References

Acton versus Blundell, Decision of the Excheguer Chamber, (12 Mees. & W 324), 1843.

Aiken, D., Nebraska groundwater law and administration, *Nebr. Law Rev.*, *59*, 915, 960–966, 1980.

Aiken, D., Ground water mining law and policy, *Colo. Law Rev.*, *52*, 505, 524, 1981.

Aiken, D., and R. Supalla, Groundwater mining and western water rights law: The Nebraska experience, *S. D. Law Rev.*, *24*, 607, 628–645, 1979.

Anderson, T., O. Burt, and D. Fractor, Privatizing groundwater basins: A model and its application in water rights, in *Scare Resource Allocation, Bureaucracy, and the Environment*, edited by T. Anderson, pp. 223, 227, Ballinger, Cambridge, Mass., 1983.

Andrews, B., and S. Fairfax, Ground water and intergovernmental relations in the Southern San Joaquin Valley of California: What are all these cooks doing to the broth, *Univ. Colo. Law Rev.*, *55*, 145, 200–201, 1984.

Arizona Revised Statues Annotated §45–401 et. seq., 1983.

Arizona State Water Commission, Alternative futures: Phase II Arizona State Water Plan 3, Ariz. State Water Comm., Phoenix, 1977.

Baker versus Ore-Ida Foods, Inc., Decision of the supreme court of Idaho, no. 11039, (95 Idaho 575, 513 P.2d 627), 1973.

Ball, S., The vertical extent of ownership in land, *Univ. Penn. Law Rev.*, *76*, 631, 1928.

Bittinger M., and E. Green, *You Never Miss The Water Till ··· (The Ogallala Story)*, Water Resources Publications, Littleton, Colo., 1980.

Bristor versus Cheatham, Decision of the supreme court of Arizona, no. 5334, (73 Ariz. 228, 240 P.2d 185), 1952.

Bristor versus Cheatham, Decision of the supreme court of Arizona, no. 5334, (73 Ariz. 227, 255 P.2d), 173, 1953.

Bruce, A., The conservation of our natural resources and of our national and virility, *Univ. Penn. Law Rev.*, *58*, 125, 1909.

Cappaert versus United States, Decision of the United States Supreme Court, no. 74-1107, (426 U.S. 126), 1976.

Chasemore versus Richards, Decision of the House of Lords of England, (7 H. of L. Cas. 349), 1859.

Cherry versus Steiner, no. 82-5765, (543 F. Supp. 1270, D. Ariz., 1982, affirmed, 716 F.2d 687, 9th Cir.), 1983.

Christensen, D., A. Morton, and E. Heady, Changing energy prices and patterns in U.S. agriculture, *Southwest. Rev.*, *2*, 85, 1982.

City of Albuquerque versus Reynolds, no. 7013, (71 N.M. 428, 37[illegible] P.2d 73), 1963.

City of Corpus Christi versus City of Pleasanton, Decision of the Supreme Court of Texas, no. A-4543, (154 Tex. 289, 276 S.W. 2d 798), 1955.

City of El Paso versus Reynolds I, no. 80-730HB, (563 F. Suppl. 379), 1983.

City of El Paso versus Reynolds II, no. 80-730HB, (597 F. Suppl. 694), 1984.

City of Los Angeles versus City of San Fernando, Decision of the supreme court of California, LA-30119, (123 Cal. Rptr. 1, 537 P.2d 1250), 1975.

Clayberg, J., The law of percolating waters, *Mich. Law Rev.*, *14*, 119, 1915.

Cline versus American Aggregates Corp., Decision of the supreme court of Ohio, no. 83-1910, (15 Ohio State 3d 384, N.E.2d), 1984.

Colorado Revised Statutes, §§37-90-104-135, 1973.

Connoll, D., A history of the Arizona Groundwater Management Act, *Ariz. State Law J.*, 313, 334, 1982.

Corker, C., Inadequacy of the present law to protect, conserve and develop groundwater use, *Rocky Mt. Min. Law Inst.*, *25*, 23-1, 23-2, 1979.

Current Creek Irrigation Co. versus Andrews, 9 Utah 2d 324, 344 P. 2d 528, 1959.

Danielson versus Kerbs AG., Inc., Decision of the supreme court of Colorado, no. 81SA165, (646 P. 2d 363, Colo.), 1982.

Davis, P., Wells and streams: Relationship at law, *Mo. Law Rev.*, *34*, 189, 1972.

Doyle, M., The transportation provisions of Arizona's 1980 Groundwater Management Act: A proposed definition of compensable injury, *Ariz. law Rev.*, *25*, 656, 667, 1983.

Drinkwine versus State, no. 75-72, (247 A.2d 485, Vermont), 1970.

Dumars, C., et al., The impact of recent court decisions concerning water and interstate commerce on water resources of the State of New Mexico, A report to Governor Toney Anaya and the legislative council pursuant to laws, 1983, chapter 98, *Natl. Resour. J.*, *24*, 688, 1984.

Dunbar, R., The Arizona groundwater controversy at mid-century, *Ariz. West*, *19*, 5, 1977.

Dunbar, R., *Forging New Rights in Western Waters*, pp. 162–172, University of Nebraska Press, Lincoln, Nebr., 1983.

Epstein, S., L. Brown, and C. Pope, *Hazardous Waste in America*, pp. 69–87, Sierra Club Books, San Francisco, Calif., 1982.

Fellhauer versus People, Decision of the supreme court of Colorado, no. 22886, (167 Colo. 320, 447 P. 2d 986), 1969.

FICO versus Bettwy Co., Decision of the supreme court of Arizona, no. 11439-2, (113 Ariz. 520, 558 P.2d 14), 1976.

Finley versus Teeter Stone, Inc., Decision of the supreme court of Maryland, no. 335, (251 Md. 428, 248 A.2d 106), 1968.

Flint, H., Groundwater law and administration A New Mexico viewpoint, *Rocky Mt. Min. Law Inst., 13*, 545, 1968.

Florida Statutes Annotated §373.012 et seq., 1985.

Forbell versus City of New York, Decision of the Court of Appeals of New York, (164 N.Y. 522, 58 N.E. 644), 1900.

Friedman, A., The economics of the common pool: Property rights in exhaustible resources, *U.C.L.A. Law Rev., 18*, 855, 1971.

Fundingsland versus Colorado Groundwater Commission, Decision of the supreme court of Colorado, (171 Colo. 487, 468 P. 2d 835), 1970.

Gagnon versus French Lick Springs Hotel Co., Decision of the supreme court of Indiana, no. 20.284, (163 Ind. 687, 22 N.E. 849), 1904.

Grant, D., Reasonable groundwater pumping levels under the Appropriation Doctrine: The law and underlying economic goals, *Natl. Resour. J., 21*, 1, 1981.

Grant, D., Reasonable groundwater pumping levels under the Appropriation Doctrine: Underlying social goals, *Natl. Resour. J., 23*, 53, 1983.

Greenleaf versus Francis, Decision of the Supreme Judicial Court of Massachusetts, (34 Mass. 117), 1836.

Griffith, G., Groundwater: Reserved rights or beneficial interest? *Stanford Law Rev., 33*, 103, 1980.

Harrison, D., and G. Sandstrom, The groundwater surface water conflict and recent Colorado water legislation, *Colo. Law Rev., 43*, 1, 1971.

Higday versus Nickolaus, Decision of the Kansas City Court of Appeals of Missouri, no. 25627, (469 S.W. 2d 859, Mo. App.), 1971.

Higdon, P., and T. Thompson, The 1980 Arizona Groundwater management code, *Ariz. State Law J.*, 621, 639–640, 1980.

Hodson, K., Dormant commerce clause and the constitutionality of intrastate groundwater management programs, *Tex. Law Rev., 62*, 537, 1983.

Holland, W., Conflicts between private appropriators of stream flows and users of groundwater in Nebraska, *Creighton Law Rev., 10*, 592, 1977.

Hotelling, H., The economics of exhaustible resources, *J. Polit. Econ., 39*, 132, 1931.

Howard versus Perrin, Decision of the supreme court of Arizona, (8 Ariz. 347, 76 Pac. 460), 1904.

Huber versus Merkel, Decision of the supreme court of Wisconsin, (117 Wis. 335, 94 N.W. 354), 1903.

Huffcut, E., Percolating waters: The rule of reasonable user, *Yale Law J., 13*, 222, 1904.

Hutchins, W., *Selected Problems in the Law of Water Rights in the West*, pp. 156–159, U.S. Dept. of Agriculture, Washington, D.C., 1942.

Indiana Code § 13-2-2-1 et. seq., 1983.

In the matter of rules and regulations governing the use, conservation and protection of water rights for both surface and underground water located in the Rio Grande and Conejos River basins and their tributaries, Decision of the supreme court of Colorado, (674 P.2d 914), 1984.

Jarvis versus State Land Department, Decision of the supreme court of Arizona, no. 9488, (104 Ariz. 527, 456 P. 2d 385), 1969.

Jensen allocation of percolating and Oklahoma ground water law of 1972, *Tulsa Law Rev., 14*, 437, 1979.

Jones versus Oz-Ark-Val Poultry Co., Decision of the supreme court of Arkansas, no. 5-1295, (306 S.W. 211, Ark.), 1957.

Kansas Statutes Annotated §§82a-1020-1035, 1984.

Katz versus Walkinshaw, Decision of the supreme court of California, LA-967, (141 Cal. 116, 70 P. 663), 1903.

Kelly, M., Management of groundwater through mandatory conservation, *Denver Law J., 61*, 1, 1983.

Kelly, W., Colorado Groundwater Act of 1957—Is groundwater the property of the public, *Rocky Mt. Law Rev., 31*, 165, 1969.

Kinney, C., *Irrigation and Water Rights II*, 2nd ed., p. 2095, Bender-Moss, San Francisco, 1912.

Kirkwood, M., Appropriation of percolating water, *Stanford Law Rev., 1*, 1, 1948.

Kuiper versus Lundvall, Decision of the supreme court of Colorado, (187 Colo. 40, 529 P. 2d 1328, 1974, cert. denied, 421 U.S. 996), 1975.

Kuiper versus Well Owners Association, Decision of the supreme court of Colorado. no. 24725, (179 Colo. 119, 490 P. 2d 268), 1971.

Kyl, J., The 1980 Arizona Groundwater Management Act: From inception to current contributional challenge, *Colo. Law Rev., 53*, 471, 476, 1982.

Library of Congress, State and national water use trends to the year 2000, a report prepared for the Committee on Environment and Public Works, U.S. Senate, Congr. Res. Serv., Library of Congr., Washington, D.C., 1980.

MacArtor versus Graylin Crest III Swim Club, Inc., Decision of the Court of Chancery of Delaware, (41 D. Ch. 26, 187 A.2d 417), 1963.

Maerz versus U.S. Steel Co., Decision of the Court of Appeals of Michigan, no. 50718, (116 Mich. App. 710, 323 N.W. 2d 524), 1982.

Maloney, F., R. Ausness, and J. Morris, *A Model Water Code*, University of Florida Press, Gainesville, Fla., 1972.

Maloney, F., L. Capehart, and R. Hoofman, Florida's "Reasonable beneficial" water use standard: Have east and west met?, *U. Fla. Law Rev., 31*, 253, 1979.

Maricopa County Municipal Water Conservation District versus Southwest Cotton Co., Decision of the supreme court of Arizona, no. 2872, (39 Ariz. 65, 4 P. 2d 369), 1931.

Martz, C., The law of underground waters, *Okla. Law Rev., 11*, 26, 27, 1958.

Mathers versus Texaco, Inc., Decision of the supreme court of New Mexico, no. 7921, (77 N.M. 239, 421 P. 2d 771), 1966.

McKenzie versus Moore, Decision of supreme court of Arizona, no. 1583, (20 Ariz. 1, 176 Pac. 568), 1918.

Meeker versus City of East Orange, Decision of the court of errors and appeals of New Jersey (77 N.J.L. 623, 74 A. 379), 1909.

Moore, C., and H. Snyder, Some legal and economic implications of sea water intrusion—A case study of ground water management, *Natl. Resour. J., 9*, 401. 1969.

Moses, R., The law of ground water—Does modern buried treasure create a new breed of pirates? *Rocky Mt. Miner. Law Inst., 11*, 277, 287, 1966.

Moses, R., Basic groundwater problems, *Rocky Mt. Miner. Law Found. Inst., 14*, 501, 509, 1969.

National Academy of Sciences Water and Choice in the Colorado Basin, *An Example of Alternatives in Water Management*, National Academy of Sciences, Washington, D. C., 1968.

National Water Commission, Water policies for the future, final report to the President and to the Congress of the United States, Nat. Water Comm., Washington, D.C., 1973.

Nebraska Revised Statutes, §46-656-674, 1943.

New Jersey Statutes Annotated §55:1A-4, 1985.

Niegro, S., Water management in South Florida: Setting the record straight, *Fla. Bar J., 57*, 337, 339, 1983.

Olson versus City of Wahoo, Decision of the supreme court of Nebraska, no. 28533, (124 Neb. 179, 299 N.W. 549), 1933.

Pasadena versus Alhambra, Decision of the supreme court of California, LA-19610, (33 Cal. 2d 908, 207 P. 2d 17), 1949.

Peck, J., Kansas groundwater management districts, *Kan. Law Rev., 29*, 51, 1981.

Pima Farms versus Proctor, Decision of the supreme court of Arizona, no. 2396, (30 Ariz. 96, 245 Pac. 369), 1926.

Pound, R., *An Introduction to the Philosophy of Law*, pp. 95–199, Harvard University Press, Cambridge, Mass., 1922.

Prather versus Eisenman, Decision of the supreme court of Nebraska, no. 41203, (200 Neb. 1, 261 N.W. 2d 766), 1978.

Prohosky versus Prudential Insurance Co. of America, Decision of the federal court for the northern district of Indiana, no. L82-90, (384 F. Supp., N.D. Ind. injunction reversed no. 84-1699-F. 2nd-), 1985.

Rea, R., Drought in Florida: Nature's response to "comprehensive planning," *Fla. Bar J., 57*, 266, 267, 1983.

Reis, R., Legal planning for ground water protection, *Southern Calif. Law Rev., 38*, 484, 489, 1965.

Reis, R., A review and revitalization: Concepts of ground water production and Management—The California experience, *Natl. Resour. J., 7*, 33, 75, 1967.

Scheiber, H., Public rights and the rule of law in American legal history, *Calif. Law Rev., 72*, 217, 235–223, 237, 1984.

Schneider, A., Groundwater rights in California: Background and law issues, technical report, Gov. Comm. to Rev. Calif. Water Law, Sacramento, 1977.

Shaw, L., The development or the law of waters in the West, *Calif. Law Rev.*, *10*, 443, 459, 1922.
Smith-Southwest Industries versus Friendswood Development Co., Decision of the United States supreme court, no. 81-613, (576 S.W. 2d 614, Texas), 1981.
Sporhase versus Nebraska, Decision of the United States supreme court, no. 81-613, (458 U.S. 941), 1982.
State of Colorado versus Southwestern Colorado River Conservation Dist., Decision of the supreme court of Colorado, no. 79SA38, (671 P. 2d 1294 Colo.), 1983.
State ex rel. Danielson versus Vickroy, Decision of the supreme court of Colorado, no. 79SA421, (627 P. 2d 752, Colo.), 1981.
State of Wisconsin versus Michels Pipeline Co., Decision of the supreme court of Wisconsin, no. 335, (63 Wis. 2d 278, 217 N.W. 2d 339), 1974.
Tehachapi-Cummings County Water Dist. versus Armstrong, Decision of the court of appeal, fifth district of California, no. 1935, (49 Cal. App. 3d 992, 122 Cal. Rptr. 918), 1975.
Templeton versus Pecos Valley Artesian Conservancy Dist., Decision of supreme court of New Mexico, no. 6257, (65 N.M. 59, 332 P. 2d 465), 1958.
Town of Chino Valley v. City of Prescott, Decision of supreme court of Arizona, no. 15501, (131 Ariz. 78, 638 P. 2d 1324 1981, appeal dismissed, 457 U.S. 1101,) 1982.
Trelease, F., The use of fresh water for secondary recovery of oil, *Rocky Mt. Miner. Law Inst.*, *16*, 605, 1970.
Trelease, F., The model water code: The wise administrator and the goddam bureaucrat, *Natl. Res. J.*, *14*, 207, 1974.
United States versus New Mexico, Decision of the United States supreme court of the United States, no. 77-510, (438 U.S. 696), 1978.
U.S. Congress, Water-related technologies for sustainable agriculture in U.S. arid/semiarid lands, Off. of Technol. Assess., U.S. Congress, Washington, D. C., 1983.
Village of Tequesta versus Jupiter Inlet Corp., Decision of the supreme court of Florida, no. 52223, (371 So. 2d 663, Fla. 1980, cert. denied, 444 U.S. 965), 1980.
Volkmann versus Crosby, Decision of the supreme court of North Dakota, no. 8028, (120 N.W. 2d 18, N.D.), 1963.
Wayman versus Murray City, Decision of the supreme court of Utah, no. 11211, (23 Utah 2d 97, 458 P. 2d 861), 1969.
Westmoreland and Cambria Natural Gas Co. versus Dewitt, Decision of the supreme court of Pennsylvania, (130 Pa. 235, 18 A. 724), 1889.
Wheatley versus Baugh, Decision of the supreme court of Pennsylvania, (25 Pa. St. Rep. 528), 1855.
Whitten versus Coit, Decision of the supreme court of Colorado, no. 20032, (153 Colo. 157, 385 P.2d 131), 1963.
Wiel, S., Need of united law for surface and underground water, *Southern Calif. Law Rev.*, *2*, 358, 1929.
Wiggins versus Brazil Clay and Coal Co., Decision of the supreme court of Indiana, no. 8835315, (440 N.E. 2d 495, Ind. App. 1982, vacated 452 N.E. 2d 958, petition for rehearing denied), 1983.
Williams, S., Free trade in water resources: Sporhase v. Nebraska ex rel. Douglas, *Supreme Court Econ. Rev.*, 2, 89, 1984.
Wright, R., *The Law of Airspace*, Bobbs-Merrill Company, Indianapolis, Ind., 1968.
Yeo versus Tweedy, Decision of the supreme court of New Mexico, no. 3408, (34 N.M. 611, 286 P. 970), 1928.

A. D. Tarlock, Chicago-Kent College of Law, Illinois Institute of Technology, 77 South Wacker Drive, Chicago IL 60606.

(Received October 12, 1984;
revised April 5, 1985;
accepted May 15, 1985.)

Water Resource Issues - Energy Environmental Analysis

I. Coal

A. Types of Leases
1. PRLAs
2. Competitive
3. Emergency

B. Four-Step Planning Process
1. Development Potential
2. Unsuitability
3. Multiple Use Tradeoff
4. Surface Owner Consultation

C. Responsibility
1. Federal/Leasing
2. State/Permitting

D. Legislation
1. Federal Water Pollution Control Act and Amendments
    a. Standard
    b. Auto-degradation
2. Surface Mining. Control and Reclamation Act
    a. Unsuitability Criteria
3. Federal Coal Leasing Amendments Act 1976
    a. Planning
4. Secretarial Decision Document

E. Problems with Leasing Process
1. Track Delineation
2. Responsibility

F. Major Issues
1. Spoil Piles
2. Antidegradation
3. Salinity
4. Subsidence

G. Case Study
1. James Creek E.I.S.

II. Oil and Gas

A. Types of Leases
1. Competitive
2. Non-competitive

B. Planning Process
1. Competitive
2. Non-competitive

C. Federal Actions with Resource Input
   1. Preliminary Exploration
      a. Notice of Intent
      b. Notice of Completion
   2. Operations
      a. Onshore Oil and Gas Order No. 1
         (1) Application to Drill
         (2) Surface Use and Operatons Plan
         (3) Abandonment
         (4) Water Well Conversion
   3. Development
      a. Notice to Lease - 2B
   4. Production
      a. Injection
   5. Abandonment

D. Legislation
   1. No Statutory Authority for Exploration
   2. Onshore Oil and Gas Order No. 1
      a. 43 CFR 3160
   3. Federal Water Pollution Control Act and Amendments
   4. Exempt from RCRA

E. Problems with Leasing Process
   1. Manpower Intensive

F. Major Issues
   1. Production Water
   2. Process Water
   3. Salinity
   4. Heavy Metals

G. Case Study
   1. Elk Spring Well #3 E.A.

DEPARTMENT OF THE INTERIOR

Bureau of Land Management

43 CFR Part 3160

[Circular No. 2538]

Onshore Oil and Gas Order No. 1; Approval of Operations on Onshore Federal and Indian Oil and Gas Leases

Under the authority of the Act of February 25, 1920, as amended and supplemented (30 U.S.C. 189, 226), and Executive Order 12291 (46 FR 13193), Part 3160, Group 3100, Subchapter C, Chapter II of Title 43 of the Code of Federal Regulations is amended as set forth below.

PART 3160—ONSHORE OIL AND GAS OPERATIONS

Section 3164.1(b) is amended by adding the following table:

§ 3164.1 Onshore Oil and Gas Orders.

* * * * *

(b) * * *

Order No.	Subject	Effective date	Federal Register reference	Supersedes
1	Approval of Operations	Nov. 21, 1983......	48 FR—........	NTL-6.

Appendix—Text of Oil and Gas Order

Note.—This appendix will not appear in the Code of Federal Regulations.

Contents

Onshore Oil and Gas Order

Federal and Indian Oil and Gas Leases

Order No. 1

Effective: November 21, 1983

Approval of Operations

Introduction

This Order is established pursuant to the authority prescribed in 43 CFR Part 3160, formerly 30 CFR 221. Approval of all proposed exploratory, development, and service wells, and all required approvals of subsequent well operations and other lease operations, shall be obtained in accordance with 43 CFR 3162.3–1, 3162.3–2, 3162.3–3, 3162.3–4 and 3162.5–1, formerly 30 CFR 221.23, 221.27, 221.28, 221.29, or 221.30, as appropriate.

All wells approved for drilling under the provisions of this Order shall have been included in a drilling plan, as required under 43 CFR 3162.3–1(d), formerly 30 CFR 221.23(d).

A drilling plan may be submitted for a single well, or for several wells that are proposed to be drilled to the same zone within a field or area of geological and environmental similarity. Plans for additional development of the leasehold should be considered in the submittal.

However, approval of Form 3160–3, formerly 9–331C (Application for Permit to Drill, Deepen, or Plug Back) is required for each well, and in order to be complete an Application for Permit to Drill (APD) shall include all information required under 43 CFR 3162.3–1 (d) and (e). A technically and administratively complete APD includes, in addition to Form 3160–3, a drilling plan, evidence of bond coverage, a designation of operator, when appropriate, and such other information as may be required by applicable Order or Notice to evaluate the proposal. Refer to section III.G. for more detailed guidance on complete APD's.

Certain subsequent well operations and other lease operations involving additional surface disturbance shall be included in a plan submitted on Form 3160–5, formerly 9–331 (Sundry Notices and Reports On Wells), and approved under the provisions of this Order pursuant to 43 CFR 3162.3–2 or 3162.3–3, formerly 30 CFR 221.27 or 221.28, respectively.

A report on all subsequent well operations shall be filed on Form 3160–5, as prescribed in 43 CFR 3162.3–2. A notice of intention to abandon a well and a subsequent report of abandonment shall also be filed on

Published in 48 F.R. 48916, October 21, 1983 – Effective November 21, 1983

m 3160–5, as required by 43 CFR
2.3–4.
ll applications for approval under
provisions of this Order shall be
mitted to the appropriate authorized
cer of the Bureau of Land
nagement (BLM). "Authorized
icer" means any person authorized to
form the duties prescribed. To be
ised of the proper BLM official and
ce with which to file an application,
lessee/operator may contact the
propriate District Manager of BLM
ing jurisdiction over lease operations
particular area.
he lessee/operator shall comply with
following requirements:
Accountability. Lessees and
erators have the responsibility to see
t their exploration, development,
duction, and construction operations
conducted in a manner which (1)
forms with applicable Federal laws
l regulations and with State and local
vs and regulations to the extent that
h State and local laws are applicable
operations on Federal or Indian
ses; (2) conforms with the lease
ms, lease stipulations, and conditions
approval; (3) results in diligent
velopment and efficient resource
overy; (4) protects the lease from
inage; (5) affords adequate
eguards for the environment; (6)
ults in the proper reclamation of
turbed lands; (7) conforms with
rent available technology and
ctice; (8) assures that underground
rces of fresh water will not be
dangered by any fluid injection
eration; and (9) otherwise assures the
tection of the public health and
ety. Lessees and operators shall be
d fully accountable for their
tractors' and subcontractors'
npliance with the requirements of the
proved permit and/or plan. Drilling/
nstruction and associated operations
all not be conducted without prior
proval of the authorized officer of
M. BLM approval of the APD does not
ieve the lessee and operator from
taining and other authorizations
quired for operations on Federal and
lian lands.
1. *Special Situations.* Lessees and
erators, as well as their contractors
d subcontractors, shall not commence
y operation or construction activity
a lease, other than cultural resource
ventories and surveying and staking
ll locations on Federal and Indian
ds, without the prior approval of the
thorized officer of BLM, except for
tain subsequent operations (see
ction IV. of this Order). The terms and
nditions of an approved permit and
illing plan, or other plan, shall not be
altered unless BLM first has approved an amended or supplemental permit and/or plan covering any such modifications.

For proposed operations on a committed State of fee tract in a Federally supervised unit or communitized tract, the operator shall furnish a copy of the approved State permit to the authorized officer of BLM which will be accepted for record purposes. In addition, in cases where an access road to a non-Federal or non-Indian drillsite will cross leased Federal or Indian lands, the operator shall submit a surface use plan only for those portions of the access road on Federal or Indian lands where new construction or reconstruction will occur. Such plans shall be submitted to the authorized officer of BLM or appropriate Federal Surface Management Agency (SMA) and approval obtained prior to commencement of construction operations on the Federal or Indian surface. For privately owned surface, refer to section VII.

III. *Drilling Operations.*

A. *Surveying and Staking.* Surveying and staking may be done without advance approval from the authorized officer of BLM or other appropriate SMA and prior to the conduct of any required cultural resource inventory, except for lands administered by the Department of Defense or other lands used for military purposes, or where significant surface disturbance is likely to occur.

Lessees and operators are strongly encouraged to notify the appropriate SMA prior to entry upon the lands for the purposes of surveying and staking. Early notification will allow the SMA to apprise the lessees and operators of any existing conditions, knowledge of which could result in saving of time and money by both industry and Government. These include but are not limited to:

—Whether a cultural resource inventory is required;
—Presence of threatened or endangered species and/or critical habitats;
—Vehicle access restrictions; and/or
—Permitting requirements applicable to affected lands outside the leasehold boundary.

Where the surface is privately owned or held in trust of Indian benefit, the lessee/operator is responsible for making access arrangements with the private surface owner or the Bureau of Indian Affairs (BIA) and Indian tribe or Indian allottee(s) prior to entry upon the lands for the purpose of surveying and staking.

Staking shall include the well location, two 200-foot directional reference stakes, the exterior dimensions of the drill pad, reserve pit and other areas of surface disturbance, cuts and fills, and centerline flagging of new roads with road stakes being visible from one to the next. Cut and fill staking applies only to the wellsite, reserve pit, and, if off-location, and ancillary facilities.

B. *Material to be Filed.*

1. *Notice of Staking.* Prior to filing a complete APD, the lessee or operator may, at its option, file a Notice of Staking (Attachment A) with the authorized officer of BLM and appropriate office of any other involved SMA. In Alaska, a copy of the Notice shall also be sent to the appropriate Borough when a subsistence stipulation is part of the lease.

The information contained in the Notice of Staking (NOS) will aid in identifying the need for associated rights-of-way and special use permits. If all required information is not included, the NOS shall be returned to the operator for modification.

2. *Application for Permit to Drill (APD).* Regardless of whether an NOS is filed, the lessee or operator shall file an APD. This application shall be administratively and technically complete prior to approval. The authorized officer of BLM shall advise the lessee or operator, within 7 working days of receipt of the application, as to whether or not the application is complete. If the application is complete, oral notification will suffice. If the application is not complete, notification to that effect shall be made in writing even though the lessee or operator may have already received oral notification. For purposes of written notification, Attachment B, Checklist For Applicant Notification, shall be mailed to the applicant within the 7-day period. The notification shall advise the lessee or operator of any defects that need correcting and of any additional information required. If the deficiencies are not corrected and/or the additional required information is not submitted within 45 days of the date of any oral or written notice (if no prior oral notice), the application shall be returned to the proponent.

Upon initiation of the APD process, the authorized officer of BLM shall consult with any other involved SMA and with other appropriate interested parties, and shall take one of the following actions within 30 days: (1) Approve the application as submitted or with appropriate modifications or stipulations; (2) return the application and advise the lessee or operator of the reasons for disapproval; or (3) advise the lessee or operator, either in writing or orally with subsequent written confirmation, of the reasons why final action will be delayed and the date such final action is expected.

When the NOS option is followed, BLM shall strive to process the subsequent related APD within 10 days of the APD's receipt. However, in either situation, the process of reviewing the APD and advising the lessee or operator as to whether it is technically and administratively complete shall be considered a part of the overall APD processing time, i.e., 30 days in case of the APD option and 10 days if the NOS process is utilized. Operators are cautioned that with respect to any particular well, the option selected initially, of either filing both an NOS and a subsequent APD or only an APD, is to be followed and there shall be no shifting between the two options. If operators fail to maintain a consistent approach in this regard, the processing time already expended shall not be counted as part of the above 30-day period.

The processing of applications shall be given a high priority, and individual applications shall be processed according to the date the application is received by the appropriate BLM office. If it is not possible for BLM actions to be taken prior to lease expiration, the lessee or operator shall be advised, at least orally, prior to the lease expiration date, with all such notifications confirmed in writing. Said advice shall detail the reasons for delay so that the lessee or operator may take such appeal or other recourse to preserve the lease as is allowed by law and/or regulation. The appropriate BLM office telephone number and address shall be furnished to the lessee or operator with the earliest notification or advice.

C. *Conferences and Inspections.* An onsite predrill inspection shall be scheduled and conducted by the appropriate BLM office within 15 days of receiving the applicant's initially-filed document, i.e., either an NOS or a complete APD. In special circumstances, the authorized officer of BLM may require the filing of a complete APD prior to the scheduling of an onsite predrill inspection. Representatives of the appropriate BLM office, the operator and other interested parties, such as any other involved SMA, the appropriate Alaska Borough (when a subsistence stipulation is part of the lease), and the operator's principal dirt and drilling contractors shall attend the predrill inspection. When appropriate, the operator's surveyor and archeologist should also participate in the inspection. If any other involved SMA is not able to participate at the desired time, the inspection may be rescheduled provided it can be conducted within the 15-day period. When private surface is involved, the lessee or operator shall furnish the name, address and telephone number of the private surface owner on the NOS form or, in the surface use program, such information shall be attached to the APD. The BLM shall invite the surface owner to participate in the onsite inspection. This invitation will be extended as early as possible. However, a surface owner's inability to attend shall not delay the scheduled inspection unless BLM can conveniently reschedule the inspection within the 15-day time period. Joint inspections, i.e., those involving any other SMA, normally shall not be held for proposed in-fill well locations in developed fields if an appropriate environmental assessment (EA) already has been completed by BLM for the field or that area of the field. However, if staffing permits, a representative of BLM shall inspect those proposed locations where a joint predrill inspection is not held. At the time of onsite inspection, staking of the location shall have occurred, as specified in part A of this section. The surface use and reclamation stipulations shall be developed during the onsite inspection and provided to the operator either at the location or within 5 working days from the date of the onsite inspection, barring unusual circumstances. These requirements shall be incorporated into the complete application, when filed, if the proponent is following the NOS option. Otherwise, these requirements shall be incorporated as conditions of the APD approval if an NOS is not filed. However, this does not preclude the possibility of additional conditions being imposed as a result of the review of the complete application.

D. *Processing Time Frames.* The following table summarizes the major time frames involved in processing most APD's:

APD Option

Action items	Days
Onsite inspection	Within 15 days after receipt of the APD.
Requirements to be imposed when APD is approved.	Developed onsite or within 5 working days thereafter.
Complete processing of APD.	Within 30 days of the APD's receipt, provided that it is technically and administratively complete at the end of the 30-day period (includes the above 15-day and 5-day periods).

NOS Option

Action items	Days
Onsite inspection	Within 15 days after receipt of the NOS.
Requirements for inclusion in APD.	Furnished onsite or within 5 working days thereafter.
Complete processing of APD.	Within 10 days of the APD's receipt, provided that it is technically and administratively complete at the end of the 10-day period.

The above timeframes together comprise the total period during which BLM anticipates it will be able to process approximately 90 percent of all APD's. However, the 30 days may not run consecutively even when APD's are filed immediately after onsite inspections. For example, any time used by lessees or operators to correct deficiencies, or to prepare and submit information initially omitted from the application and which causes delays in processing beyond BLM's control, shall not be counted as part of the 30-day period. However, BLM shall continue to process applications up to the point where any missing piece of information or an uncorrected deficiency renders further processing impractical or impossible. Processing delays which extend the 30-day processing time are expected to occur in less than 5 percent of the cases. In addition, delays in conducting onsite inspections within 15 days of receiving an NOS (or an APD if an NOS is not filed), or delays in providing all stipulations to the operator within 5 working days of an onsite inspection may occur in less than 5 percent of the cases during periods of severe weather conditions and in areas where certain environmental concerns or jurisdictional conflicts exist.

Such areas include, but are not limited to:

1. Certain tribally or individually owned Indian trust or restricted lands.
2. Lands withdrawn for Federal reservoirs and Federal lands surrounding such reservoirs.
3. Lands in formally designated wilderness areas, lands formally proposed for such designation, lands within BLM Wilderness Study Areas or lands within Forest Service Further Planning Areas.
4. National Recreation Areas.
5. Wildife Refuges.
6. Certain Federal lands in Alaska.
7. Lands under jurisdiction of the Department of Defense.
8. Lands where a major problem exists with respect to cultural resources.
9. Lands known to contain threatened or endangered species and/or critical habitats.

30-day time frame for completion APD process also may be ded in most cases where it is sary to prepare an EA, and in all where it is necessary to prepare vironmental impact statement

sees and operators are also ned that if the NOS/APD process s less than 30 days prior to the d date of commencement of g operations, the process may not npleted within the time desired.

Cultural Resources Clearance. se consultation with the involved and the State Historic Preservation r on matters that relate to the ction of historic and cultural rces is provided in BLM (36 CFR a)(1)), lessees and operators d contact the involved SMA at 15 days prior to the submission of OS or APD to determine whether ctions are necessary to locate and fy historic and cultural resources. n actions are necessary, lessees perators are encouraged to lete the work and report prior to bmission of any other material to thorized officer of BLM but, in any , no later than the time the lete APD is submitted. Survey and a related report shall be red only if the involved SMA has n to believe that properties listed, gible for listing, in the National ter of Historic Places (NRHP) are nt in the area of potential effect. ric and cultural resources work on tely owned surface shall be taken only with the consent of the e surface owner. If the private ce owner refuses entry for that se, the lessee or operator shall use st efforts to conduct its approved tions in a manner that avoids se effects on any properties which sted, or may be eligible for listing, NRHP.

Threatened and Endangered es Clearance and Other Critical onmental Concerns. The involved shall identify any threatened and ngered species and/or critical at problems and other onmental concerns, e.g., wilderness wilderness study areas, wild and c rivers, etc., to minimize the bility of drill site relocation. Should MA, if that agency is not BLM, be e to carry out this responsibility, shall do so. BLM shall identify any n or potential surface geological rds. If any of these concerns exist, nation in that regard shall be eyed to the lessee/operator by BLM ter than when the surface use and nation stipulations are provided; however, the lessee/operator can ensure earlier identification of potential conflict in these areas of concern by contacting the involved SMA prior to the submittal of an NOS or APD. The authorized officer of BLM should be timely apprised of any contacts with any other involved SMA.

G. *Components of a Complete Application for Permit to Drill.*

1. *Complete Application.* If an NOS is filed, the lessee/operator shall prepare and submit a complete APD within 45 days of the onsite inspection pursuant to the requirements of this subsection. Failure to timely submit an APD within this time frame may result in the lessee/operator having to repeat the entire process. The complete APD shall be submitted in triplicate to BLM, together with any additional copies required by the authorized officer. As provided in 43 CFR 3162.3–1(d), formerly 30 CFR 221.23(d), a complete application consists of:

(a) Form 3160–3, (b) a drilling plan (or reference thereto) containing information required by section G.4., below, (c) evidence of bond coverage as required by Department of the Interior regulations, (d) designation of operator, where necessary, and (e) such other information as may be required by applicable Orders and Notices, including a cultural resource report (if required and not already filed). The APD shall be signed by the lessee/operator official having the responsibility and authority to supervise and direct all activities related to the permit and who can be contacted in the event of a problem. The authorized officer may require additional information in unusual circumstances. However, where the proposed well is to be completed for injection purposes (disposal or production enhancement), lessees and operators also shall obtain an underground injection permit from the Environmental Protection Agency (EPA) or the State, where the State has achieved primacy. Any information submitted in support of obtaining that permit shall be accepted by the authorized officer to the extent that it satisfies the information submission requirements of this Order.

2. *Designation of Operator.* The lessee may authorize the actual conduct of operations in its behalf by designating another party as operator in a manner and form acceptable to the authorized officer. Lessees shall notify the authorized officer in writing whenever an existing designation of operator is cancelled. A designated operator cannot designate a different party as operator.

3. *Form 3160–3, formerly 9–331C, (Application for Permit to Drill, Deepen, or Plug Back).* This Form shall be completed in full and submitted to the authorized officer together with all necessary information referred to under section G.1. above. The following points a. through f. are specific as to appropriate information requirements of the Form and shall be stated thereon, or as an attachment thereto, for each proposed well:

a. A well location plat shall be attached depicting the proposed location, as determined by a registered surveyor, in feet and direction from the nearest section lines of an established public land survey or, in areas where there are no public land surveys, by such other method as is acceptable to the authorized officer. The plat shall be signed by the surveyor, certifying that the location has, in fact, been staked on the grounds as shown on the plat.

b. The elevation given shall be the above-sea-level datum of the unprepared ground.

c. The type of drilling tools and associated equipment to be utilized shall be stated.

d. The proposed casing program shall include the size, grade, weight, type of thread and coupling, and setting depth of each string, and whether it is new or used.

e. The amount and type of cement, including additives to be used in setting each casing string, shall be described. If stage-cementing techniques are to be employed, the setting depth of the stage collars and amount and type of cement, including additives, to be used in each stage shall be given. The expected linear fill-up of each cemented string or each stage, when utilizing stage-cementing techniques, shall be provided.

f. The anticipated duration of the total operation shall be given in addition to the anticipated starting date. A copy of the approved Form 3160–3 and the pertinent drilling plan, along with any conditions of approval, shall be available at the drillsite to authorized or delegated representatives of the United States whenever active construction, drilling, or completion operations are under way.

4. *Drilling Plan.* A drilling plan in sufficient detail to permit a complete appraisal of the technical adequacy of, and environmental effects associated with, the proposed project shall be prepared and either submitted with each copy of Form 3160–3, or referenced thereon if it is already on file with BLM or is being submitted for more than one well. The plan shall be developed in conformity with the provisions of the lease, including attached stipulations, and the guidelines provided by this Order or other land use documents.

Each drilling plan shall contain a description of the drilling program and surface use program. The BLM shall send a copy of appropriate parts of the plan to any other involved SMA and may send a copy of the plan to other interested Federal, State, and local agencies. All information identified as proprietary by the applicant pursuant to 43 CFR 3162.8, formerly 30 CFR 221.33, shall first be deleted. The drilling program shall include a description of the pressure control system and circulation mediums, the testing, logging and coring program, pertinent geologic data, and information on expected problems and hazards. The drilling program shall be reviewed for adequacy by BLM. The criteria/standards set forth in the operational manual section (currently designated CDM 643.1.3E, Technical Considerations), or in effect at the time of submission of the APD, generally will be utilized in evaluating the technical adequacy of a proposed drilling plan. If the program is considered adequate, BLM shall require modification of the drilling program.

The surface use program shall contain a description of the road and drill pad location and construction methods for containment and disposal of waste material, and other pertinent data as the authorized officer may require. The surface use program shall provide for safe operations, adequate protection of surface resources and uses and other environmental components, and shall, for Federal and Indian surface, include adequate measures for reclamation of disturbed lands no longer needed for either drilling or other subsequent operations. Where the surface is privately owned, the authorized officer may require the submission of the reclamation plan between the lessee or operator and landowner in order to determine if it is adequate to protect nearby Federal and Indian surface from significant impacts generated by the operation. In developing the surface use program, the lessee or operator shall make use of such information as is available from the involved SMA concernng the surface resources and uses, environmental considerations, and local reclamation procedures. The surface use program shall be reviewed for adequacy by BLM and by any other involved SMA. The criteria/standards set forth in the Surface Operating Standards for Oil and Gas Exploration and Development Handbook, Second Edition, August 1978, or as subsequently revised, generally shall be utilized in evaluating the adequacy of a proposed surface use plan. If the surface use program is considered inadequate, BLM shall, in consultation with any other involved SMA, require modifications or amendment of the program or otherwise set forth stipulations or conditions of approval as are necessary for the protection of surface resources/uses and the environment, and for the reclamation of the areas to be disturbed when no longer needed for operational purposes.

a. *Guidelines for Preparing Drilling Program.* The following information shall be included as part of the drilling plan but shall be made specific to each well if the plan covers more than one well:

(1) Estimated tops of important geologic markers.

(2) Estimated depths at which the top and the bottom of anticipated water (particularly fresh water), oil, gas or other mineral-bearing formations are expected to be encountered and the lessee's or operator's plans for protecting such resources.

(3) Lessee's or operator's minimum specifications for pressure control equipment to be used and a schematic diagram thereof showing sizes, pressure ratings (or API series), and the testing procedures and testing frequency.

(4) Any supplementary information more completely describing the drilling equipment and casing program as set forth on Form 3160-3.

(5) Type and characteristics of the proposed circulating medium or mediums to be employed in drilling, the quantities and types of mud and weighting material to be maintained, and the monitoring equipment to be used on the mud system.

(6) The anticipated type and amount of testing, logging, and coring.

(7) The expected bottom hole pressure and any anticipated abnormal pressures or temperatures or potential hazards, such as hydrogen sulfide, expected to be encountered, along with contingency plans for mitigating such identified hazards.

(8) Any other facets of the proposed operation which the lessee or operator wishes to point out for BLM's consideration of the application.

(b) *Guidelines for Preparing Surface Use Program.* In preparing this program, the lessee or operator shall submit maps, plats, and narrative descriptions which adhere closely to the following (maps and plats should be of a scale no smaller than 1:24,000 unless otherwise stated below):

(1) *Existing Roads.* A legible map (USGS topographic, county road, Alaska Borough, or other such map), labeled and showing the access route to the location, shall be used for locating the proposed well site in relation to a town (village) or other locatable point, such as a highway or county road, which handles the majority of the through traffic to the general area. The proposed route to the location, including appropriate distances from the point where the access route exits established roads, shall be shown. All access roads shall be appropriately labeled. Any plans for improvement and/or a statement that existing roads will be maintained in the same or better condition shall be provided. Existing roads and newly constructed roads on surface under the jurisdiction of an SMA shall be maintained in accordance with the standards of the SMA.

Information required by items (2), (3), (4), (5), (6), and (8) of this subsection also may be shown on this map if appropriately labeled or on a separate plat or map.

(2) *Access Roads to Be Constructed and Reconstructed.* All permanent and temporary access roads that are to be constructed, or reconstructed, in connection with the drilling of the proposed well shall be appropriately identified and submitted on a map or plat. Width, maximum grade, major cuts and fills, turnouts, drainage design, location and size of culverts and/or bridges, fence cut and/or cattleguards, and type of surfacing material, if any, shall be stated for all construction. In addition, where permafrost exists, the methods for protection from thawing must be indicated. Modification of proposed road design may be requird during the onsite inspection.

Information also should be furnished to indicate where existing facilities may be altered or modified. Such facilities include gates, cattleguards, culverts, and bridges which, if installed or replaced, shall be designed to adequately carry anticipated loads.

(3) *Location of Existing Wells.* It is recommended that this information be submitted on a map or plat and include all wells (water, injection or disposal, producing, and drilling) within a 1-mile radius of the proposed location.

(4) *Location of Existing and/or Proposed Facilities if Well Is Productive.*

(a) *On well pad*—A map or plat shall be included showing, to the extent known or anticipated, the location of all production facilities and lines to be installed if the well is successfully completed for production.

(b) *Off well pad*—A map or plat shall be included showing to the extent known or anticipated, the existing or new production facilities to be utilized and the lines to be installed if the well is successfully completed for production. If

construction, the dimensions of the
ity layout are to be shown.
he information required under (a)
) above is not known and cannot be
rately presented and the well
equently is completed for
uction, the operator shall then
ly with section IV. of this Order.
*Location and Type of Water
ly (Rivers, Creeks, Springs, Lakes,
's, and Wells).* This information
be shown by quarter-quarter
on on a map or plat, or may be a
en description. The source and
portation method for all water to
sed in drilling the proposed well
be noted if the source is located on
ral or Indian lands or if water is to
sed from a Federal or Indian project.
water is obtained from other than
ral or Indian lands, only the
ion need be identified. Any access
s crossing Federal or Indian lands
are needed to haul the water shall
escribed in items G.4.b. (1) and (2),
opropriate. If a water supply well is
drilled on the lease, it shall be so
d under this item, and the
orized officer of BLM may require
iling of a separate APD.
Construction Materials. The lessee
perator shall state the character and
ded use of all construction
rials, such as sand, gravel, stone
soil material. If the materials to be
are Federally-owned, the proposed
ce shall be shown by either quarter-
ter section on a map or plat, or a
en description. The use of materials
r BLM jurisdiction is governed by
FR 3610.2–3. The authorized officer
inform the lessee or operator if the
rials may be used free of charge or
application for sale is required. If
naterials to be used are Indian
ed or under the jurisdiction of SMA
than BLM, the specific tribe and or
Superintendent of BIA, or the
opriate SMA office shall be
acted to determine the appropriate
edure for use of the materials.
*Methods for Handling Waste
osal.* A written description shall be
of the methods and locations
osed for safe containment and
osal of each type of waste material
cuttings, garbage, salts, chemicals,
ge, etc.) that results from the
ng of the proposed well. Likewise,
arrative shall include plans for the
tual disposal of drilling fluids and
produced oil or water recovered
g testing operations.
Ancillary Facilities. The plans, or
equent amendments to such plans,
identify all ancillary facilities such
mps and airstrips as to their
ion, land area required, and the
methods and standards to be employed in their construction. Such facilities shall be shown on a map or plat. The approximate center of proposed camps and the center line of airstrips shall be staked on the ground.

(9) *Well Site Layout.* A plat of suitable scale (not less than 1 inch=50 feet) showing the proposed drill pad and its location with respect to topographic features is required. Cross section diagrams of the drill pad showing any cuts and fills and the relation to topography are also required. The plat shall also include the proposed location of the reserve and burn pits, access roads onto the pad, turnaround areas, parking areas, living facilities, soil material stockpiles, and the orientation of the rig with respect to the pad and other facilities. Plans, if any, to line the reserve pit shall be detailed.

(10) *Plans for Reclamation of the Surface.* The program for surface reclamation upon completion of the operation, such as configuration of the reshaped topography, drainage system, segregation of spoils materials, surface manipulations, waste disposal, revegetation methods, and soil treatments, plus other practices necessary to reclaim all disturbed areas, including any access roads or portions of well pads when no longer needed, shall be stated. An estimate of the time for commencement and completion of reclamation operations, dependent on weather conditions and other local uses of the area, shall be provided.

(11) *Surface Ownership.* The surface ownership (Federal, Indian, State or private) at the well location, and for all lands crossed by roads which are to be constructed or upgraded, shall be indicated. Where the surface of the well site is privately owned, the operator shall provide the name, address and telephone number of the surface owner, unless previously provided.

(12) *Other Information.* The lessee or operator is encouraged to submit any additional information that may be helpful in processing the application.

(13) *Lessee's or Operator's Representative and Certification.* The name, address and telephone number of the lessee's or operator's field representative shall be included. The lessee or operator submitting the APD shall certify as follows:

I hereby certify that I, or persons under my direct supervision, have inspected the proposed drill site and access route; that I am familiar with the conditions which currently exist; that the statements made in this plan are, to the best of my knowledge, true and correct; and that the work associated with operations proposed herein will be performed by ———— and its contractors and subcontractors in conformity with this plan and the terms and conditions under which it is approved. This statement is subject to the provisions of 18 U.S.C. 1001 for the filing of a false statement.

Date ————.
Name and Title ————.

5. *Environmental Review Requirements.*

When an onsite inspection is conducted, it shall be made by representatives of the authorized officer and the operator, and other interested parties such as the involved SMA, the appropriate Alaska Borough (when a subsistence stipulation is part of the lease), and the operator's principal (construction and drilling) contractors. It is recommended that, when appropriate, the operator's surveyor and archeologist should also participate in the inspection. The purpose of this inspection shall be to ensure the staked location, access roads and other areas proposed for surface disturbance are geologically and environmentally acceptable, giving appropriate consideration to all applicable Federal laws and regulations. Lessees and operators are encouraged to designate their future drilling sites so that several locations may be inspected at one time.

a. *Federal Responsibilities.* When an inspection is made, the information obtained shall be utilized by BLM in appraising the environmental effects associated with the proposed action and in preparing pertinent portions of the required environmental documentation. As the approving agency, BLM has the lead responsibility for completing the environmental review process and establishing the terms and conditions under which the proposed action may be approved. The conduct of the environmental review process, under the Department of the Interior's implementing procedures pursuant to the National Environmental Policy Act, will result in the preparation of a Record of Review (ROR) and/or an EA, consistent with pertinent regulations and procedures. This review shall identify the probable and potential environmental impacts associated with the proposal and methods for mitigating these impacts and shall be the basis of the approving official's determination as to whether approval of the proposed activity would or would not constitute a major Federal action significantly affecting the quality of the human environment as defined by section 102(2)(C) of the National Environmental Policy Act of 1969. A "would constitute" determination shall necessitate the preparation of an EIS. In that case, final action on the APD shall not be taken until the EIS and Record of Decision are completed.

b. *Other Considerations.* Lessees and operators are strongly encouraged to file their NOS and/or complete APD at least 30 days in advance of the time when they wish to commence operations and to consult with the involved SMA as early as possible to identify potential areas of concern (see sections III. E. and F.).

IV. *Subsequent Operations.* Subsequent operations shall be conducted in accordance with 43 CFR Part 3160, formerly 30 CFR 221. However, where the proposed subsequent operation will result in the well being converted for injection purposes (disposal or production enhancement), lessees and operators also shall obtain an underground injection permit from EPA or the State, where the State has achieved primacy. Any information submitted in support of obtaining that permit shall be accepted by the authorized officer of BLM to the extent that it satifies the information submittal requirements of this Order.

A. *Well and Production Operations.* Before conducting further well operations that involve change in the original plan, a detailed written statement of the work shall be filed on Form 3160–5 or 3160–3, as appropriate, with the authorized officer and approval obtained before the work is started. These operations include redrilling, deepening, performing casing repairs, plugging-back, altering casing, performing nonroutine fracturing jobs, recompleting in a different interval, performing water shut-off, and converting to injection or disposal. Within 30 days of the completion of such operations, a subsequent report shall be filed on Form 3160–5 and, if the well is recompleted, a recompletion report on Form 3160–4, pursuant to 43 CFR 3162.3–2 and the information collection approval note, formerly 30 CFR 221.27 and 221.2–1.

Unless additional surface disturbance is involved and so long as the operations conform to the standard of prudent operating practice, no prior approval is required for routine fracturing or acidizing jobs, or recompletion in the same interval, but a subsequent report of these operations shall be filed on Form 3160–5, formerly 9–331, within 30 days of completion, pursuant to 43 CFR 3162–2.3 and the information collection approval note; formerly 30 CFR 221.27 and 221.2–1.

Neither prior approval nor a subsequent report is required for well clean-out work, routine well maintenance (such as pump, rods, and tubing work), or for repair, replacement, or modification of surface production equipment, provided no additional surface disturbance is involved. However, the modification of any production, treating, and measurement facilities shall require the submission of a revised schematic diagram within 30 days of the completion of such operations, pursuant to 43 CFR 3162.7–2, formerly 30 CFR 221.34.

B. *Surface Disturbing Operations.* Pursuant to 43 CFR 3162.3–2 and 3162.3–3, formerly 30 CFR 221.27 and 221.28, lessees and operators shall submit, for the approval of the authorized officer, a proposed plan of operations on Form 3160–5 prior to undertaking any subsequent new construction, reconstruction, or alteration of existing facilities including, but not limited to, roads, emergency pits, firewalls, flowlines, or other production facilities on any lease when additional surface disturbance will result. If, at the time the original APD was filed, the lessee or operator elected to defer submitting information for item III.G.4.b.(4), "Location of Existing and/or Proposed Facilities if Well is Productive," the lessee or operator shall supply this information for approval prior to construction and installation of the facilities. The authorized officer, in consultation with any other involved SMA, may require a field inspection before approving the proposal.

C. *Emergency Repairs.* Emergency repairs may be conducted without prior approval provided that the authorized officer is promptly notified. Sufficient information shall be submitted to permit a proper evaluation of any resultant surface disturbing activities as well as any planned accommodations necessary to mitigate potential adverse environmental effects.

D. *Environmental Review.* The environmental review procedures discussed in section III.G.5. of this Order shall also apply to subsequent operations which involve additional surface disturbance.

V. *Well Abandonment.* No well abandonment operations may be commenced without the prior approval of the authorized officer. In the case of newly drilled dry holes or failures and in emergency situations, oral approval may be obtained from the authorized officer subject to prompt written confirmation. For old wells not having an approved abandonment plan, a sketch showing the disturbed area and roads to be abandoned, along with the proposed reclamation measures, shall be submitted with Form 3160–5. On Federal and Indian surface, the appropriate SMA may request additional reclamation measures at abandonment, which normally shall be made a part of BLM's approval of abandonment. Within 30 days following completion of the well abandonment, the lessee or operator shall file with the authorized officer of BLM a Subsequent Report of Abandonment on Form 3160–5, in accordance with 43 CFR Part 3160, formerly 30 CFR Part 221. Upon completion of reclamation operations, the lessee or operator shall notify the authorized officer when the location is ready for inspection, via an additional Form 3160–5. Final abandonment shall not be approved until the surface reclamation work required by the approved drilling permit or approved abandonment notice has been completed to the satisfaction of the involved SMA.

VI. *Water Well Conversion.* The complete abandonment of a well which has encountered usable fresh water shall not be approved if the SMA or surface owner wants to acquire the well. If, at abandonment, the SMA or surface owner elects to assume further responsibility for the well, the SMA or surface owner, as appropriate, shall reimburse the lessee or operator for the cost of any recoverable casing or wellhead equipment which is to be left in or on the hole solely because it is to be completed as a water well. The lessee or operator shall abandon the well to the base of the deepest fresh water zone of interest, as required by the authorized officer, and shall complete the surface cleanup and reclamation, as required by the approved drilling permit or approved abandonment notice, immediately upon completion of the conversion operations.

VII. *Privately Owned Surface.*—A. *Federal oil and gas leases.* Where the well site and access road surface are privately owned or are held in trust for Indian benefit, the lessee or operator is responsible for reaching an agreement with BIA or the private surface owner as to the requirements for the protection of surface resources and reclamation of disturbed areas and/or damages in lieu thereof. However, if the authorized officer or any other involved SMA determines that the surface of Federal or Indian-owned lands in proximity to the proposed well site or access road on private surface will be significantly affected, the lessee or operator may be required to furnish a copy of any existing agreement between the lessee or operator and the surface owner to the authorized officer. If the agreement on private surface is considered inadequate to protect the surface of adjacent Federal or Indian-owned lands, the authorized officer or other involved SMA may prescribe additional measures to protect the adjacent Federal or Indian lands. In the event there is no agreement between the surface owner and the operator, the operator may comply with the provisions of the law or the regulations governing the Federal or Indian right of reentry to the surface (See Subpart 3814 of this title) and the authorized officer may then proceed to issue the permit.

B. *Indian oil and gas leases.* Where the well site and access road surface are privately owned or are held in trust for an Indian or Indian tribe other than the owner of the oil and gas rights, the lessee or operator is responsible for reaching an agreement with the surface owner (or the BIA if the surface is held in trust for numerous or unlocatable Indian owners) as to the requirement for the protection of surface resources and reclamation of disturbed areas and/or damages in lieu thereof. However, if the authorized officer or any other involved SMA determines that the surface of Federal or Indian-owned lands in proximity to the proposed well site or access road on private surface will be significantly affected, the lessee or operator may be required to furnish the authorized officer a copy of any existing agreement between the lessee or operator and the surface owner. If the agreement on private surface is considered inadequate to protect the surface of adjacent Federal or Indian-owned lands, the authorized officer or other involved SMA may prescribe additional measures to protect the adjacent Federal or Indian-owned lands. In the event there is no agreement between the surface owner and the operator, the authorized officer may permit the operator to conduct operations if he/she determines that: (1) a good faith effort has been made by the operator to reach agreement with the surface owner; (2) adequate security is posted, in the form of a bond, escrow account or by other means, to compensate the surface owner for any damages; and (3) there is no legal obstacle to conducting operations in the absence of surface owner consent.

VIII. *Reports and Activities Required After Well Completion.* Within 30 days after the well completion, the lessee or operator shall furnish 2 copies of Form 3160-4, formerly 9-330 (Well Completion or Recompletion Report and Log) to the authorized officer. However, no later than the fifth business day after any well begins production anywhere on a lease site or allocated to a lease site, or resumes production in the case of a well that has been off production for more than 90 days, the lessee or operator shall notify the authorized officer of the date on which production has begun or resumed.

The notification may be provided orally if promptly confirmed in writing.

Dated: August 9, 1983.

Jeffrey F. Zabler,

Acting Assistant Director for Fluid Leasable Minerals.

Approved:

Dated: August 17, 1983.

Arnold E. Petty,

Acting Associate Director, Bureau of Land Management.

BILLING CODE 4310-84-M

Attachment A

SAMPLE FORMAT

NOTICE OF STAKING (Not to be used in place of Application for Permit to Drill Form 3160-3)	6. Lease Number
1. Oil Well |__| Gas Well |__| Other (Specify)	7. If Indian, Allottee or Tribe Name
2. Name of Operator:	8. Unit Agreement Name
3. Name of Specific Contact Person:	9. Farm or Lease Name
4. Address & Phone No. of Operator or Agent	10. Well No.
5. Surface Location of Well Attach: a) Sketch showing road entry onto pad, pad dimensions, and reserve pit. b) Topographical or other acceptable map showing location, access road, and lease boundaries.	11. Field or Wildcat Name 12. Sec., T., R., M., or Blk and Survey or Area

15. Formation Objective(s)	16. Estimated Well Depth	13. County, Parish or Borough	14. State

17. Additional Information (as appropriate; must include surface owner's name, address, and telephone number)

18. Signed__________ Title__________ Date__________

Note: Upon receipt of this Notice, the Bureau of Land Management (BLM) will schedule the date of the onsite predrill inspection and notify you accordingly. The location must be staked and access road must be flagged prior to the onsite.

Operators must consider the following prior to the onsite:
a) H_2S Potential
b) Cultural Resources (Archeology)
c) Federal Right of Way or Special Use Permit

IMPORTANT: SEE REVERSE SIDE FOR INSTRUCTIONS

BILLING CODE 4310-84-C

ctions for Preparation of
ment A

eral: This provides notice to the
of Land Management (BLM) that
g has been (or will be) completed
ll locations on Federal or Indian
and serves as a request to
le an onsite inspection. The
l and one copy of this notice,
er with a map and sketch, should
mitted to the appropriate BLM

item not completed may be
ation for not promptly scheduling
site inspection.

cific Considerations: Items
ed herein should be reviewed and
ted thoroughly prior to the onsite.
items affect placement of
n, road, and facilities. Failure to
pared with complete, accurate
ation at the onsite may
itate later re-evaluation of the site
additional onsite inspection.

S Potential: Prevailing winds,
routes, and placement of living
rs must be considered.

ultural Resources: Archeological
s, if required, should be done
o, during or immediately following
site. Changes in location due to
quent archeological findings may
e an additional onsite. Contact
ed Surface Management Agency
for detailed site specific
ements.

ederal Right-of-Way or Special
ermit: Access roads outside the
old boundary which cross Federal
will require a right-of-way grant or special use permit and should be discussed with the BLM or other involved SMA at the time of filing the Notice of Staking.

Supplemental Checklist: The following items, if applicable, should be submitted with or prior to the Application For Permit to Drill (APD) to ensure timely approval of the application. Contact the BLM regarding specific requirements relating to each item.

a. Bonding.

b. Designation of Operator.

c. Report of Cultural Resources/ Archeology.

d. H_2S Contingency Plan.

e. Status of Plan of Development and Designation of Agent for wells in Federal units.

f. Federal Right-of-Way (BLM) or Special Use Permit (Forest Service).

Timetable: The onsite inspection will be scheduled and conducted by the BLM within 15 days after receipt of this notice. Surface protection and rehabilitation requirements will be made known to the operator by the BLM during the onsite or no later than 5 working days from the date of inspection, barring unusual circumstances. These requirements are to be incorporated into the complete APD. However, this does not exclude the possibility of additional conditions of approval being imposed.

Attachment B

Date— ______________________

Bureau of Land Management

Checklist for Applicant Notification

Receipt and Acceptability of Application for Permit To Drill (APD)

Lease No.————
Well No.————
Lessee————
Operator————
Date APD Received————

1.—APD complete as submitted.

2.—APD is deficient in the following area(s) *and* (see items 3, 4, or 5 below):

—Designation of Operator
—Designation of Agent under————unit agreement
—Bonding
—Cultural Resources Report (depends on Federal Surface Management Agency's Requirements
—Form 9-331C
—Drilling Plan
—Other

(Refer to attachment(s) for any specifics)

3.—APD is retained; to be processed upon receipt of further information as noted above.

4.—APD is being processed; final action pending receipt of further information as noted above.

5.—APD is returned for the following reasons:————

____

____

Note:— A returned APD herewith may be resubmitted when convenient at which time it will be reviewed again for technical and administrative completeness.

A retained but deficient APD must be brought to a technically and administratively acceptable level of completion within 45 days of the date of this notice or the application will be returned unapproved.

[FR Doc. 83-28042 Filed 10-20-83; 8:45 am]
BILLING CODE 4310-84-M

Dated: September 21, 1983.
Harold W. Furman II,
Acting Assistant Secretary of the Interior.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION DIVISION

Notice to Lessees and Operators
of Federal\ and Indian Oil and Gas Leases
(NTL-2B)

Disposal of Produced Water

This Notice supersedes NTL-2 and 2A and is issued pursuant to the authority prescribed in 30 CFR 221.4 and 221.32. Lessees and operators of onshore Federal and Indian oil and gas leases or fee and State leases committed to federally supervised unitized or communitized areas shall comply with the following requirements for the handling, storing, or disposing of water produced from oil and gas wells on such leases.

As used in this Notice, the term "District Engineer" means the District Engineer, U.S. Geological Survey. However, in the State of Alaska, the requirements of this Notice will be administered by the Area Oil and Gas Supervisor.

I DISPOSAL REQUIREMENTS AND APPLICATIONS FOR APPROVAL OF DISPOSAL METHODS

By October 1, 1977, all produced water from the above said leases must be disposed of by (1) injection into the subsurface; (2) lined pits; or, (3) by other acceptable methods. All such disposal methods must be approved in writing by the District Engineer regardless of the physical location of the disposal facility. Any method of disposal which has not been approved as of October 1, 1977, will be considered as an incident of noncompliance and will be grounds for issuing a shut-in order until an acceptable manner for disposing of said water is provided and approved by the District Engineer. Lessees and operators are encouraged to file applications in this regard as promptly as possible and are forewarned that applications for approval of existing disposal facilities which are filed after July 1, 1977, may not be timely approved.

Enclosure 7

No additional approval is required for facilities previously approved by the Geological Survey which involve the disposal of produced water into the subsurface or in lined surface pits. Likewise, no further approval is necessary for existing injection facilities utilized for pressure maintenance or secondary recovery operations.

Lessees and operators who are presently disposing of water in unlined surface pits must timely file applications with the District Engineer for approval of present or proposed disposal methods. Likewise, lessees and operators who are presently disposing of produced water in the subsurface or in lined surface pits without approval of the Geological Survey must also file applications for approval thereof by the District Engineer.

The District Engineer may require modification of any disposal facility prior to October 1, 1977, whenever it is determined that continued use of such facility is endangering the fresh water in the area or is otherwise adversely affecting the environment.

Any application to dispose of produced water must specify the proposed method of disposal and provide the information necessary to justify the method. Required information which must be included in applications for approval of produced water disposal in the subsurface, in lined pits, or in unlined pits is set forth in Sections II, III, and IV, respectively, of this Notice. Additional information may be required by the District Engineer in individual cases. Previous applications filed in response to NTL-2 and NTL-2A which do not meet the data requirements of this Notice must be supplemented or resubmitted.

A single application may be submitted for several leases or facilities provided that (1) the leases or facilities are located in the same field; (2) the produced water is from the same formation or is of similar quality; (3) the volume and source of the water is shown separately for each disposal facility; and, (4) the method of disposal is the same in every case.

II DISPOSAL IN THE SUBSURFACE

If approval is requested for subsurface water injection in connection with secondary recovery operations or for disposal purposes, the lessee or operator must furnish information which includes:

No additional approval is required for facilities previously approved by the Geological Survey which involve the disposal of produced water into the subsurface or in lined surface pits. Likewise, no further approval is necessary for existing injection facilities utilized for pressure maintenance or secondary recovery operations.

Lessees and operators who are presently disposing of water in unlined surface pits must timely file applications with the District Engineer for approval of present or proposed disposal methods. Likewise, lessees and operators who are presently disposing of produced water in the subsurface or in lined surface pits without approval of the Geological Survey must also file applications for approval thereof by the District Engineer.

The District Engineer may require modification of any disposal facility prior to October 1, 1977, whenever it is determined that continued use of such facility is endangering the fresh water in the area or is otherwise adversely affecting the environment.

Any application to dispose of produced water must specify the proposed method of disposal and provide the information necessary to justify the method. Required information which must be included in applications for approval of produced water disposal in the subsurface, in lined pits, or in unlined pits is set forth in Sections II, III, and IV, respectively, of this Notice. Additional information may be required by the District Engineer in individual cases. Previous applications filed in response to NTL-2 and NTL-2A which do not meet the data requirements of this Notice must be supplemented or resubmitted.

A single application may be submitted for several leases or facilities provided that (1) the leases or facilities are located in the same field; (2) the produced water is from the same formation or is of similar quality; (3) the volume and source of the water is shown separately for each disposal facility; and, (4) the method of disposal is the same in every case.

II DISPOSAL IN THE SUBSURFACE

If approval is requested for subsurface water injection in connection with secondary recovery operations or for disposal purposes, the lessee or operator must furnish information which includes:

1. The designated name and number of the proposed dispos~l well and its location in feet and direction from the nearest section lines of an established survey. The applicable Federal or Indian oil and gas lease number or other permit and/or the ownership of the surface and minerals if other than Federal or Indian.

2. The daily quantity and sources of the produced water and a water analysis which includes total dissolved solids, pH, and the concentrations of chlorides and sulfates.

3. The injection formation and interval.

4. The quality of the fluids in the injection interval, i.e., total dissolved solids.

5. The depth and areal extent of all usable water (i.e., less than 10,000 ppm total dissolved solids) aquifers in the area.

6. The size, weight, grade and casing points of all casing strings, the size hole drilled to accommodate each string, the amount and type of cement, including additives used in cementing each string, and the top of the cement behind each casing string. In addition, bond logs may be required in certain instances.

7. The total and plugged back depth of the well.

8. The present or proposed method of completing the well for injection including the type and size of tubing and packer to be utilized, the setting depth of the packer, anticipated injection pressure, and information concerning any corrosion inhibitor fluid which is to be placed in the tubing-casing annulus.

9. Plans for monitoring the system to assure that injection is confined to the injection interval and measures to be taken should it be necessary to shut-in the disposal system.

In order to be approved, subsurface disposal must be confined (1) to formations which contain water of similar or poorer quality than the injected water or (2) to formations that contain water of such poor quality as to eliminate any practical use thereof.

In general, it will be required that subsurface disposal be accomplished through tubing utilizing a packer which is designed to hold pressure from above and below. The packer should be set at a depth where the casing is protected by competent cement but normally not more than 50 feet above the injection interval. Other procedures or methods of subsurface disposal may be approved by the District Engineer when justified by the lessee or operator.

III DISPOSAL IN LINED PITS

Where approval is requested for surface disposal in a lined pit, the lessee or operator must supply information which includes:

1. A topographic map of suitable scale which shows the size and location of pit.
2. The daily quantity, sources of the produced water, and a water analysis which includes the concentrations of chlorides, sulfates, and other constituents which are toxic to animal, plant, or aquatic life.
3. The evaporation rate for the area compensated for annual rainfall.
4. The method for periodic disposal of precipitated solids.
5. The type of material to be used for lining the pit and the method of installation.
6. The method to be employed for the detection of leaks and plans for corrective action should a leak occur in the liner.

The material used in lining pits must be impervious, weather-resistant, and not subject to deterioration when contacted by hydrocarbons, aqueous acids, alkalies, fungi, or other substances likely to be contained in the produced water. Lined pits constructed after the issuance of this Notice must have an underlying gravel-filled sump and lateral system or other suitable devices for the detection of leaks. The District Engineer shall be provided an opportunity to inspect the leak detection system prior to the installation of the pit liner.

IV DISPOSAL IN UNLINED PITS

Surface disposal into unlined pits will not be considered for approval by the District Engineer unless the lessee or operator can show by application that such disposal meets any one or more of the following criteria:

In general, it will be required that subsurface disposal be accomplished through tubing utilizing a packer which is designed to hold pressure from above and below. The packer should be set at a depth where the casing is protected by cemented casing but normally not more than 50 feet above the injection interval. Other procedures or methods of subsurface disposal may be approved by the District Engineer when justified by the lessee or operator.

III DISPOSAL IN LINED PITS

Where approval is requested for surface disposal in a lined pit, the lessee or operator must supply information which includes:

1. A topographic map of suitable scale which shows the size and location of pit.

2. The daily quantity, sources of the produced water and a water analysis which includes the concentrations of chlorides, sulfates, and other constituents which are toxic to animal, plant, or aquatic life.

3. The evaporation rate for the area compensated for annual rainfall.

4. The method for periodic disposal of precipitated solids.

5. The type of material to be used for lining the pit and the method of installation.

6. The method to be employed for the detection of leaks and plans for corrective action should a leak occur in the liner.

The material used in lining pits must be impervious, weather resistant, and not subject to deterioration when contacted by hydrocarbons, aqueous acids, alkalies, fungi, or other substances likely to be contained in the produced water. Lined pits constructed after the issuance of this Notice must have an underlying gravel-filled sump and lateral system or other suitable devices for the detection of leaks. The District Engineer shall be provided an opportunity to inspect the leak detection system prior to the installation of the pit liner.

IV DISPOSAL IN UNLINED PITS

Surface disposal into unlined pits will not be considered for approval by the District Engineer unless the lessee or operator can show by application that such disposal meets any one or more of the following criteria:

1. The water to be disposed of has an annual weighted average concentration of not more than 5,000 ppm of total dissolved solids, provided that such water does not contain objectionable levels of any constituent toxic to animal, plant, or aquatic life.

2. That all, or a substantial part, of the produced water is being used for beneficial purposes. For example, produced water used for purposes such as irrigation and livestock or wildlife watering shall be considered as being beneficially used.

3. The water to be disposed of is not of poorer quality than the surface or subsurface waters in the area which reasonably might be affected by such disposal or the surface and subsurface waters are of such poor quality as to eliminate any practical use thereof.

4. The volume of water to be disposed of per facility does not exceed five barrels per day on a monthly basis.

5. The specific method of disposal has been granted a surface discharge permit under the National Pollutant Discharge Elimination System (NPDES).

Applications for approval of unlined surface pits pursuant to exception Nos. 1, 2, 3, or 4, above, must include:

1. The daily quantity and sources of the produced water and for exception Nos. 1 through 3, a water analysis which includes total dissolved solids, pH, and the concentrations of chlorides and sulfates.

2. A topographic map of suitable scale which shows the size and location of the pit.

3. The evaporation rate for the area compensated for annual rainfall.

4. The estimated percolation rate based on the soil characteristics under and adjacent to the pit.

5. The depth and areal extent of all usable water (i.e., less than 10,000 ppm total dissolved solids) aquifers in the area.

Where beneficial use is the basis for the application, the justification submitted must contain written confirmation from the user(s) and the water analysis must also include the oil and grease content, temperature, and the concentration of other constituents which are toxic to animal, plant, or aquatic life.

If the application is made on the basis that surface and subsurface fresh waters will not be affected by disposal in an unlined pit, the justification must also include:

1. Analyses of all surface and subsurface waters in the area which might reasonably be affected by the proposed disposal.

2. Maps or plats showing the location of surface waters, fresh water wells, and existing water disposal facilities within two miles of the proposed disposal facility.

3. Reasonable geologic and hydrologic evidence showing that the proposed disposal method will not adversely impact on existing water quality or major uses of such waters; the depth of the shallowest fresh water aquifer in the area and the presence of any impermeable barrier(s).

4. A copy of any State order or other authorization granted as a result of a public hearing which is pertinent to the District Engineer's consideration of the application.

If the application is for disposal pursuant to an NPDES permit, only a topographic map showing the size and location of the pit together with a copy of the approved permit and the most recent "Discharge Monitoring Report" will be required.

V GENERAL REQUIREMENTS FOR PERMANENT SURFACE PITS

Lined and unlined pits approved for water disposal shall:

1. Have adequate storage capacity to safely contain all produced water even in those months when evaporation rates are at a minimum.

2. Be constructed, maintained, and operated to prevent unauthorized surface discharges of water. Unless surface discharge is authorized, no siphon, except between pits, will be permitted.

3. Be fenced to prevent livestock or wildlife entry to the pit, when required by the District Engineer.

4. Be kept reasonably free from surface accumulations of liquid hydrocarbons by use of approved skimmer pits, settling tanks, or other suitable equipment.

5. Be located away from the established drainage patterns in the area and be constructed so as to prevent the entrance of surface water.

VI TEMPORARY USE OF SURFACE PITS

Unlined surface pits may be used for handling or storage of fluids used in drilling, redrilling, reworking, deepening, or plugging of a well provided that such facilities are promptly and properly emptied and restored upon completion of the operations. Mud or other fluids contained in such pits shall not be disposed of by cutting the pit walls without the prior authorization of the District Engineer. Until finally restored, unattended pits must be fenced to prevent access by livestock and wildlife. Unless otherwise specified by the District Engineer, unlined pits may be used for well evaluation purposes for a period of 30 days.

Unlined pits may also be retained as temporary containment pits for use only in an emergency provided such pits have been approved by the District Engineer. Any emergency use of such pits shall be reported to the District Engineer as soon as possible and the pit shall be emptied and the liquids disposed of in an approved manner within 48 hours following its use, unless such time is extended by the District Engineer.

VII DISPOSAL FACILITIES FOR NEW WELLS

With the approval of the District Engineer, produced water from wells completed after the issuance date of this Notice may be temporarily disposed of into unlined pits for a period up to 90 days. During the period so authorized, an application for approval of the permanent disposal method, along with the required water analysis and other information, must be submitted to the District Engineer. Failure to timely file an application within the time allowed will be considered an incident of noncompliance and will be grounds for issuing a shut-in order until the application is submitted. With the approval of the District Engineer, the disposal method

3. Be fenced to prevent livestock or wildlife entry to the pit, when required by the District Engineer.

4. Be kept reasonably free from surface accumulations of liquid hydrocarbons by use of approved skimmer pits, settling tanks, or other suitable equipment.

5. Be located away from the established drainage patterns in the area and be constructed so as to prevent the entrance of surface water.

VI TEMPORARY USE OF SURFACE PITS

Unlined surface pits may be used for handling or storage of fluids used in drilling, redrilling, reworking, deepening, or plugging of a well provided that such facilities are promptly and properly emptied and restored upon completion of the operations. Mud or other fluids contained in such pits shall not be disposed of by cutting the pit walls without the prior authorization of the District Engineer. Until finally restored, unattended pits must be fenced to prevent access by livestock and wildlife. Unless otherwise specified by the District Engineer, unlined pits may be used for well evaluation purposes for a period of 30 days.

Unlined pits may also be retained as temporary emergency pits for use only in an emergency provided such pits have been approved by the District Engineer. Any emergency use of such pits shall be reported to the District Engineer as soon as possible and the pit shall be emptied and the liquids disposed of in an approved manner within 48 hours following its use, unless such time is extended by the District Engineer.

VII DISPOSAL FACILITIES FOR NEW WELLS

With the approval of the District Engineer, produced water from wells completed after the issuance date of this Notice may be temporarily disposed of into unlined pits for a period of to 90 days. During the period so authorized, an application for approval of the permanent disposal method, along with the required water analysis and other information, must be submitted to the District Engineer. Failure to timely file an application within the time allowed will be considered an incident of noncompliance and will be grounds for issuing a shut-in order until the application is submitted. With the approval of the District Engineer, the disposal method may be continued pending his final determination. Once the District Engineer has determined the proper method of disposal, the lessee or operator will have until October 1, 1977, or 60 days following receipt of the District Engineer's determination, whichever is the longer, in which to make any changes necessary to bring the disposal method into compliance. However, if the disposal method then employed is endangering the fresh water in the area or otherwise constitutes a hazard to the quality of the environment, the District Engineer will direct prompt compliance with the requirements of this Notice.

VIII UNAVOIDABLE DELAY

A single extension of time not to exceed three months (six months in arctic and subarctic areas) may be granted by the District Engineer where the lessee or operator conclusively shows by application that, despite the exercise of due care and diligence, he has been unable to timely comply with the requirements of the Notice provided that such delay will not adversely affect the environment.

IX REPORTS

All unauthorized discharges or spills from disposal facilities must be reported to the District Engineer in accordance with the provisions of NTL-3.

Beginning October 1, 1978, and thereafter on an annual basis, lessees and operators must submit a report for each facility which includes the total volume disposed of during the reporting period and a current water analysis which provides the same type of information required for approval of the original application. Provided, however, that:

1. Where disposal is approved pursuant to Section IV (4), no annual water analysis will be required.

2. Where disposal is approved pursuant to a NPDES permit, a copy of the required discharge monitoring report may be submitted in lieu of the above annual report.

3. Where a single application was approved for several leases and/or facilities, a composite annual report covering all such leases and facilities may be submitted.

X COMPLIANCE

Compliance with this Notice does not relieve a lessee or operator of the responsibility for complying with more stringent applicable Federal or State water quality laws and regulations, including those which are subsequently promulgated pursuant to the Safe Drinking Water Act (P.L. 92-523), or with other written orders of the Geological Survey.

JAN 1 1976
Date

Area Oil and Gas Supervisor

APPROVED:

Russell G. Wayland
Chief, Conservation Division

DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION DIVISION

Supplement No. 1 to
Notice to Lessees and Operators
of Federal and Indian Oil and Gas Leases
(NTL-2B)

Disposal of Produced Water

The requirements of Section IX (Reports) of NTL-2B as issued January 1, 1976, are hereby revised to read as follows:

IX REPORTS

All unauthorized discharges or spills from disposal facilities must be reported to the appropriate District Engineer in accordance with the provisions of NTL-3, as revised or supplemented.

Beginning October 1, 1978, and thereafter on an annual basis, each lessee or operator who is utilizing a previously approved unlined pit for the disposal of produced water on a regular basis, must, as a minimum, file with the District Engineer a listing of all such pits which still meet one or more of the criteria necessary to justify the continued use thereof. The listing must be certified as correct by the lessee or operator and must (1) identify each individual pit by its location and, if applicable, by the Federal or Indian lease number and (2) specify which of the criteria set forth in Section IV of NTL-2B justify a continuation of the District Engineer's approval to utilize the facility for disposal purposes. Where any previously approved unlined pit no longer meets one of the applicable criteria, the lessee or operator must file an application for approval of an acceptable alternative disposal method pursuant to Section II or III of NTL-2B.

The District Engineer may require a detailed annual report on any facility regularly used for disposal purposes. However, as a general rule, detailed annual reports will not be required for those unlined pits approved for temporary or emergency use or for those approved facilities which utilize lined pits or subsurface injection as the disposal method.

The annual certifications and reports (when required) will be reviewed to assure that disposal in each unlined pit remains justified. As such, the lessee or operator will receive no response from the District Engineer unless it is determined that the continued use of the unlined pit for disposal purposes is no longer warranted.

Date

Oil and Gas Supervisor
Eastern Area

APPROVED:

Russell G. Wayland
Acting Chief, Conservation Division

RECEIVED
JUL 2 1 1978
OFFICE OF
CONSERVATION MANAG
CENTRAL REGION

Course 7000.1
Instructors: Muller
Jackson
Murphy

RIPARIAN AREA MANAGEMENT

Objectives

(1) To introduce the topic of riparian area management from a Bureauwide, multiple resource perspective.

(2) To learn the hydrologic and geomorphic components of riparian condition.

(3) To learn concepts in stream riparian restoration.

(4). To discuss implementation of riparian restoration projects through field-level watershed activity plans.

(5) To be able to apply structural solutions, if appropriate, in gully restoration projects.

Topic Outline

I. Introduction to the Riparian Area Management Issue

II. Major Bureauwide activities in support of Riparian Area Management

III. Riparian Area Function: The hydrologic/geomorphic perspective

IV. Concepts in Stream Riparian Restoration

A. Incised Streams

B. Laterally Unstable Streams

V. Watershed Activity Plans for Riparian Restoration

A. Long Gulch

B. Elephant Skin Wash

VI. Gully Restoration

WATERSHED ACTIVITY PLANS

TOPIC OUTLINE

Presentation of two watershed Activity Plans that have been implemented in the BLM-Montrose District.

Brief Introduction to Activity Plans

I. Elephant Skin Wash Salinity Control - Watershed Activity Plan

A. Project Objectives

1. Retain salt and sediment
2. Flood control
3. Provide livestock and wildlife water
4. Increase vegetation cover
5. Improve wildlife habitat

B. Location and Setting

1. Activity Plan maps
2. Climate
3. Geology
4. Soils
5. Vegetation
6. Water

C. Project Identification

1. Major project components and reasons for the particular project design

D. Project Design

1. Hydrologic analysis
2. Project survey and construction

E. Clearances

1. Water rights
2. Cultural
3. T&E

F. Maintenance

1. Inspection/maintenance
2. Protection from livestock damage

G. Slide Show

H. Monitoring

1. Sediment
2. Salinity
3. Photo points
4. Flood control/livestock-wildlife water
5. Vegetation cover

II. Long Gulch Sediment Control and Riparian Habitat Improvement Project

A. Project Objectives

1. Reduce sediment yield
2. Improve riparian zone condition
3. Flood control
4. Increase vegetation production
5. Improve wildlife habitat
6. Provide water for livestock and wildlife

B. Location and Setting

1. Activity plan maps
2. Climate
3. Geology
4. Vegetation
5. Water

C. Problem identification and proposed treatments for 4 project sites

D. Design standards for proposed treatment of site I

1. Channel preparation
2. Check dam location and spacing
3. Check dam construction
4. Spillway sizing
5. Risk analysis

E. Clearances

1. Water rights
2. Cultural
3. T&E

F. Slide Show

G. Proposed monitoring

1. Channel cross sections
2. Longitudinal profile
3. Channel stability rating
4. Rainfall/runoff relationship
5. Photo points
6. Vegetation transects
7. Livestock exclosure

CONCEPTS IN STREAM RIPARIAN REHABILITATION[1/]

Bruce P. Van Haveren
Bureau of Land Management, Bldg. 50, Denver Federal Center,
P.O. Box 25047, Denver, Colorado 80225-0047; and

William L. Jackson
Bureau of Land Management, Bldg. 50, Denver Federal Center,
P.O. Box 25047, Denver, Colorado 80225-0047

ABSTRACT

In this paper we discuss the interrelationships between riparian systems and the hydrologic and geomorphic processes operating in the associated stream channels. We explain how the proper hydrologic function of the floodplain, stream-dependent water table, and stream channel erosion and deposition processes are all necessary for a healthy riparian ecosystem. These relationships form the basis for a discussion of rehabilitation principles and approaches recommended for use on degraded riparian areas. We introduce and discuss two types of channel conditions - incised streams and laterally unstable streams - which are commonly associated with degraded riparian areas. Proper identification of the causes of degradation and stage of channel evolution are required before developing a rehabilitation plan. We stress that stream riparian systems undergoing major geomorphic or hydrologic adjustments should not be treated with habitat improvements until the channel has reached a new dynamic equilibrium. Finally, riparian rehabilitation should not be attempted in stream systems where watershed condition is poor or downward-trending.

1/ Presented at the Wildlife Management Institute Fifty-First North American Wildlife and Natural Resources Conference, March 21-26, 1986, Reno, Nevada

CONCEPTS IN STREAM RIPARIAN REHABILITATION

Bruce P. Van Haveren

Bureau of Land Management, Bldg. 50, Denver Federal Center,

P.O. Box 25047, Denver, Colorado 80225-0047; and

William L. Jackson

Bureau of Land Management, Bldg. 50, Denver Federal Center,

P.O. Box 25047, Denver, Colorado 80225-0047

The purpose of this paper is to discuss the interrelationships between riparian systems and the hydrologic and geomorphic processes operating in the associated stream channels. We show how the proper hydrologic function of the floodplain, stream-dependent water table, and stream channel erosion and deposition processes are all necessary for a healthy riparian ecosystem. These factors and interrelationships are brought to bear in a discussion of rehabilitation principles and approaches for use on degraded riparian areas. We consider the stream riparian zone to be the entire active channel area including that portion of the floodplain which supports a riparian vegetation community.

RIPARIAN ZONES: GEOMORPHIC AND HYDROLOGIC FUNCTION

Stream riparian zones have important geomorphic and hydrologic roles which support their high level of biological productivity. The most productive stream riparian zones often are associated with alluvial stream systems. That is, they are deposition zones and occur in fluvial sediments transported and reworked by the stream. A major role of the riparian zone is to function as a floodplain and dissipate stream energies associated with high flows. This, in turn, permits sediments to deposit and continue development of the alluvial valley floor.

Alluvial riparian zones also function as shallow aquifers which recharge at high flows and drain at low flows. This interaction between surface flows and groundwater storage results in moderated high flows and enhanced, or prolonged base flows. The shallow aquifer condition also creates the moist soil conditions for plant growth, which characterize riparian zones.

Thus, it is the geomorphic and hydrologic characteristics of riparian zones which establish the basic components of biological habitat, including wet soils and instream structural features such as pools, riffles, gravels, and stream banks. The vegetation which thrives in riparian zones, in turn, contributes to their proper geomorphic and hydrologic functioning. Disruption of normal geomorphic or hydrologic function, or the vegetation on which it depends, usually results in impairment to overall riparian resource values.

STREAM CHANNEL ADJUSTMENTS AND RIPARIAN CONDITION

Stream channels, in association with adjacent riparian zones, adopt forms and normal modes of function which allow water and sediment to be discharged efficiently (Leopold and Langbein, 1962; Yang, 1971). Stream channel form, in turn, contributes to the physical and biological makeup of the riparian system (Brussock et al., 1985). Variables such as channel slope, channel and floodplain shape, and hydraulic geometry reflect long-term watershed conditions, but adjust continuously in response to changes in controlling factors such as discharge, sediment delivery, or changes in channel bed or bank conditions (Schumm, 1971). Three classes of channel adjustments influence riparian conditions:

Channel evolution: Channel evolution refers to channel adjustments, usually at the geologic time scale, which occur as part of overall landscape evolution (Schumm, 1956; Strahler, 1968). In an analysis of rehabilitation potential, it is important to relate channel and riparian conditions to their evolutionary status and to identify potential threshold conditions (Bull, 1979).

Rapid channel response: Rapid channel response refers to channel adjustments which occur rapidly in response to sudden changes in the long-term equilibrium condition of controlling factors, or to the exceedence of critical geomorphic thresholds. For example, sudden changes in discharge, sediment delivery, or channel/floodplain conditions may initiate periods of excessive channel instability and adjustment (Heede, 1980; Harvey et al., 1985). Also, more gradual changes resulting from channel evolution eventually may cause exceedence of a stability threshold for slope or base-level elevation which in turn initiates periods of rapid adjustment--for example, downcutting--throughout the channel network (Schumn, 1977; Bull, 1979). Instream structures associated with stream riparian rehabilitation projects may establish new critical or threshold conditions that may initiate adjustments within the channel system (Heede, 1986).

Normal channel dynamics: Normal channel dynamics refers to adjustments which occur as part of normal channel/riparian function under dynamic equilibrium conditions. Channels and adjacent riparian areas continuously undergo incremental or periodic adjustments under normal high flow conditions (Heede, 1975; Jackson and Beschta, 1982). This is because the main external factors acting on the system--discharge and sediment delivery rates--are highly irregular over short timeframes, even though long-term average conditions of discharge and sediment delivery may be fairly stable. Channel adjustments associated with conditions of dynamic equilibrium include incremental bank cutting, cycles of streambed scour and fill, and adjustments to normal inputs of large organic debris. In addition, flood flows and riparian areas interact to cause sediment deposition on floodplains. Many biological systems are dependent upon normal channel and floodplain adjustments associated with dynamic equilibrium systems (e.g., Coats et al., 1985). Thus, it may be important to avoid excessive rigidity in rehabilitating stream riparian systems.

Most channel adjustments involve interactions with stream riparian zones. Normal adjustments associated with dynamic equilibrium processes may serve to enhance or rejuvenate riparian conditions. Excessive adjustments, associated with rapid response to changes in controlling factors, may temporarily or permanently impair normal riparian conditions.

REHABILITATION APPROACHES

Stream riparian rehabilitation requires (a) description or classification of riparian area degradation, (b) identification of the cause(s) of impaired riparian conditions, and (c) formulation and implementation of riparian rehabilitation objectives and strategies which allow reestablishment of a viable and sustainable riparian condition. This last requirement may be especially challenging since the rehabilitation objective--especially in the case of large, incised channels or arroyos--may not be to reestablish the former riparian situation, but to establish a new equilibrium condition that supports a viable riparian zone.

In general, impairment of riparian condition is characterized by either excessive channel incision and the subsequent dewatering of the riparian zone, or direct destruction of riparian vegetation with the subsequent loss of channel bank and floodplain integrity and the acceleration of lateral channel adjustments. The nature of riparian impacts and the concepts in riparian rehabilitation are different for these two classes of impaired riparian function.

Impaired Water Table Function: The Case of the Incised Channel

Deeply incised drainages occur throughout the world and are particularly common in arid and semiarid deserts and rangelands. In the western United States, large gullies and arroyos commonly occur in fine-grained, deep alluvial deposits, and are characterized by unresistant beds and steep fine-grained banks. Incised channels result from either downstream base-level lowering or localized gullying initiated by increased runoff rates or lowered resistance to erosion. In semiarid regions, gully initiation occurs when the erosional threshold is exceeded--usually at the steepest portion of the valley (Schumm, 1969). When base-level lowering is triggered in a stream system, channel incision progresses upstream into all tributaries unless stopped by a resistant geologic structure (Heede, 1981a). Channel incision produces two important changes which affect the associated riparian system. Advancing gully systems increase peak discharge (Wallace and Lane, 1976), making the stream very efficient at scouring channel beds and banks and transporting sediment. Channel bed degradation produces a drop in the local water table and imposes a subsequent water stress on the riparian vegetation (Groeneveld and Griepentrog, 1985). A loss of riparian vegetation in turn produces additional hydrologic changes--lowered resistance to flow and therefore higher flow velocities during flood events (Schumm and Meyer, 1979). Channel incision, then, often leads to impaired hydrologic function of the stream system as well as impaired resource values of the riparian ecosystem.

While small gullies may undergo cycles of cutting and filling, large gullies and arroyos undergo a more complex evolution (Harvey et al., 1985). The evolution of medium to large gullies and arroyos is depicted in Figure 1. Properly analyzing where a gully or incised channel is in its cycle of development helps considerably in the assessment of management alternatives. Also, a gully that develops in response to a general base-level adjustment is more difficult to control than a discontinuous gully that is reacting to local watershed conditions.

Referring to Figure 1, channels in Condition A are not incised and often support a productive riparian resource. The key to the management of Condition A channels is to determine their susceptibility to incision (Schumm, 1969; Harvey et al., 1985), then manage land uses to prevent incision. Management may be best accomplished in these situations by controlling intensive land uses, such as concentrated livestock grazing, in the riparian zone as well as contributing upland areas. Low (flush with the bed) instream base control structures or upstream detention structures (combined with improved upland watershed management) can contribute to the stability of Condition A channels. Also, proper management of large organic debris in the riparian zone can contribute to the maintenance of proper channel slope and instream sediment storage (Heede, 1985; Swanson and Lienkaemper, 1978). If incision is likely to occur as a result of base-level adjustment, a barrier dam or drop structure may be necessary to stop headward migration of the incision. Generally, prevention of incision is a very cost-effective stream management practice (Heede, 1986).

Condition B channels are recently incised and are characterized by narrow steep banks. If the gully is small, appropriate land use management may allow reestablishment of a Condition A channel. Combining land use management with installation of gully plugs may hasten the recovery of small Condition B channels (Heede, 1981b). If the gully is large, and especially if it has not reached a firm or resistant bed level, properly designed structures will be very expensive to install, and the feasibility of returning to a Condition A channel is greatly reduced. Furthermore, large Condition B channels will be the least responsive of all incised channel conditions to improved land use management, including rest from livestock grazing.

Condition C channels are in the early stages of widening--a prerequisite to stabilization and reestablishment of a riparian resource. In essence they are midway between the stable conditions exemplified by Conditions A and E. If a resistant base level has been reached, a reasonably stable channel condition may be achieved simply by promoting establishment of a dense cover of bank vegetation. If livestock grazing is limiting riparian vegetation establishment, intensive management must be applied, such as the creation of riparian pastures or the implementation of grazing systems that favor riparian vegetation maintenance. Flood flows, however, will still erode the upper banks until a stable flood flow channel can be established. While bank controls such as jacks or loose rock revetments could be used at critical situations in Condition C channels, they would be resisting natural widening tendencies and may not be cost effective. Base controls would have to be carefully designed and installed to confine flood flows or they would be breached at the ends (Figure 2). Furthermore, a reestablished riparian resource in a Condition C channel may have less ultimate value than a riparian resource reestablished in the more naturally stable Condition D or E channel. A final alternative for Condition C channels would be to try to return them to Condition A, if the resource values justified it. Although it would be expensive, barrier dams or base controls could be considered.

It may be possible to successfully establish beaver in Condition C channels. Beaver transplanting has been used to restore riparian conditions in southwestern Wyoming (Brayton, 1984).

The most effective management strategy for Condition D and E channels is to passively allow for vigorous reestablishment of streambank and riparian vegetation. Some upper floodplain control on point bars or in abandoned flood flow channels, or bank control on outer meander banks may be justified in certain situations in Condition D channels. Generally, structures, except possibly those for fish habitat improvement, would not be warranted in Condition E channels. Management of land use in Condition D and E channels will often be a very cost-effective treatment.

Impaired Channel Bank and Floodplain Function: The Case of the Laterally Unstable Channel

The second type of impaired riparian function occurs on streams with relatively stable beds when streamside riparian vegetation is directly impacted by land use in the riparian zone. Changes in vegetation composition and reductions in vegetation cover, vigor, or production, which may result from concentrated livestock grazing, timber harvesting, or road construction, directly alter the structural integrity of stream banks and floodplains. This, in turn, encourages excessive channel adjustments which further impact the riparian zone. Unlike channels in fine, deep alluvium which are prone to incision, coarse alluvial channels, or channels with structurally controlled beds, tend to respond to direct riparian impacts by becoming wider and shallower with less steep banks (Figure 3) (Kauffman et al., 1983; Duff, 1977; Platts, 1981a; Platts, 1981b). In addition to possessing poor aquatic habitat attributes (Kauffman et al., 1984; Platts, 1981b; Platts, 1981c) channels impacted in this way may become less capable of conveying high flows and may directly impact riparian areas by bank cutting or channel realignment during high flow periods. Riparian area problems caused by this type of channel condition are aggravated by increased instream sediment loads resulting from upstream erosion (Jackson and Beschta, 1984).

Riparian zones characterized by widened channels, frequent channel re-alignments, and poorly vegetated banks and floodplains, generally can be rehabilitated rapidly by revegetation of the riparian streamside zone provided that soil water in the riparian zone has not been affected by excessive channel incision. The management objective in this case is almost always to establish a Condition Z Channel (Figure 3). For stream riparian areas impacted by livestock grazing, for example, elimination or reduction of livestock grazing in the riparian zone generally results in quick and dramatic recovery (Platts and Rinne, 1985)(Figure 4). Other potentially effective riparian management strategies include implemen-tation of deferred grazing systems, adjusting season of grazing use, creation of riparian pastures, development of off-site water sources, and drift or corridor fences.

Restoration of riparian vegetation through land use management is the preferred method for rehabilitating this class of impaired stream riparian area. However, more active management may be required in certain circumstances. This is particularly true when riparian conditions are no longer amenable to rapid revegetation by passive means--either because the soil resource has been removed, normal sources of large debris are absent, or the stream system itself has become too unstable to permit successful revegetation within an acceptable time frame. In this situation, structural techniques including channel bank erosion controls and proper grading of floodplains may contribute to improved conditions for revegetation. In the extreme case, channels may actually be reconstructed using proper hydrologic, hydraulic, and geomorphic criteria to establish conditions conducive to establishment of vigorous vegetation (Jackson and Van Haveren, 1984; Orsborne et al., 1985). The objective in any sort of structural solution should always be to provide the conditions necessary for natural revegetation and evolution to a properly functioning stream riparian system which will quickly become stable on its own, independent of rigid man-made structures.

MANAGEMENT CONSIDERATIONS

The overriding consideration in planning a riparian rehabilitation program is to determine the rehabilitation potential of the target area and identify the root causes of the degraded riparian condition. If the causes are due to upstream watershed disturbances, those areas should be stabilized so that riparian rehabilitation can proceed without interference (Jackson and Van Haveren, 1984). If the disturbance is due to land-use management conflicts, those conflicts must be resolved before an improvement project is initiated. Stream riparian rehabilitation should not be used to circumvent the real causes of stream degradation (Platts and Rinne, 1985).

In addition, we cannot overemphasize the need to understand and work with the natural recovery processes operating in a stream riparian system (Cairns et al., 1979). Rehabilitation should strive to establish the physical and biological conditions that favor rapid recovery by natural processes (U.S. Dep. Transport., 1979; Jackson and Van Haveren, 1984; Platts and Rinne, 1985; Hasfurther, 1985). Finally, stream riparian systems undergoing major adjustments should not be treated with habitat improvements until the channel has reached a new dynamic equilibrium.

Once it is determined that conditions warrant a rehabilitation program, rehabilitation objectives need to be carefully formulated. The objectives should consider existing and future watershed condition, hydrologic regime, and the desired rate of recovery. If time is not an important consideration and watershed and channel stability are favorable, then a passive approach to rehabilitation--simply letting nature take its course--may be the best alternative.

Generally, three questions should guide the formulation of recommendations for the use of structures in channel/riparian restoration projects. First, will the structure permit the system to reach a condition of natural stability more rapidly than can be achieved passively (i.e., without structures)? Second, are the benefits achieved by accelerated rehabilitation sufficient to justify the costs? Third, will the achieved condition be self-sustaining, as opposed to being dependent upon the integrity of the structure? In most cases, the answer to all three questions should be yes.

SUMMARY AND CONCLUSIONS

Because all stream riparian systems are unique, stream riparian rehabilitation should be approached systematically using problem-solving techniques. The specific causes of riparian degradation should be ascertained. We believe that riparian degradation is generally associated with one of two different types of channel conditions--lateral instability or stream incision. These conditions must be identified and dealt with first in any proposed rehabilitation project. Treatment methods should work with, not against, the natural channel adjustment processes. If the stream channel is evolving towards a new stage of dynamic equilibrium and watershed condition is static or improving, riparian rehabilitation may simply involve no more than waiting for the natural healing processes to work.

REFERENCES CITED

BRAYTON, D.S. 1984. The beaver and the stream. J. Soil and Water Cons. 39(2):108-109.

BRUSSOCK, P.P., A.V. BROWN, and J.C. DIXON. 1985. Channel form and stream ecosystem models. Water Resources Bulletin 21(5):859-866.

BULL, W.B. 1979. Threshold of critical power in streams. Geol. Soc. Amer. Bull. Part I, V. 90. pp. 453-464.

CAIRNS, J., Jr., J.R. STAUFFER, Jr., and C.H. HOCUTT. 1979. Opportunities for maintenance and rehabilitation of riparian habitats: eastern United States. In Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, R.R. JOHNSON and J.F. McCORMICK, eds., pp. 304-317. USDA Forest Service General Technical Report WO-12, Washington, D. C.

COATS, R., L. COLLINS, J. FLORSHEIM, and D. KAUFMAN. 1985. Channel change, sediment transport, and fish habitat in a coastal stream: Effects of an extreme event. Environ. Management 9(1): 35-48.

DUFF, D.A. 1977. Livestock grazing impacts on aquatic habitat in Big Creek, Utah. Presented at the Workshop on Livestock and Wildlife - Fisheries Relationships in the Great Basin, Sparks, NV. May 3-5, 1977.

ELLIOTT, J.G. 1979. Evolution of large arroyos - the Rio Puerco of New Mexico. Unpub. M.S. Thesis, Colorado State University, Fort Collins. 106 p.

GROENEVELD, D.P. and T.E. GRIEPENTROG. 1985. Interdependence of ground-water, riparian vegetation, and streambank stability: a case study, pp. 44-48. In JOHNSON, R.R., C.D. ZIEBELL, D.R. PATTON, P.F. FFOLLIOTT, and R.H. HAMRE, tech. coords. Riparian ecosystems and their management: reconciling conflicting uses. General Technical Report RM-120. USDA Forest Service, Fort Collins, CO. 523 p.

HARVEY, M.D., C.C. WATSON, and S.A. SCHUMM. 1985. Gully Erosion. USDI Bureau of Land Management Technical Note 366. Service Center, Denver, Colorado. 181 p.

HASFURTHER, V.R. 1985. The use of meander parameters in restoring hydrologic balance to reclaimed stream beds. In The Restoration of Rivers and Streams, pp. 21-40, J. A. Gore (Ed.). Butterworth Publishers, Stoneham, Mass. 280 p.

HEEDE, B.H. 1975. Mountain watersheds and dynamic equilibrium. In Watershed Management, pp. 407-420. Amer. Soc. Civil Engineers, New York, New York.

------. 1980. Stream dynamics: An overview for land managers. USDA Forest Service General Technical Report RM-72, Ft. Collins, Colorado. 26p.

------. 1981a. Analysis and guidelines for watershed rehabilitation, pp.103-117, In Proceedings, Symposium on Watershed Rehabilitation in Redwood National Park and other Pacific Coastal Areas, R. N. Coats (Ed.) 360 p.

------. 1981b. Rehabilitation of disturbed watersheds through vegetation treatment and physical structures. In Interior West Watershed Management, pp. 257-268, D.M. Baumgartner (Ed.), Washington State University Cooperative Extension, Pullman, Washington.

------. 1985. Interactions between streamside vegetation and stream dynamics, pp. 54-58. In JOHNSON, R.R., C.D. ZIEBELL, D.R. PATTON, P.F. Ffolliott, and R.H. HAMRE, tech. coords. Riparian ecosystems and their management: reconciling conflicting uses. General Technical Report RM-120. USDA Forest Service, Fort Collins, CO. 523 p.

------. 1986. Designing for dynamic equilibrium in streams. Water Resources Bulletin (In Press).

JACKSON, W.L. and R.L. BESCHTA. 1982. A model of two-phase bedload transport in an Oregon coast range stream. Earth Surface Processes and Landforms, 7(6): 517-527.

JACKSON, W.L. and B.P. VAN HAVEREN. 1984. Design for a stable channel in coarse alluvium for riparian zone restoration. Water Resources Bulletin 20(5): 695-703.

KAUFFMAN, J. BOONE, AND W.C. KRUEGER. 1984. Livestock impacts on riparian ecosystems and streamside management implications - A Review. Journal of Range Management 37(5): 430-438.

------, ------, and M. VAVRA. 1983. Impacts of cattle on streambanks in Northeastern Oregon. Journal of Range Management 36(6): 683-685.

LEOPOLD, L.B., and W.B. LANGBEIN. 1962. The concept of entropy in landscape evolution. U.S. Geol. Surv. Prof. Pap. 500-A.

ORSBORNE, J.F., K. AMERMAN, B. CLARK, K. COULTON, B. NAIK, and J. STYPULA, 1985. Crooked River Habitat Improvement Project Final Report, R.L. Albrook Hydraulics Laboratory, Washington State University, Pullman, Wash. 111 p.

PLATTS, W.S. 1981a. Streamside management to protect bank-channel stability and aquatic life. In Interior West Watershed Management, pp. 245-256, D.M. Baumgartner (Ed.). Washington State University Cooperative Extension, Pullman, Washington.

------. 1981b. Effects of sheep grazing on a riparian-stream environment. USDA Forest Service Research Note INT-397. 6pp.

------. 1981c. Sheep and cattle grazing strategies on riparian-stream environments. In Proceedings of Wildlife-Livestock Relationships Symposium, University of Idaho, Moscow, Idaho, April 20-22. pp. 251-270.

PLATTS, W.S. and J.N. RINNE. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. North American Journal of Fisheries Management 5(2A): 115-125.

SCHUMM, S.A. 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. America Bull. 67: 597-646.

------. 1969. A geomorphic approach to erosion control in semiarid regions. Trans. of the ASAE 12:60-68.

------. 1971. Fluvial geomorphology: Channel adjustment and river metamorphosis In River Mechanics, H.W. SHEN (Editor), Vol. I, pp. 5-1 to 5-22, Ft. Collins, Colorado.

------. 1977. The Fluvial System. John Wiley and Sons. New York, New York. 338p.

SCHUMM, S.A. and D.F. MEYER. 1979. Morphology of alluvial rivers of the Great Plains. In Riparian and Wetland Habitats of the Great Plains, pp. 9-14. Proceedings of the 31st Annual Meeting of the Forestry Committee, Great Plains Agricultural Council. Great Plains Agric. Counc. Publ. No. 91, 88 p.

STRAHLER, A.N. 1968. Quantitative geomorphology. In Encyclopedia of geomorphology. R. Fairbridge (Editors). Reinhold Book Corp., New York, pp. 898-912.

SWANSON, F.J. and G.W. LIENKAEMPER. 1978. Physical consequences of large organic debris in Pacific Northwest streams. USDA Forest Service General Technical Report PNW-69, 12 p.

U. S. DEPARTMENT OF TRANSPORTATION. Federal Highway Administration. 1979. Restoration of fish habitat in relocated streams. FHWA-1P-79-3. 63 p.

WALLACE, D.E. and L.J. LANE. 1976. Geomorphic thresholds and their influence on surface runoff from small semiarid watersheds, pp. 169-176. In Hydrology and Water Resources in Arizona and the Southwest, Volume 6. Arizona Academy of Science, Tucson.

YANG, C.T. 1971. Potential energy and stream morphology. Water Resour. Res. 7(2): 311-322.

FIGURE CAPTIONS

Figure 1. Hypothetical sequence of arroyo evolution (after Elliott, 1979).

Figure 2. Inappropriate design and placement of a low check dam in a Condition C channel.

Figure 3. Hypothetical sequence of non-incised stream channel evolution from laterally unstable (X) to laterally stable condition (Z).

Figure 4. Rest from livestock grazing restored a Condition Z channel.

Figure 1

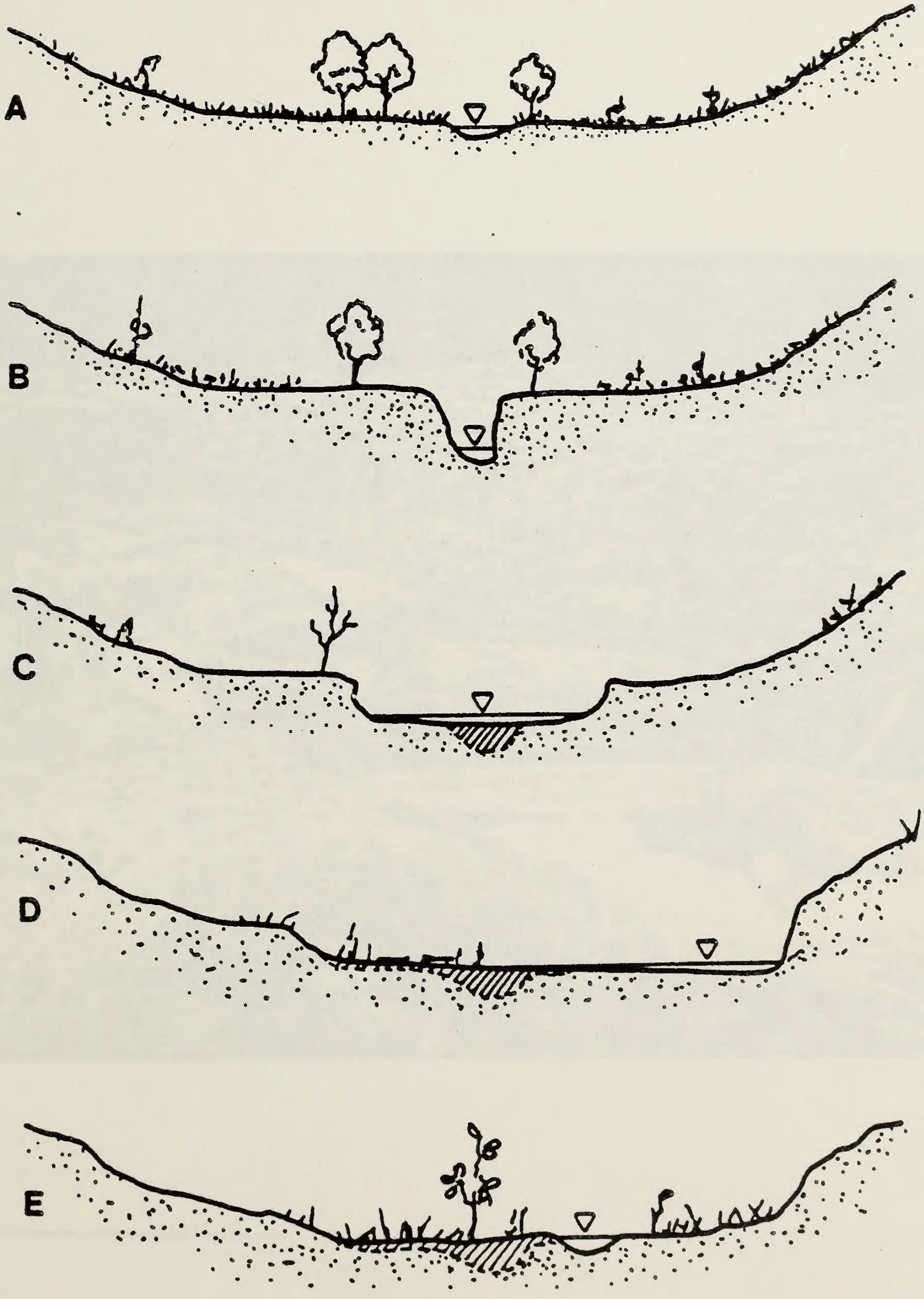


Figure 2

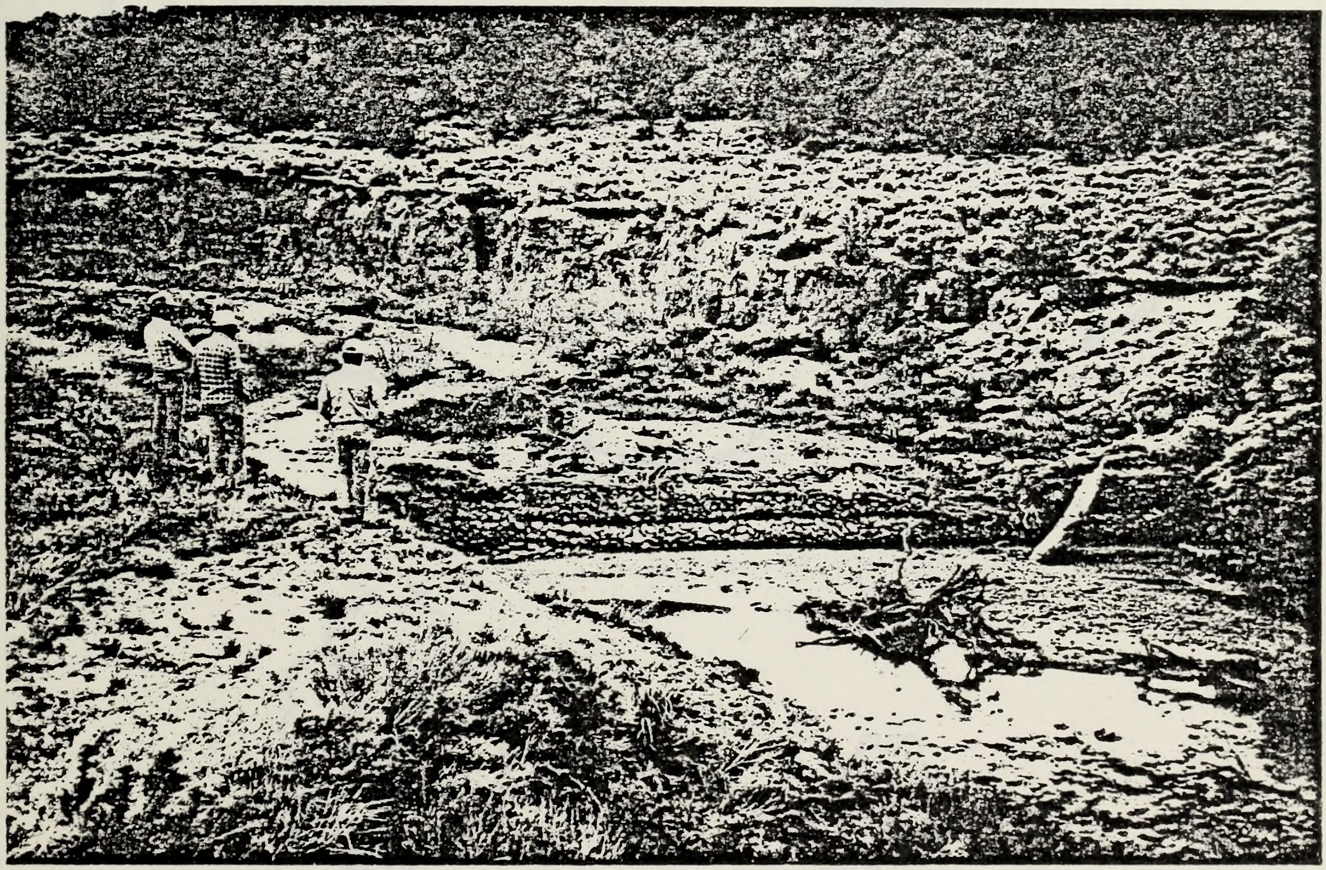


Figure 3

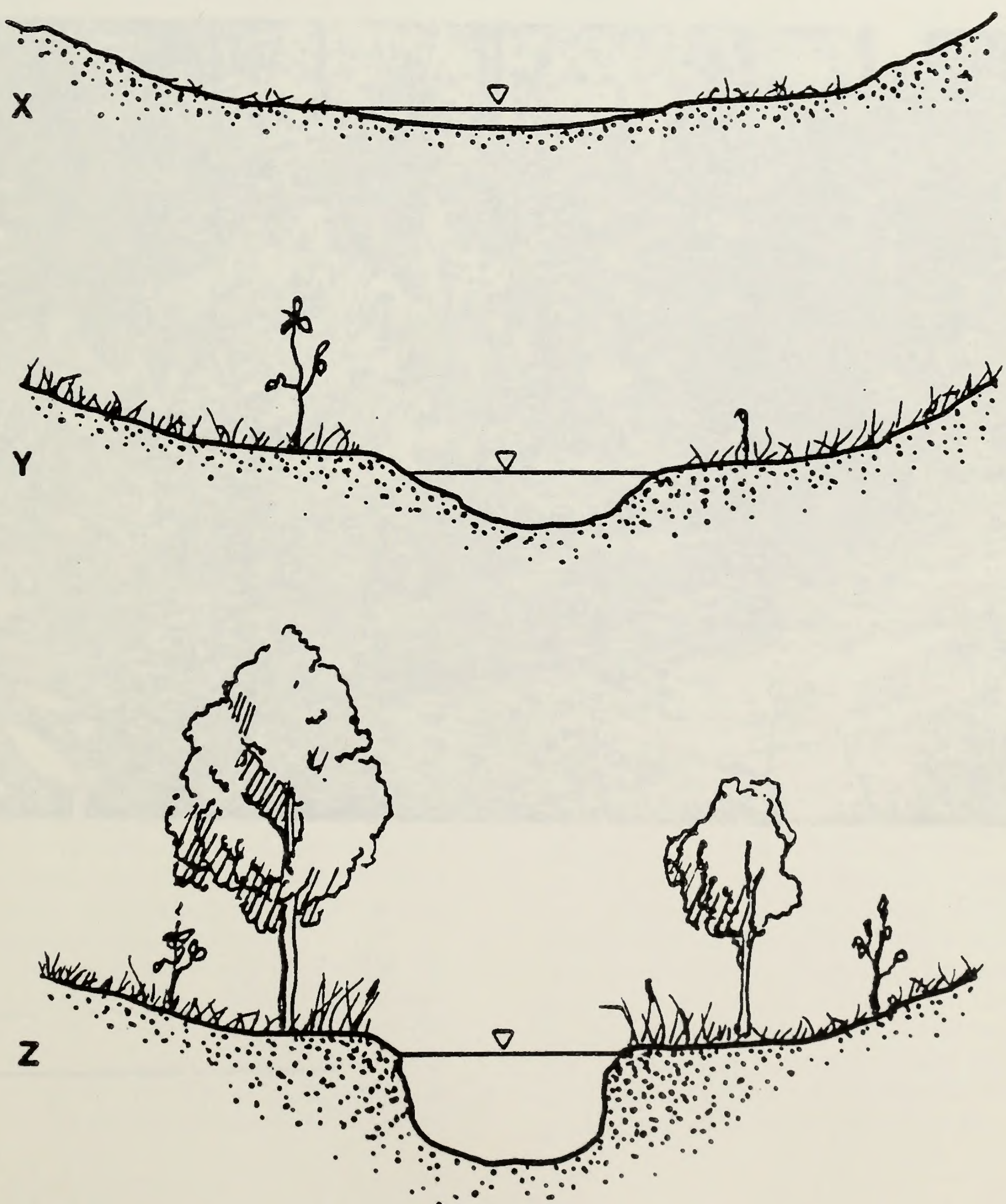


Figure 4

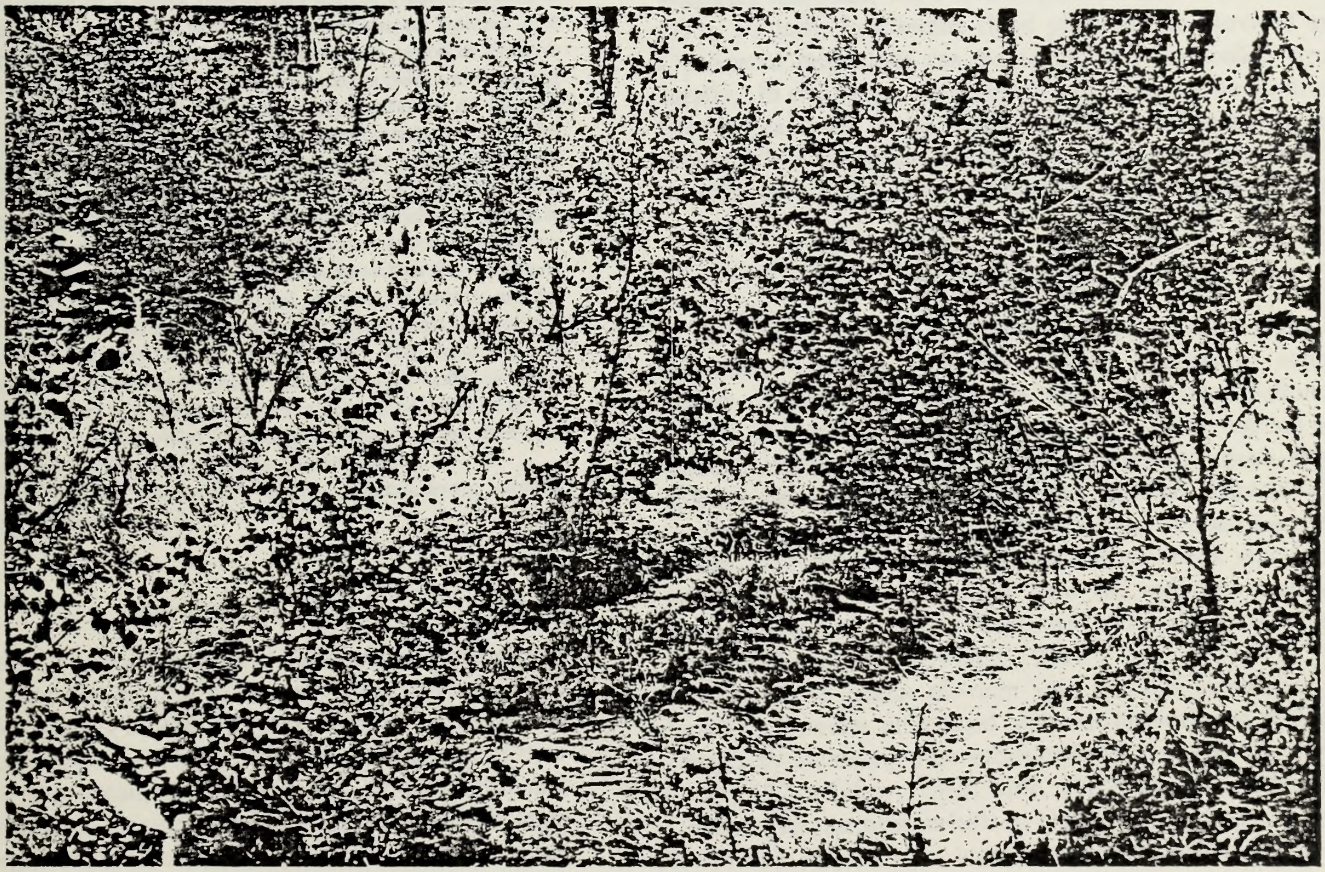


Figure 4

WATER RESOURCES BULLETIN
VOL. 20, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 1984

DESIGN FOR A STABLE CHANNEL IN COARSE ALLUVIUM FOR RIPARIAN ZONE RESTORATION[1]

William L. Jackson and Bruce P. Van Haveren[2]

ABSTRACT: Geomorphic, hydraulic and hydrologic principles are applied in the design of a stable stream channel for a badly disturbed portion of Badger Creek, Colorado, and its associated riparian and meadow complexes. The objective is to shorten the period of time required for a channel in coarse alluvium to recover from an impacted morphologic state to a regime condition representative of current watershed conditions. Channel geometry measurements describe the stream channel and the normal bankfull stage in relatively stable reaches. Critical shear stress equations were used to design a stable channel in noncohesive materials with dimensions which approximate those of less disturbed reaches. Gabion controls, spaced at approximately 300 m intervals, are recommended to help reduce the chance of lateral migration of the newly constructed channel. Controls are designed to allow for some vertical adjustment of the channel bed following increased bank stability due to revegetation. The flood plain is designed to dissipate flood flow energy and discourage multiple flood channels. The channel has approximately a 90 percent chance of remaining stable the first two years following construction, the time estimated for increased stability to occur due to revegetation.
(KEY TERMS: riparian restoration; stream rehabilitation; alluvial channels, stable channels.)

INTRODUCTION

The Bureau of Land Management has studied the restoration of a badly degraded portion of Badger Creek, located 17 km northeast of Salida, Colorado (Figure 1). The objective was to develop and implement a plan to shorten the period of time required for the stream channel and associated riparian and meadow complexes to evolve from an impacted morphologic state to a regime condition representative of current watershed conditions. A more stable stream channel is believed to be a prerequisite to reestablishment of channel bank and flood plain vegetation. In turn, revegetation is a requirement for a properly functioning stream-riparian system.

The purpose of this paper is to apply geomorphic, hydraulic, and hydrologic principles in a design for a non-rigid channel which will allow for the restoration of the riparian system at the project site. We hypothesize that a channel designed according to these principles, with dimensions approaching as closely as possible the present regime hydraulic geometry, but consistent with the stability requirements of coarse, unvegetated materials, will evolve to a stable, natural condition if (1) a properly functioning flood plain can be provided and (2) laterial migrations can be temporarily controlled structurally. In our design, we attempted to achieve a compromise between excessive project costs and risk of failure due to high flows. While the design procedure has been made as general as possible, each project situation must be analyzed individually.

BACKGROUND

Flow (Qw) and sediment discharge (Qs) are the primary independent variables influencing the morphology of natural stream channels with adjustable beds and banks (Schumm, 1971). Adjustable channels tend to have stable regimes and adjust variables such as cross-sectional area and shape, slope, channel patterns, bedforms and bed material characteristics to accommodate long-term patterns of water and sediment discharge. A third independent variable, streambank vegetation, influences bank stability, flood flow and sediment transport characteristics and also affects the morphology of stream channels (Parsons, 1965; Platts, 1981).

Channels in coarse alluvium with erodible banks may respond to increases in bedload sediment delivery and peak discharges by increasing their width-to-depth ratio (Nevins, 1969; Grant, 1977; Kelsey, 1980; Lisle, 1982; Lyons and Beschta, 1983). This, in turn, results in higher flow resistance (Lisle, 1982) and may – if changes in sediment regime dominate changes in flow regime – cause a decrease in capacity to convey flood flows. In the extreme case, channel widening may lead to multiple flood flow channels and braiding (Heede, 1980). Extreme channel instability, frequent lateral migration, and inability to effectively convey upstream inputs of water and sediment are characteristics of these channels. The extreme conditions which cause channel morphology changes may result in decreased channel stability under more common flow levels (e.g., small to moderate floods) (Lisle, 1982). The result is that the channel may not return promptly to its

[1]Paper No. 84071 of the *Water Resources Bulletin.* Discussions are open until June 1, 1985.
[2]U.S. Dept. of the Interior, Bureau of Land Management, Division of Resource Systems, Denver Service Center, Denver Federal Center, Denver, Colorado 80225.

predisturbance regime conditions. Both instream and riparian characteristics, therefore, may be altered for a period of time much longer than the watershed disturbance which caused the impact.

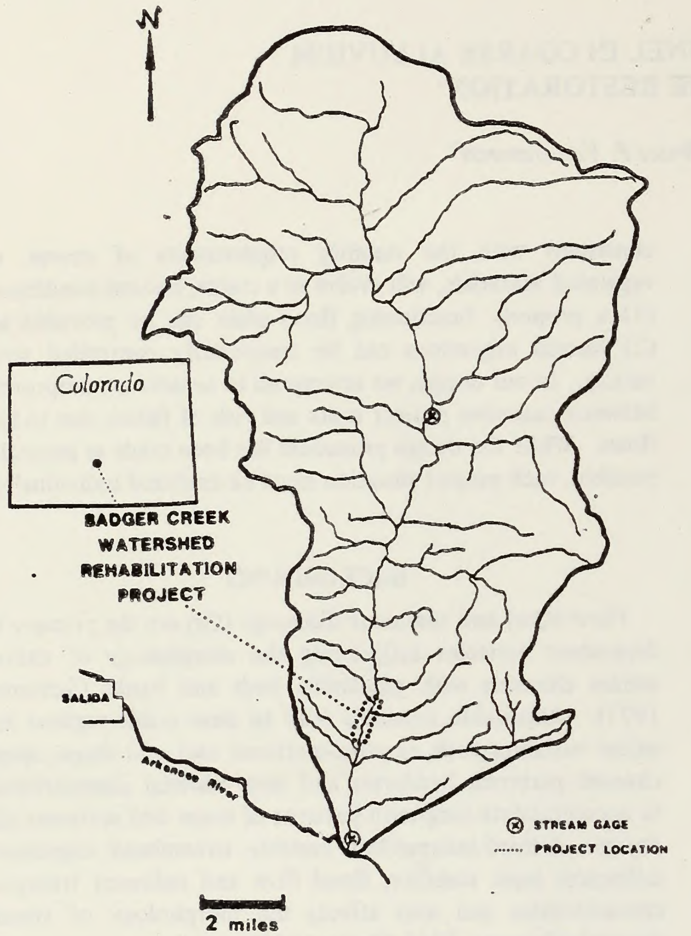


Figure 1. Badger Creek Location Map.

A channel in erodible material is considered stable if design discharges and sediment loads can be conveyed without causing bank or bed erosion or deposition more than normally associated with a regime condition. Stable channel designs must take into consideration (1) channel capacity, (2) channel geometry, and (3) bed and bank stability (Doubt, 1965).

Channel capacity requirements are determined by hydrologic analyses and are expressed as design discharges. Channel geometry relates to factors such as cross-sectional shape, channel patterns, slope and flood plain topography, and represents the integrated response of channel geometry variables to Qw and Qs. Generalized relationships between hydrologic, hydraulic, and geometric variables have been developed (Leopold and Maddock, 1953). However, the variables in these relationships cannot be solved deterministically except in the case of a triangular channel (Lane and Foster, 1980). Present regime channel geometry, therefore, must be surmised from available evidence.

Bed and bank stability refer to the requirements for a channel to convey flows and bed material without undergoing long-term net changes in hydraulic geometry. Stability does [illegible]quire immobility. In fact, it is assumed that natural c[illegible]l function will involve a mobile bed condition and localized fluctuations in geometry about a long-term stable average (Andrews, 1982; Jackson and Beschta, 1982). Bed and bank stability can be quantified using hydraulic and sediment transport design procedures.

Since we assume there will be an initial incompatibility between the desired channel geometry and bed and bank stability requirements, a fourth consideration in stable channel design is required. The process of adjustment from the initial stable channel geometry in noncohesive materials to the final regime geometry must be analyzed. In general, channel widening will occur when either Qw or Qs, or both, increase (Schumm, 1971). Channel depth will decrease when Qs increases but will increase with an increase in Qw. Thus, one can deduce that channels which have become wider and shallower have been subject to increases in Qs. In cases where upstream watershed disturbances caused the channel changes, it is also likely that increases in Qw have been experienced, but the tendency for channel deepening in response to increased water discharges may be masked if the effects of increased sediment discharge are dominant. Thus, when conditions which caused channel impacts have abated, the direction of adjustment in channel geometry will be towards somewhat narrower, deeper channel cross-sections with steeper ch[illegible] banks. This tendency will be enhanced when revegetatio[illegible] banks causes an increase in apparent cohesion and an increase in bank stability relative to beds.

PROJECT AREA

The Badger Creek watershed is 569 km^2 with steep slopes and generally shallow soils. High rates of runoff and erosion occur during summer convectional storms. Total watershed relief is 1490 m. Vegetation is primarily pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteosperma*) at lower elevations. Aspen (*Populus tremuloides*), grasses, and forbs are found at higher elevations. Average annual basin precipitation is 409 mm. A flood frequency curve (Figure 2) was developed for the Badger Creek project site using regional relationships and procedures described by Hedman and Osterkamp (1982) and McCain and Jarrett (1976). That curve, plus analysis of stream gage data collected at two U.S. Geological Survey gaging stations (station numbers 7093740 upper; 7093775 lower) (Figure 1), suggest that large, infrequent peak flows in excess of 280 m^3s^{-1} do occur. A large spring, located just upstream from the upper gaging station, contributes a fairly constant base flow of approximately 0.14 m^3s^{-1}. The perennial flow is one reason Badger Creek has a resident brown trout fishery.

The lower Badger Creek project area was a broad, gen[illegible] sloping alluvial meadow which had been eroded as a result [illegible] a stream channel system which became more active than its historic norm. This was probably caused by changes in watershed conditions due to overgrazing, timber harvest, road building and mineral exploration which resulted in increased sediment delivery, and possibly increased frequency of large peak flows. Also, reduced vegetative cover due to livestock grazing may have caused on-site decreases in bank stability. The project site on lower Badger Creek presently consists of considerable coarse material (gravel, cobbles, boulders), small berms, and abandoned channels (Figure 3). The active channel is poorly developed, and supports no bank vegetation. Because of an extremely permeable bed, the flow becomes intermittent over the 1.7 km length of channel in the project area. This results in the periodic elimination of all fish habitat within the project area during low flow months (August and September).

There is indication that watershed conditions have improved in recent years. Certain reaches of Badger Creek have begun to restabilize as grasses, willows and cottonwoods begin to invade the wetter streamside sites. This is particularly pronounced within 300 m upstream or downstream of reaches where natural controls (e.g., rock outcrops) prohibit lateral migration of the channel. If left alone, the project site may eventually restabilize and reclaim itself; we do not know the time required for this to occur.

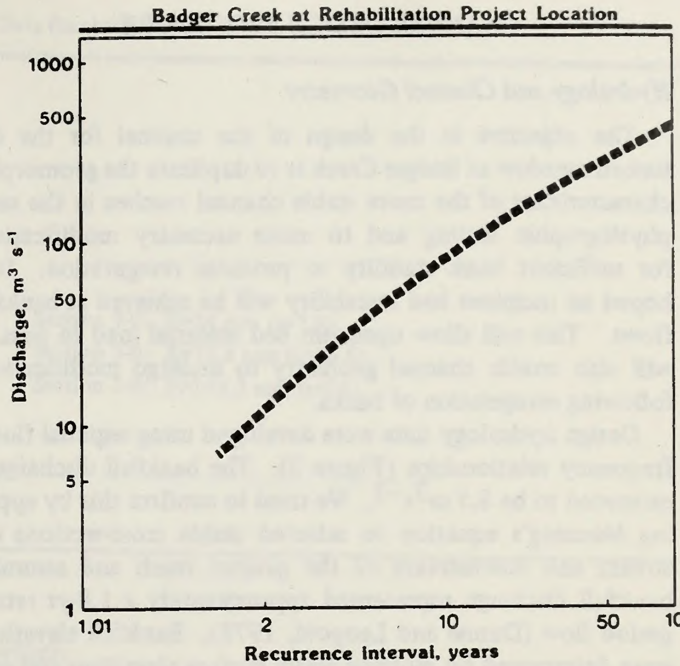


Figure 2. Flood Frequency Curve for Badger Creek Project Site (based upon regional relationships).

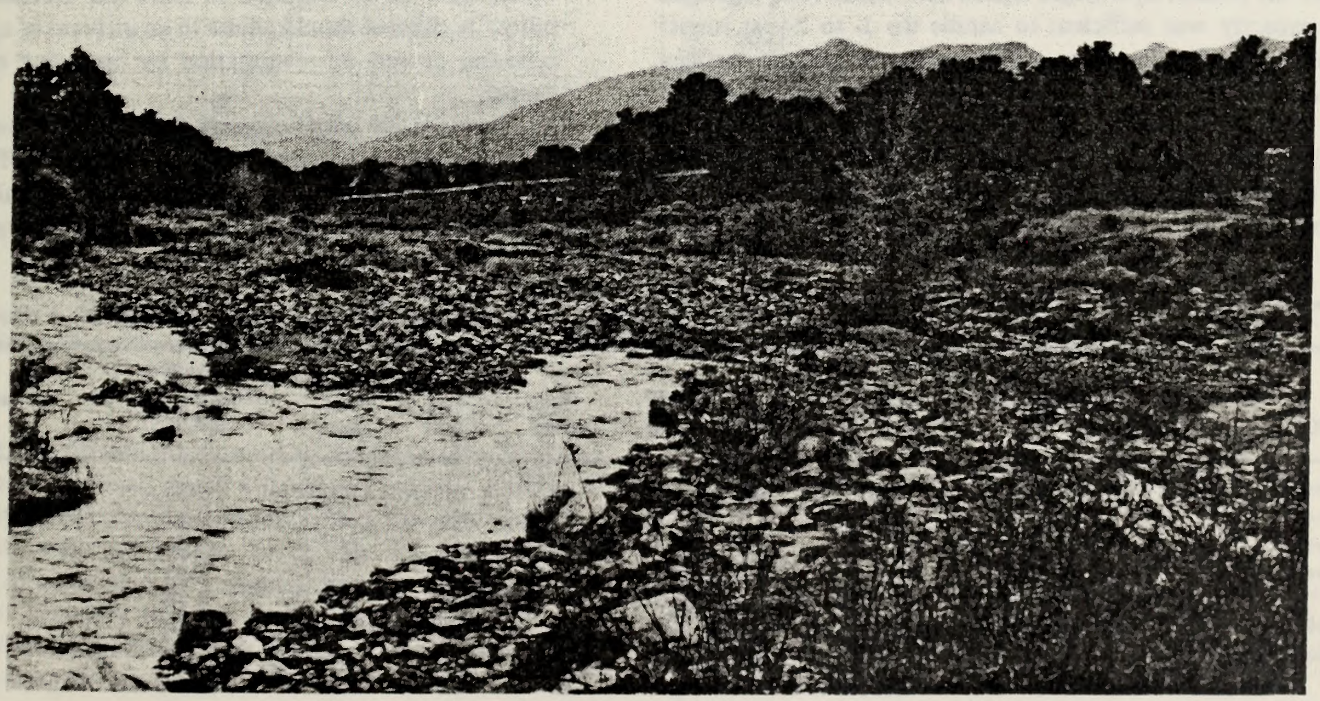


Figure 3. Photograph of Badger Creek in Project Site.

CHANNEL DESIGN PROCEDURE

Hydrology and Channel Geometry

The objective in the design of the channel for the disturbed meadow at Badger Creek is to duplicate the geomorphic characteristics of the more stable channel reaches in the same physiographic setting and to make necessary modifications for sufficient bank stability to promote revegetation. It is hoped an incipient bed instability will be achieved at bankfull flows. This will allow upstream bed material load to pass. It will also enable channel geometry to undergo modifications following revegetation of banks.

Design hydrology data were developed using regional flood-frequency relationships (Figure 2). The bankfull discharge is estimated to be 8.5 m^3s^{-1}. We tried to confirm this by applying Manning's equation to selected stable cross-sections upstream and downstream of the project reach and assuming bankfull discharge represented approximately a 1.8-yr return period flow (Dunne and Leopold, 1978). Bankfull elevations were determined by plotting water surface elevations and estimated bankfull elevations versus channel distance at several points upstream and downstream from each cross-section. A best fit line was used to determine bankfull capacity at these cross-sections. Bankfull discharge calculated by this method averaged 6.5 m^3s^{-1}. To be conservative, the design channel capacity was selected to be 8.5 m^3s^{-1}. A rough estimate of the 100-year return period flow is 425 m^3s^{-1} and is used as a capacity value for floodplain design.

Channel geometry data were collected in a downstream reach where the channel appeared to be functioning properly under the present hydrologic regime (i.e., banks were vegetated and capacity was sufficient to handle the 1- to 2-year runoff event). Down valley slope, valley bottom width and surficial geology are the same at the downstream reach as at the project site. Six cross-sections (cross-sections 1-6) and a longitudinal profile of the channel thalweg were surveyed. A bed material size analysis was performed at each cross-section. Width/depth ratios and median particle diameters were then plotted as a function of channel slope (Figures 4 and 5). In addition, hydraulic data were calculated and summarized ([illegible]s1 and 2).

A detailed longitudinal profile was then surveyed for the existing channel in the disturbed meadow. Three cross-sections (cross-sections 7-9) were measured to represent the prerehabilitation conditions. Cross-section 9 was selected because it appeared to represent a transition between oversized and undersized channel reaches in the project reach.

Dimensions for the final, rehabilitated channel were selected from the slope information from the project reach (Figures 4 and 5). The width/depth ratio selected was an average of the data collected because of the absence of a strong relationship with slope, S. The hydraulic data from Tables 1 and 2 were averaged to serve as additional design criteria. Hydraulic data from cross-section 9 served as one check on design discharge. We used conservative data to provide some factor of safety in the channel design. A design channel slope of 0.024 was selected because it represented the average slope of the stable reach and enabled us to maintain a sinuosity of 1.1, which is similar to that of the stable reach. No systematic pool-riffle pattern was observed in the stable reaches of Badger Creek.

Bed and Bank Stability

Following the initial channel design, critical shear stress equations were used to check channel bed and bank s[illegible] (Graff, 1971). Because bank materials in the disturbed m[illegible] are essentially noncohesive and unvegetated, it is expected that a channel design based upon the geomorphic criteria would have to be modified to allow for increased bank stability. A channel should adjust to an increase in apparent bank cohesion caused by revegetation by becoming narrower and deeper.

Therefore, an initial channel design would have to be shallower and wider than the final desired channel. This would be accomplished by designing less steep channel banks than those in presently stable reaches. A final, natural regime channel

TABLE 1. Badger Creek Channel Data.

XSEC*	Width (m)	Average Depth (m)	Slope ($m.m^{-1}$)	Area (m^2)	R** (m)	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Manning Velocity, ms^{-1} (n=.045)	Q, Bankfull, m^3s^{-1} (n=.045)
1***	7.9	0.49	0.014	3.9	0.44	15	38	160	1.53	5.9
2***	7.6	0.40	0.033	3.0	0.35	12	90	160	2.01	5.9
3***	5.8	0.67	0.018	3.9	0.55	13	45	190	2.01	7.8
4***	5.3	0.61	0.017	3.3	0.49	12	37	120	1.83	5.9
5	6.7	0.27	0.030	1.8	0.24		70	160	1.49	2.6
5***	10.4	0.34	0.030	3.6	0.34	23	70	160	1.86	6.7
6***	7.3	0.30	0.016	2.3	0.29	13	35	75	1.22	2.8
7	10.4	0.76	0.028	7.8	0.66	15	50	110	2.84	22.1
8	21.3	0.36	0.010	16.2	0.70	30	80	140	1.77	3.1
9***	5.2	0.76	0.021	3.9	0.59	27	90	180	2.29	8.9

* = XSECS 1-6 taken in undisturbed channel, XSECS 7-9 taken in project section prior to rehabilitation.

** = hydraulic radius.

*** = field estimated bankfull discharge (1.8-yr. event).

TABLE 2. Badger Creek Summary Data (bankfull conditions).

W/D average for all sections (1-6): $\bar{X}$=18.9 (s=8.3)
W/D average for sections 1-4, 5b: $\bar{X}$=16.8 (s=9.2)

Q: Average for all sections (1-6): 5.4 m^3s^{-1} (s=.39)
Q: Average for sections 1-4, 5b: 6.5 m^3s^{-1} (s=.82)
Q: Section 9: 8.9 m^3s^{-1}

D_{16}	Section 1-4, 5b: $\bar{X}$=14.7 mm (s=4.2)	Section 7-9: $\bar{X}$=24 mm (s=7.9)
D_{50}	Section 1-4, 5b: $\bar{X}$=52.5 mm (s=22.5)	Section 7-9: $\bar{X}$=73.3 mm (s=20.8)
D_{84}	Section 1-4, 5b: $\bar{X}$=144.4 mm (s=40.6)	Section 7-9: $\bar{X}$=143.3 mm (s=35)

Overall slope: Downstream: 0.025 $m \cdot m^{-1}$
Project reach: 0.024 $m \cdot m^{-1}$
Drainage area at project reach: 497 km^2

should then naturally evolve from a wider, shallower channel.

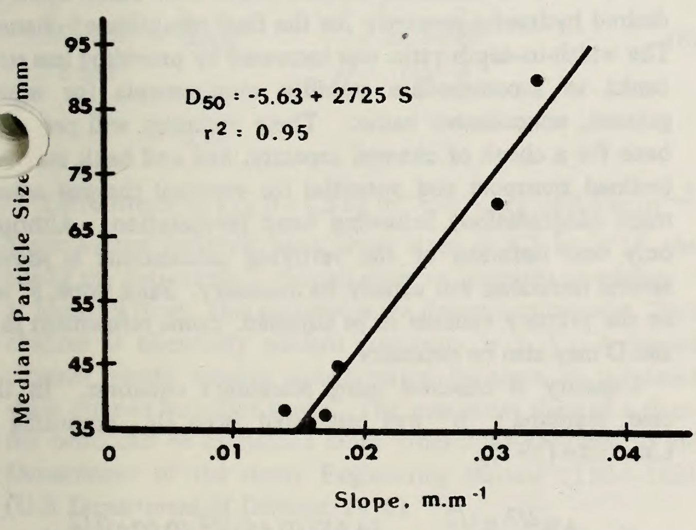


Figure 4. Median Particle Diameter of Bed Material Versus Slope: Downstream Stable Channel Reach.

Iterative calculations are required to design a stable channel in noncohesive materials which will meet all capacity, stability and geometry requirements and evolve to a narrower, deeper channel with vegetated banks. To do this, the final desired channel is approximated by a trapezoidal shape which best represents the geometry data but with less steep banks to provide for initial bank stability (see definition sketch, Figure 6). Cross-sectional area, A, is then

$$A = wD - CD \quad (1)$$

where:

$$C = D/\tan\theta$$
$$w = 19d$$

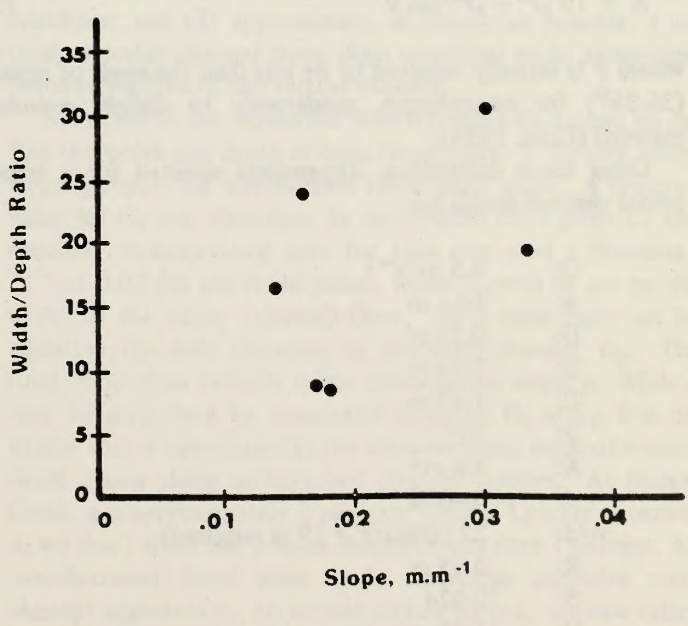


Figure 5. Width-to-Depth Ratio Versus Slope: Downstream Stable Channel Reach.

Depth, D, in Equation (1) is defined as shown in Figure 6 and differs from average depth, d, used in the calculation of w/d ratios from channel geometry data. The average depth of a trapezoidal channel, d, is

$$d = D - D\left(\frac{C}{w}\right) \quad (2)$$

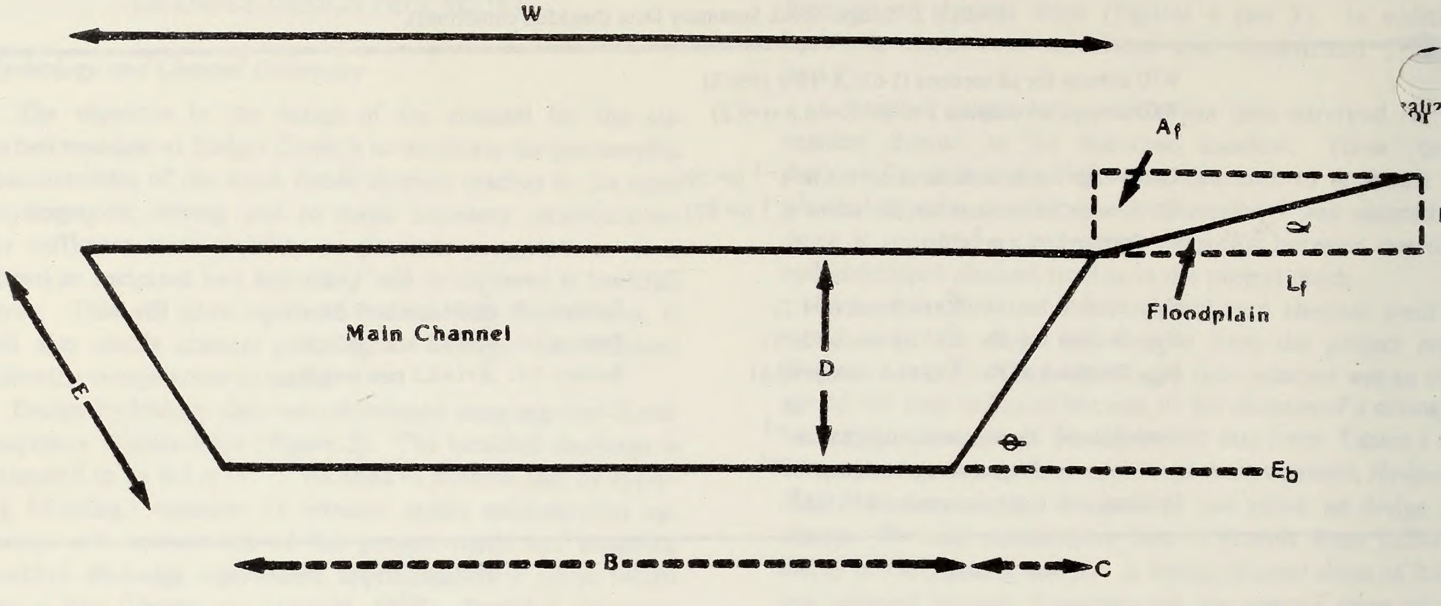


Figure 6. Design Channel Definition Sketch.

Therefore cross-section area, A, is

$$A = 19 D^2 - D^2/\tan\theta \quad (3)$$

where θ is initially selected to be less than the angle of repose (36-38°) for noncohesive, moderately to slightly rounded material (Lane, 1955).

Using these definitions, dimensions selected for a trapezoidal channel design are:

Q:	$8.5\ m^3s^{-1}$
w:	10.1 m
D:	0.53 m
B:	7.16 m
C:	1.47 m
θ:	20°
A:	$4.6\ m^2$
d:	0.46 m
w/d:	22 (slightly > 19 as required)
R:	0.45 m
S:	0.024
V:	1.83 m/s
D_{16}:	15 mm
D_{50}:	60 mm
D_{84}:	158 mm

where R is hydraulic radius, V is mean flow velocity (Q/A), and D_{16}, D_{50}, and D_{84} are bed material particle sizes for which 16 percent, 50 percent, and 84 percent, respectively, of all bed material by weight is finer. Because significant differences in bed material size between disturbed and undisturbed channel reaches did not exist, average values for particle size were used.

The channel variables selected above were based upon the desired hydraulic geometry for the final rehabilitated channel. The width-to-depth ratio was increased by providing less steep banks to accommodate stability requirements for nonvegetated, noncohesive banks. These variables will pro[illegible] basis for a check of channel capacity, bed and bank sta[illegible], bedload transport and potential for eventual channel adjustment (degradation) following bank revegetation. Although only one iteration of the verifying calculations is shown, several iterations will usually be necessary. Bank slope, θ, will be the primary variable to be adjusted. Some refinement in W and D may also be necessary.

Capacity is checked using Manning's equation. In this case, Manning's "n" was calculated from D_{84} according to Limerinos (1970).

$$Q = \frac{AR^{2/3}S^{1/2}}{n} = \frac{(4.65)(0.45)^{2/3}(0.024)^{1/2}}{0.045} \quad (4)$$

$$= 9.4\ m^3s^{-1}$$

which is sufficient to contain the design bankfull discharge with a small safety factor.

Bed and bank stability are checked using critical shear stress equations. Average bed shear stress, τ_o is

$$\tau_o \text{ bed} = \gamma_w RS$$

$$= (1{,}000)(0.45)(0.024) = 10.8\ kg\ m^{-2} \quad (5)$$

and average bank shear stress, $\tau_{o\ bank}$ is:

$$\tau_{o\ bank} = 0.77\ \tau_{o\ bed}$$

$$= 8.3\ \text{kg m}^{-2}\ \text{(Simons and Senturk, 1977)} \qquad (6)$$

where γ_w is the specific weight of water.

Critical shear stress, $\tau_{c\ bed}$ is determined from Lane (1955) for coarse material:

$$\tau_{c\ bed} = 0.08\ D_{75} \qquad (7)$$

$$= (0.08)(120) = 9.6\ \text{kg m}^{-2}$$

Lane generally added 20 percent to his calculated values. Thus τ_c = 11.5 kg m^{-2}. In either case, bed instability is achieved approximately at bankfull discharge, which meets the design objective.

Critical shear stress for the banks is calculated using procedures in Graff (1971). The angle of repose, ϕ, for coarse materials is approximately 38^o. The ratio of critical shear stress of the bank to the bed is

$$\frac{\tau_{c\ bank}}{\tau_{c\ bed}} = \cos\phi \sqrt{\frac{1-\tan^2\theta}{\tan^2\phi}} \qquad (8)$$

$$= 0.83$$

Therefore, if $\tau_{c\ bed}$ is 11.5 kg m^{-2}, $\tau_{c\ banks}$ is 9.5 kg m^{-2}. Since aveage bankfull bank shear stress is 8.3 kg m^{-2}, the banks are also stable – though close to incipient instability – at bankfull flow. This also meets the design requirement. This channel is essentially straight (sinuosity is 1.1). A curved channel would require consideration be given to increased shear stresses on outer banks. The maximum shear at a channel bend can be calculated from procedures provided in the Department of the Army Engineering Manual 1110-1-1601 (U.S. Department of Defense, 1970).

As banks begin to revegetate (in approximately 2 to 5 years based on local observation), the effective value of ϕ will increase, thus bank stability will increase. Vegetation will increase resistance to flow (and, therefore, Manning's "n") and result in slightly greater depths to convey a given discharge. Thus, as bank stability increases, bed shear stress will increase for a given discharge and consequently bed stability will decrease. In addition, bedload transport capacity will increase. If bedload transport rates into the rehabilitated reach do not exceed the transport capacity of the reach, some degradation will be encouraged which will reestablish the desired channel capacity. Increased bank cohesion and resistance to flow should also cause some bank deposition and steepening to ᐧur. Therefore, the rehabilitated channel should evolve to ᐧgime geometry representative of current watershed conditions.

Because channel cross-section slopes and bed material sizes in the rehabilitated reach and the more stable upstream reach are so similar, a general balance in bedload transport should be achieved. Gabion controls, discussed below, should reduce the risk of excessive degradation which could occur if bedload transport out of the project reach exceeds that into the reach. However, excessive aggradation could occur if inputs of bed material from upstream are unusually large. Several methods for quantifying bedload transport are provided in Graff (1971).

Flood Plain Design and Control of Lateral Migrations

We believe the keys to achieving channel stability and rapid evolution to a regime geometry are proper flood plain design and control of lateral channel migrations to provide the requisite stability to establish bank vegetation. A properly designed flood plain provides three important functions: (1) dissipation of destructive flood flow energy and discouragement of secondary or multiple channels, (2) concentration of primary flow energy in the main channel, and (3) depositional area for fine sediments and a moist, rich habitat for vegetation growth.

The objectives in the design of the flood plain are to: (1) provide sufficient spillover capacity for up to 50- to 100-year flood; (2) encourage fine sediment deposition, revegetation, and evolution towards a natural geomorphic and riparian condition; and (3) approximate, as closely as possible, a natural or stable channel flood plain condition while minimizing required earthwork and related expense.

Referring to the definition sketch (Figure 6), L_f and H_f define the width and depth of each flood plain. The down valley slope specifies the downstream flood plain slope. A required value for H_f can, therefore, be determined for a given L_f and required cross-sectional area for flow (we used a Manning's "n" of 0.03 for the flood plain), where L_f will be set by the width of the valley (alluvial) floor. H_f is most easily set by adjusting the base elevation of the main channel, E_b. The final flood plain variable is the cross-section slope, α. While α may be prescribed by reasonable limits of H_f or L_f, it is desirable that α approximates the cross-sectional slope of mature flood plains along undisturbed channel reaches. At Badger Creek, α is approximately 2 percent. Even if L_f were to permit it, we don't think the α value should be less than 1 percent. An over-flattened flood plain could encourage excessive main channel aggradation. In certain situations (e.g., narrow valley floor) H_f will be large and must be greater than 2 percent. However, over-steepened flood plains may encourage excessive main channel scour.

Lateral channel migration – which will be discouraged in part by proper flood plain design – can be further controlled by periodic placement of structures to force the main channel through a predetermined location. As stated above, it was observed that natural bed and bank controls caused by rock outcrops seemed to restrict the lateral movement of the channel for roughly 300 m upstream and downstream of the control. Therefore, we recommended the placement of gabions at approximately 300 m intervals along the rehabilitated channel.

The gabions should be constructed of large (1m x 2m x 0.5 m) river-type baskets one layer deep and two baskets wide. They should be placed 0.5 m below the channel bed, but flush with the channel bank to allow vertical adjustment of the channel but no lateral movement. Gabion wings, flush with the flood plain, should extend at the design flood plain slope approximately 8 m onto each flood plain. In addition to discouraging lateral migrations of the channel, the gabions will also provide a lower base level for a degrading channel. Because the gabions are either submerged or flush with the channel, they should become inconspicuous following complete channel rehabilitation.

DISCUSSION

The final dimensions for the Badger Creek designed channel area are given above. Figure 7 depicts the expected evolution of the channel following revegetation of the banks from the initial trapezoidal shape to a final case where banks are more stable due to revegetation and the cross-section is narrower and deeper. The designed channel is fairly straight and it is not expected that a systematic pool-riffle pattern will develop.

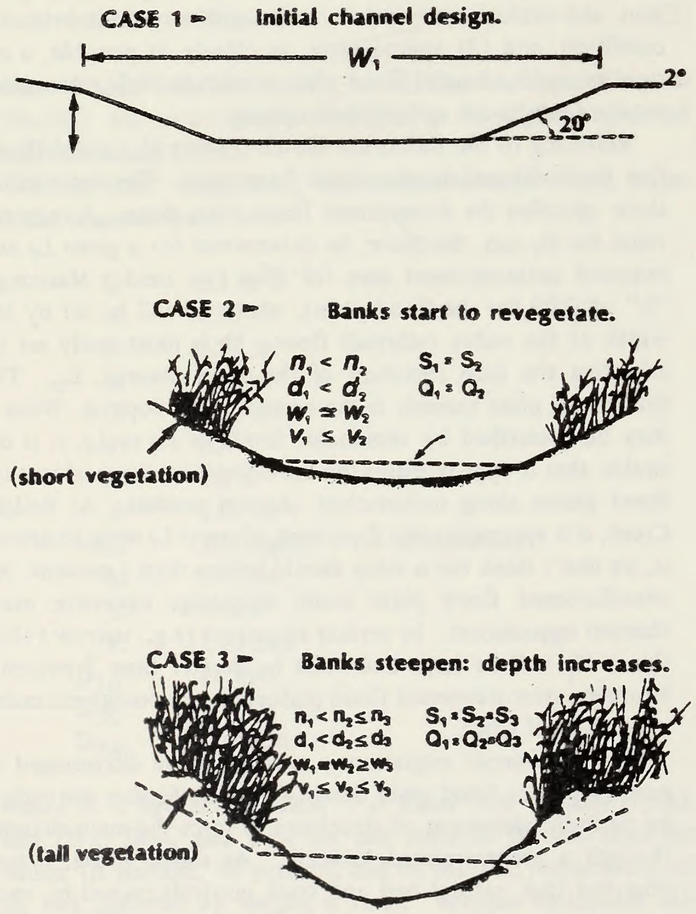


Figure 7. Sketch Showing Expected Evolution of the Rehabilitated Channel from Case 1 (initially constricted) to Case 2 (initial vegetative stabilization of banks) to Case 3 (final regime channel).

Implementation of the Badger Creek restoration project was originally scheduled for the fall of 1983, but has been postponed indefinitely, so validation of the design is not possible at this time. In addition to construction of the channel and flood plain, grass seeding and willow planting are planned. Also, willows and cottonwoods are expected to become established on the channel banks through natural succession.

While the per-kilometer cost of a channel project of this type is low compared to a constructed, immobile channel, there is a clear risk of project failure. The stable channel design given above is based on a conservative design flow of 8.5 m^3s^{-1}. We estimate the return period of this flow to be approximately two years. The reconstructed channel is designed to withstand the two-year return flow regardless of the number of events. The major concern is for flows having a return period of between 5 and 20 years. Flows with return periods greater than 20 years have less than a 10 percent chance of occurring in the first two years of project life. The five-year flood has a 36 percent chance of being equaled or exceeded in the first two years. This represents a high risk, since the five-year flood (approx. 54 m^3s^{-1}) could do considerable damage to the new channel. With the installation of the gabion controls, we feel the channel could withstand one such flood event without serious consequences. The ten-year flood (approx. 110 m^3s^{-1}) has a 19 percent chance of occurring at least once in the first two years. Again, the gabion controls would probably prevent destruction of the new channel by the ten-year flood, lowering the risk of total project failure.

We feel the design channel, together with the gabion controls, represents a reasonable compromise between excessive project costs and high risk of failure. After the initial two years, the channel stability will gradually increase as vegetation invades the banks and flood plain. The channel will evolve over time into a slightly narrower and deeper configuration. With this evolution towards greater stability, the risk of project failure decreases with time. A monitoring program, including discharge and periodic channel geometry measurements, is planned to quantify the actual results of the channel and riparian restoration project.

We attempted to make our channel design procedure as generalized as possible. However, we cannot overemphasize the importance of analyzing each project situation individually. Especially important is assessing the direction of disturbance from the geomorphic norm and determining both the probable cause of the disturbance and the current watershed condition. Since a disturbed channel is an effect of watershed conditions, it is important not to attempt this type of project until the watershed condition which caused the disturbance is corrected.

ACKNOWLEDGMENTS

We gratefully acknowledge the thorough review and constructive suggestions provided by Jeffrey B. Bradley and anonymous reviewers. Additional review and field assistance was provided by Howard Wertsbaugh, BLM Canon City District Hydrologist.

LITERATURE CITED

drews, E. D., 1982. Bank Stability and Channel Width Adjustment, ast Fork River, Wyoming. Water Resources Res. 18(4):1184-1192.

bt, P. D., 1965. Design of Stable Channels in Erodible Materials. *In:* Proc. of the Third Federal Interagency Sedimentation Conf. U.S. Dept. of Agri. Misc. Publ. 970:373-376.

Dunne, T. and L. B. Leopold, 1978. Water in Environmental Planning. W. H. Freeman and Co., San Francisco, 818 pp.

Graff, W. H., 1971. Hydraulics of Sediment Transport. McGraw-Hill Book Co., New York, New York, 513 pp.

Grant, P. J., 1977. Recorded Channel Changes of the Upper Waipawa River, Ruahine Range, New Zealand. Water Soil Tech. Publ. No. 6, 22 pp.

Hedman, E. R. and W. R. Osterkamp, 1982. Streamflow Characteristics Related to Channel Geometry of Streams in Western United States. USGS Water-Supply Paper 2193, 17 pp.

Heede, B. H., 1980. Stream Dynamics: An Overview for Land Managers. U.S.D.A. For. Serv. Gen. Tech. Rep. RM-72, 26 pp.

Jackson, W. L. and R. L. Beschta, 1982. A Model of Two-Phase Bedload Transport in an Oregon Coast Range Stream. Earth Surf. Processes and Landforms 7:517-527.

Kelsey, H. M., 1980. A Sediment Budget and an Analysis of Geomorphic Processes in the Van Duzen River Basin, North Coastal California, 1941-1971. Geol. Soc. Am. Bull. 91(4):1119-1216.

Lane, E. W., 1955. Design of Stable Channels. Trans. Am. Soc. Civ. Engr. 120:1234-1260.

Lane, L. U. and G. R. Foster, 1980. Modeling Channel Processes with Changing Land Use. *In:* Symposium on Watershed Management 1980. American Soc. Civ. Engr., New York, New York, pp. 200-213.

Leopold, L. B. and T. Maddock, Jr., 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geol. urv. Prof. Paper 252, 57 pp.

erinos, J. T., 1970. Determination of the Manning Coefficient from Measured Bed Roughness in Natural Channels. U.S. Geol. Surv. Water Supply Paper 1898-B, 47 pp.

Lisle, T. E., 1982. Effects of Aggradation and Degradation on Riffle-Pool Morphology in Natural Gravel Channels, Northwestern California. Water Resources Res. 18(6):1643-1651.

Lyons, J. K. and R. L. Beschta, 1983. Land Use, Floods, and Channel Changes: Upper Middle Fork Willamette River, Oregon (1936-1980). Water Resources Res. 19(2):463-471.

McCain, J. F. and R. D. Jarrett, 1976. Manual for Estimating Flood Characteristics of Natural-Flow Streams in Colorado. Colo. Water Cons. Board Tech. Manual No. 1, 68 pp.

Nevins, T. H. F., 1969. River Training – The Single Thread Channel. New Zealand Engineering, December 15, pp. 367-373.

Parsons, D. A., 1965. Vegetative Control of Streambank Erosion. *In:* Proc. of the Third Federal Interagency Sedimentation Conference. U.S. Dept. of Agric., Misc. Pub. 970, pp. 130-136.

Platts, W. S., 1981. Streamside Management to Protect Bank-Channel Stability and Aquatic Life. *In:* Proc. Interior West Watershed Mgt. Symp., D. M. Baumgartner (Editor). Washington State Univ. Extension Serv., Pullman, Washington, pp. 245-255.

Schumm, S. A., 1971. Fluvial Geomorphology: Channel Adjustment and River Metamorphosis. *In:* River Mechanics, Vol. I, H. W. Shen (Editor). Fort Collins, Colorado, pp. 5.1-5.22.

Simons, D. B. and F. Senturk, 1977. Sediment Transport Technology. Water Resources Publications, Ft. Collins, Colorado, 807 pp.

United States Department of Defense, 1970. Hydraulic Design of Flood Control Channels. Department of the Army Engineering Manual 1110-2-1601, Office of the Chief of Engineers, Washington, D.C., Appendix III, p. 35.

WATERSHED ACTIVITY PLAN

LONG GULCH SEDIMENT CONTROL

AND

RIPARIAN HABITAT IMPROVEMENT

PROJECT

TABLE OF CONTENTS

Tables, Figures, and Photographs

Appendices

Long Gulch Sediment Control and

Riparian Habitat Improvement Project

Decision/Record Rationale

I. Long Gulch Project

Proposed is the construction of a sediment control project to reduce downstream sediment yields, heal a gullied drainageway, and restore the riparian habitat in the drainageway. The project area is comprised of loamy, alluvial soils in a historic riparian zone, and is located approximately six miles southeast of Gunnison, Colorado.

II. Alternatives

A. Alternative I - Check Dams and Headcut Treatment - Proposed Action (see page 20 of the attached Activity Plan).

B. Alternative II - Headcut Treatment (see page 20 of the attached Activity Plan).

C. Alternative III - No Action (see page 20 of the attached Activity Plan).

III. Decision and Rationale

A. Decision

Adopt the proposed action.

B. Rationale

1. The proposed project would be in compliance with the Gunnison Basin MFP, BLM policy, and several Federal statutes and executive orders which are listed on page 2 of the attached Activity Plan.

2. The proposed project would reduce downstream sediment yields and restore historic riparian habitat. Secondary benefits would include: increased livestock forage, improved wildlife habitat, seasonal water for livestock and wildlife, flood control, and improved visual quality.

C. Mitigation

No mitigation is necessary for this project other than that already incorporated in the proposed action.

D. Compliance/Monitoring

Contract compliance would be handled by the GBRA Engineering Technician.

A monitoring plan is outlined on pages 25 and 26 of the attached Activity Plan.

IV. Conclusion

Based on the analysis in the attached EA, I conclude that selecting the preferred alternative will not result in significant impacts to the environment, and therefore conclude an EIS is not necessary.

Area Manager — Date 4/5/85

District Manager — Date 4/29/85

Watershed Activity Plan

Long Gulch Sediment Control and Riparian Habitat Improvement Project

I. Introduction

A. Purpose

The Federal Land Policy and Management Act (FLPMA), Public Lands Improvement Act, and other Federal statutes and executive orders direct the Bureau of Land Management (BLM) to prevent undue degredation of public lands and maintain and improve soil and water conditions on that land. Forage production for livestock and wildlife, wildlife cover, and vegetative cover for watershed protection are dependent upon maintaining the soils inherent productivity. Surface water produced on public land is important for livestock, wildlife, fisheries, recreational, domestic agricultural and industrial usage. These uses are enhanced by the maintenance of good watershed conditions on public land.

The Montrose District has chosen Long Gulch, a 25 square mile watershed located approximately six miles southeast of Gunnison, Colorado (Figure 1) for sediment control and gully rehabilitation work. Portions of this drainage network are actively headcutting and contributing sediment to downstream private farmland and the Tomichi Creek drainage. Sediment which reaches the Tomichi Creek to Gunnison River drainages is eventually deposited in Blue Mesa Reservoir, approximately 15 miles downstream. Much of the drainage stem has potential for restoration of riparian habitat.

B. Objectives

The objectives of this project are to:

1. reduce downstream sediment yields by 300 tons per year;
2. reduce accelerated channel erosion and the resultant soil loss on actively eroding portions of the drainage system. Promote aggradation of the gullied portions of the channel and stabilize 10 active knickpoints and headcuts;
3. raise the alluvial water table and restore the riparian zone along three miles of the drainage system;
4. decrease downstream peak flows (flood control);
5. increase vegetation production for watershed cover and available forage for livestock and wildlife;
6. improve habitat (cover) for wildlife;
7. provide seasonal water for livestock and wildlife.

C. Constraints

Range management is concerned that livestock have continued access to water and forage in the project area. Construction of any exclosures would need to be closely coordinated with that program and provisions made for livestock needs. All exclosures would need to be constructed with a gate to allow release of livestock that crawl through the fence. The lower wire would need to be spaced close enough to the ground that livestock calves could not easily crawl underneath it. Any exclosures constructed would have to comply with wildlife program specifications for safety of deer and elk. Water troughs would need to have escape ramps for animals falling into the trough.

D. Authority

Objective #8 of the soil, water and air portion of the Gunnison Basin Management Framework Plan (MFP) is to maximize the containment of sediments through a combination of water control structures, land use restrictions and vegetation treatment. BLM written policy is to stop the deterioration of public lands due to accelerated erosion and runoff and rehabilitate those areas where watershed values are significantly below their potential. This policy is supported by several Federal statutes and executive orders, among them the Watershed Protection Act and Flood Control Act of 1954, FLPMA of 1976, Public Rangelands Improvement Act of 1978 and Executive Orders 11752 and 11990.

E. Project Summary

This project would utilize several gully treatment techniques to rehabilitate gullied drainageways, control sediment yield and restore riparian habitat. This activity plan addresses the proposed action, which is to construct 35 porous check dams utilizing gabions, single fence or double fence structures on the main stem of Long Gulch (see Figure 2, Site 3) and 27 check dams on one of its tributaries (see Figure 2, Site 1). The lower 2.5 miles of the main stem would be treated by constructing a grassed waterway (see Figure 2, Site 4). Approximately 10 headcuts would be stabilized on the treated tributaries (see Figure 2, Sites 1 & 2). Also one tributary channel would be redefined in two short (200 feet) stretches that were filled in with sediment (see Figure 2, Site 1). A fragile, well vegetated, natural seep area on the treated tributary would be fenced off with a livestock exclosure to prevent trampling and additional headcutting. Plantings of cottonwood, willow or other woody riparian vegetation may be performed via wildlife funding. A 1.2 mile long stretch of an infrequently used BLM spur road would be closed and put to bed. Short portions of the county road (Six Mile Lane) may need to be relocated or water barred. (This will be coordinated with the Gunnison County Road Department.) A second tributary drainage, that was burned, and is exhibiting some gully erosion would be monitored and recommended for treatment if the channel does not heal itself naturally (see Figure 2, Site 2). Other alternatives for site 1 are discussed in the environmental assessment (pg. 20).

The objectives outlined in this plan are supported by several objectives in the Gunnison Basin MFP, Gunnison Basin HMP and Lower Cochetopa Common Allotment AMP. See Section I.D. and II.B. for a full description of these supporting objectives.

The benefit/cost ratio for Site 1 is approximately 0.525. Costs are estimated to be about $15,000 while $7,880 benefits would accrue over a five year period. Benefit/cost ratio and cost estimates will be calculated for subsequent phases of this project when a more detailed survey and design is done and the EA is written for each phase.

Table 1-Proposed Treatment Schedule

Project Phase	Implement in FY	Cost Estimate
Site 1 - 27 check dams, seep exclosure	85	$15,000
Site 2 - Monitor, riprap knickpoints and headcuts or build check dams as needed	-	-
Site 3 - 35 check dams		
Phase A - Upstream from spring in N1/2 Sec. 31, T. 49 N., R. 2 E.	86-87	-
Phase B - Downstream from spring	88-89	
Site 4 - Grassed waterway	90	-

II. Project Identification and Background

A. Location and Setting

1. Location

Long Gulch is located in the Gunnison River Basin, which is part of the Upper Colorado River Basin (see Figure 1). Long Gulch extends into both Saguache and Gunnison Counties, Colorado. The legal description of the proposed project area is:

New Mexico Principal Meridian

T49N	R1E	Secs. 13, 14, 24, 25, part
T49N	R2E	Secs. 30, 31, part
T48N	R2E	Secs. 6, part

2. Climate

The climate is semi-arid with mean annual precipitation ranging from 12 to 16 inches at the lower and upper ends of the watershed, respectively. July and August have the highest precipitation with much of it coming from violent convective thunderstorms. May and June are the driest months. Cold winters and cool summers prevail with a mean annual temperature of approximately 37°F and a 90 day frost-free season.

3. Topography and Geology

The area is a moderately rolling to steeply rolling upland dissected by drainageways. High mountains form the southern flank of the watershed and flat topped mesas separate it from Cochetopa Creek watershed to the east. Elevations range from 7800 feet at the lower end to 9700 feet at the headwaters near Cooper Mountain.

Precambrian metamorphic rocks, tuffs and colluvial gravel deposits occur on the uplands and mesas in the watershed. Igneous rocks underlie Schisto Basin near the headwaters.

4. Soils

The narrow alluvial bottoms have deep, very poorly drained to well drained, dark colored soils that are stratified and vary widely in texture. Loam and sandy loam textures are prevalent, though. Gravel and cobble areas are interspersed throughout the soil. Due to their great variability, these soils are not named or classified (USDA, SCS 1976). Drainageways that are not protected by adequate plant cover are subject to entrenchment and headcutting. The alluvial water table in most areas has been lowered by the entrenchment of drainageways.

The surrounding uplands have deep and moderately deep, well drained loamy soils on the north and west slopes. These soils have a medium runoff rate and moderate to high erosion rate. The south slopes are occupied by mainly shallow, droughty, well drained loamy soils. These soils have a high runoff rate and moderate to high erosion rate. These upland soils are classified at the Great Group level as Argiborolls, Cryoborolls, and Haploborolls.

5. Water Resources

Long Gulch is an intermittent stream that flows largely in response to snowmelt and rainfall events. There are several springs that also supply water to the stream. At low flow this water is lost in the alluvium, presently. Raising the water table would extend the period of flow in the stream. Long Gulch drains northward into Tomichi Creek and eventually into the Gunnison River. The average stream gradient is about 2.5 percent with side tributaries up to 4 or 5 percent slope. Water quality is generally poor due to high sediment loads during peak flows.

6. Vegetation

The vegetation along the wetter portions of the drainageways is meadow grasses, sedges, rushes, willow, and narrowleaf cottonwood. Where the alluvial water table has been lowered and along drier portions of the drainageways, big sagebrush and rabbitbrush dominate the site with a variable understory composition including western wheatgrass, Basin wild rye, needlegrasses, forbs and other shrubs. Portions of the drainageways that were prescribed burned in 1983 are dominated by grass and forbs.

The upland areas support Wyoming big sagebrush or black sagebrush with Greene's rabbitbrush, Indian ricegrass, pine needlegrass, bottlebrush squirreltail and various forbs the principal understory species.

There are no known populations of threatened, endangered or sensitive plant species in the watershed area.

7. Wildlife

Sage grouse, mourning dove, raptors and many non-game birds occur in Long Gulch. Deer and elk winter on the uplands adjacent to Long Gulch and deer make some year-round use of the drainageways. Rabbits, coyotes, rodents, and other non-game mammals are present in the watershed.

No known populations of threatened, endangered or sensitive animal species occur in the watershed or are likely to occur there.

8. Recreation, Visual Resources

Recreational use in Long Gulch watershed is light. It includes dove, sagegrouse and big game hunting, and ORV use. The area is designated open for ORV use in the Gunnison Basin ORV Plan.

The watershed is in VRM Class IV. This class allows landscape modifications of any visual contrast level which may dominate natural features. However, project designs should incorporate characteristic forms, lines, colors and textures in the area when feasible.

9. Cultural Resources

Archeological sites consisting of lithic scatters have been found in adjacent drainages. A class III pedestrian survey will be conducted prior to initiation of any construction activities and significant sites will be protected.

B. Current Management

The Long Gulch watershed is encompassed by Lower Cochetopa Common Allotment #6312. The permittees run cow/calf operations from May 16 to October 15 under a rest rotation system. Each pasture is rested 1 year out of 4. The recently revised AMP includes general objective #4 stating goals to maximize soil water infiltration while minimizing soil erosion and sediment yield. The AMP identifies extensive portions of Long Gulch and other sites totaling over 4,000 acres for sagebrush reduction using prescribed burning and herbicide spraying techniques.

The Gunnison Basin Habitat Management Plan includes the Long Gulch Watershed. One of the primary objectives of that plan is the maintenance and improvement of riparian habitat through protection and rehabilitation. Objective R-5 is to rehabilitate historic riparian areas that have been lost or impacted from the lowering of water tables. Objective R-4 is to decrease soil erosion in riparian areas by maintaining or improving stream bank stability. These recommendations are further supported by MFP wildlife recommendation WL-24.6 which states that on sites where gullying is severe and/or vegetation is lacking or invaded by shrubs, treat the area by constructing gully plugs (gabions or detention dams) and vegetative treatment.

Public interest in a land exchange involving over 4,000 acres of private land in the Long Gulch watershed is being analyzed. This represents most of the private land in the watershed.

Mineral activity is minimal at present though there are numerous mining claims in the area.

This activity plan and the proposed projects are in conformance with the Gunnison Basin Management Framework Plan, 1979.

C. Problem Identification and Proposed Treatments

1. Introduction

There are four project sites identified in the Long Gulch watershed (see Figure 1 & 2), each requiring a different management approach to achieve the stated objectives. Project sites 3 and 4 are located on the main stem of Long Gulch while sites 1 and 2 are tributary drainages. The project sites are numbered in treatment priority. Since site 1 is of primary importance, more site-specific data has been collected on this area. As more data is collected on the other sites it will be incorporated into this document via amendments or environmental assessments.

Sites 1 and 2 are adjacent tributary watersheds of 2.2 and 0.9 square miles, respectively. The drainage bottoms of these two watersheds were prescribed burned (temporarily removing most of the watershed cover) in the spring of 1983 to enhance livestock forage. In late July of the same year these areas were subjected to a high intensity-short duration thunderstorm which initiated gully formation.

2. Site 1

Site 1 was selected as first priority for treatment because of the severity and immaturity of it's gully system, and the potential for continued channel erosion and riparian habitat loss. It appears that an earthen dam associated with a spring development, immediately upstream from the gully system, breached during the

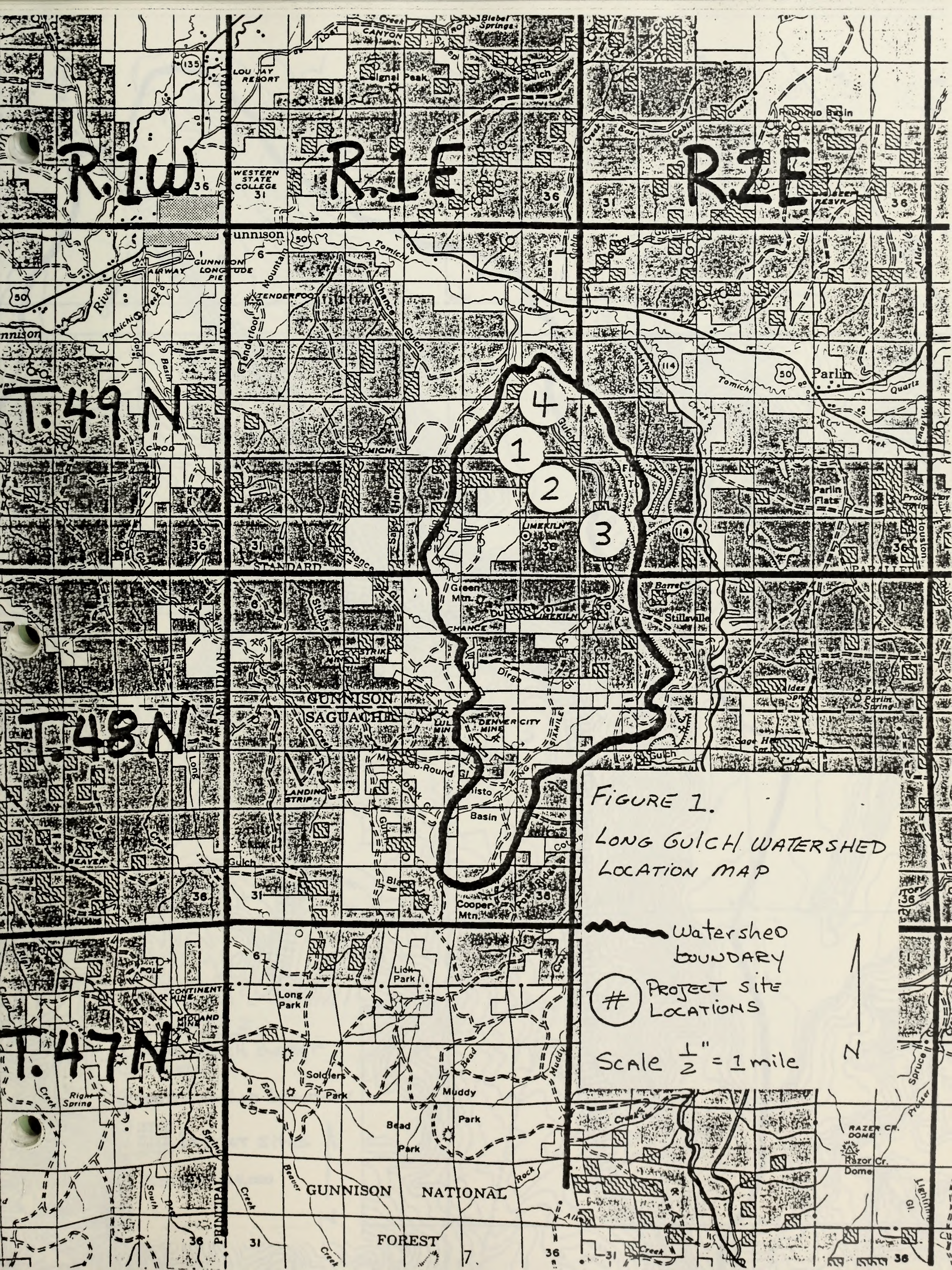


Figure 1.
Long Gulch Watershed Location Map

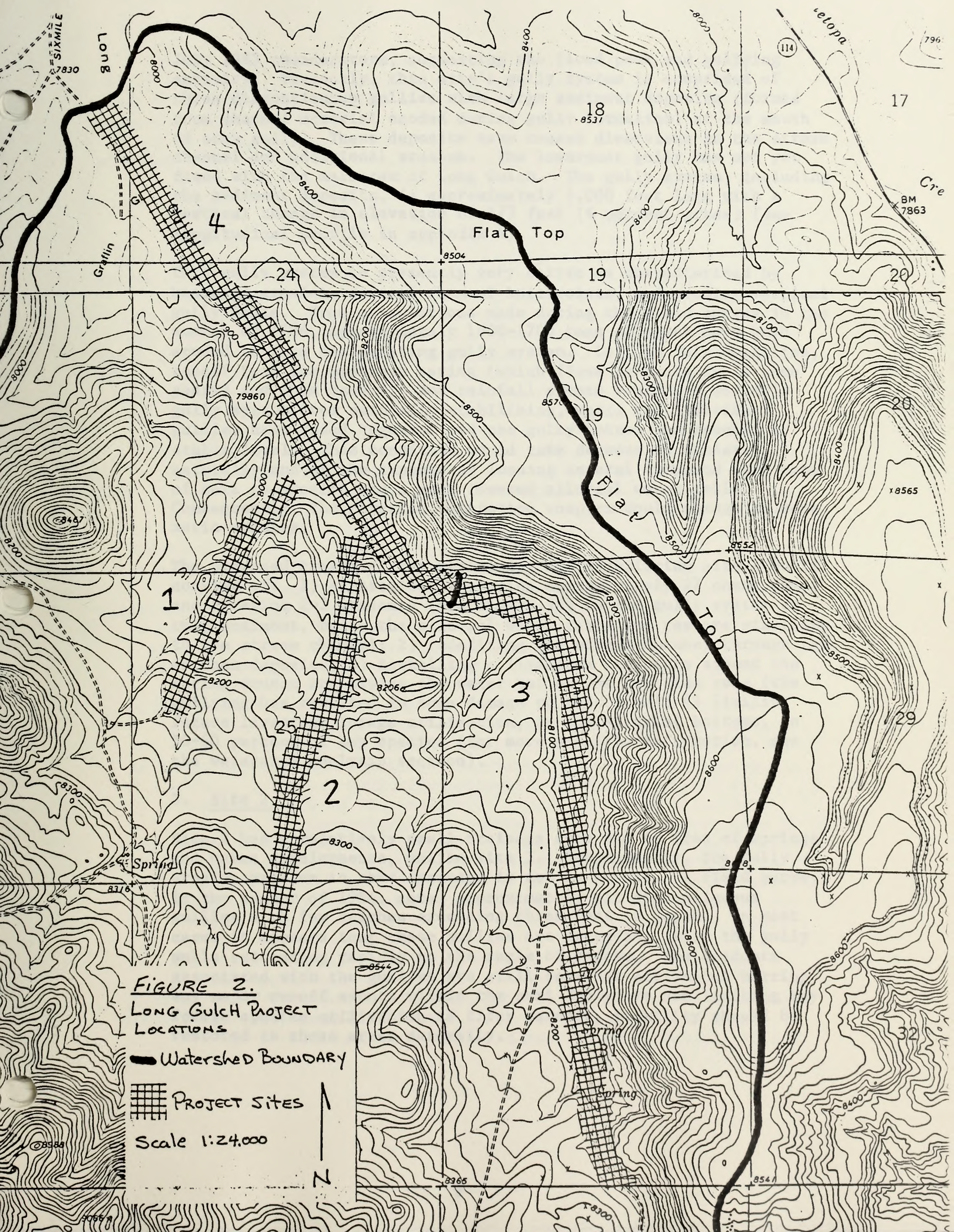


FIGURE 2. Long Gulch Project Locations

July 1983 thunderstorm, augmenting the flood peak and gullying activity. Presently, this site's gully system is comprised of three discontinuous gullies with large sediment deposits (formed from channel material eroded during gully formation) at the mouth of each gully. These deposits have caused diversions in the stream channel and additional erosion. The lowermost gully has not yet fused with the mainstem of Long Gulch. The gully system, including the sediment deposits, is approximately 4,000 feet long with a vertical change in elevation of 173 feet (4 percent grade) (see longitudinal profile in appendix 4).

This gully system is presently very active as characterized by headward erosion, several channel knickpoints, and eroding vertical gully banks. From calculations made during the field survey in the summer of 1984, approximately 1600-1700 tons of earth have been eroded to form the existing gully system. Left in this condition, runoff from the upstream spring (which flows perennially in some years) and from snowmelt and rainfall events would prevent this gully system from naturally stabilizing, until the individual gullies have fused together and the gully bottom has reached a stable level. This condition would take decades to achieve naturally and at the expense of loosing several thousand more tons of soil to erosion and a much lowered alluvial water table. Consequently, the riparian vegetation complex would change to more xeric species.

The proposed treatment for reclaiming and stabilizing site 1 would consist of: 1) strategically placing approximately 27 check dams, and treating 2-3 headcuts (see figure 5A) in the gully system to trap sediment, raise the alluvial water table and restore stability to the stream channel; 2) redefining the stream channel through the earthen deposits; 3) installing a livestock exclosure around the spring source and piping the water out of the riparian zone (the gullying has resulted in some damage to this area); 4) limiting future livestock forage utilization, in the alluvial bottoms, to 50-60 percent of key species (for more specific information, see the watershed analysis section).

3. <u>Site 2</u>

Site 2 has a relatively small drainage area and is free of springs and water developments, unlike site 1. Consequently, the gully erosion problem in this drainage is not as severe. A field survey, in the summer of 1984, noted approximately six discontinuous gullies with few reaches exceeding three feet in depth. In most cases it appears that these gullies are aggrading, with the gully walls retreating rapidly to the angle of repose. The headcuts associated with the gullies are still somewhat active but barring any major runoff events within the next 2-3 years and limiting key forage species utilization to fifty percent, stability should be restored to these areas naturally.

Therefore, it was decided that no structural treatment would initially be necessary for this drainage. Rather, a routine field reconnaissance would be conducted to monitor the condition of the gully system (This would be a part of the monitoring plan discussed in Section IV of this document). If these gullies continue to degrade, as determined by monitoring, structural treatment would be considered.

4. Sites 3 and 4

Sites 3 and 4 are located along the lower-gullied reaches of Long Gulch (see Figure 2). The topographical low point of site 4 drains approximately 22.35 square miles. Excessive past livestock grazing, and poor road location and maintenance are probably the factors primarily responsible for the present gully system. The gully is continuous for approximately 4.5 miles through sites 3 and 4. The gully is in a mature stage, meaning it has reached a stable base level and most of the gullied walls are vegetated to varying degrees and relatively stable. Consequently, the sediment yield and channel erosion is now lower than during earlier stages of gully development. The objective, therefore, in treating this gully system is to raise the alluvial ground water table and attenuate the intermittent flow regime to enhance and increase the size of the present riparian zone.

Long Gulch, in sites 3 and 4, is for the most part, intermittent. However, alluvial springs in site 3 do provide perennial flow for some distance downstream. This water usually subs into the alluvium and resurfaces several times before being lost permanently to the thicker alluvial deposits in the lower reaches of site 4. Site 3 exhibits gully reaches greater than six feet deep. The gully gets progressively shallower downstream where at the lower portion of site 4, the channel is entrenched 1-3 feet. The availability of water (alluvial springs), and potential to raise the water table and gully bottom, makes site 3 an attractive candidate for riparian habitat improvement. The degree of structural treatment performed on site 4 would heavily depend on the success achieved in treating site 3.

The proposed treatment on site 3 would consist of: 1) the installation of approximately 35 check dams; 2) the closing and reclaiming of the spur road off of six mile lane, running north and south through the center of section 31; 3) future livestock forage utilization would be limited to 50-60 percent of key species, in the riparian zone.

Due to the relatively shallow gullying in site 4, in-channel structures would not be cost effective. Therefore, assuming successful treatment of site 3, a grassed waterway (see Figure 3) would be proposed for site 4. Livestock forage utilization would be limited to 50-60 percent of the key species.

D. Description and Design Standards for Proposed Treatments (Alternative 1)

1. Site 1

A system of check dams strategically installed on site 1 (see Figure 2) would transform the present active gully system into a stream channel closely resembling that of pre-gully conditions. The ckeck dams would achieve this condition by widening the gully, thereby, reducing water velocity and tractive forces on the channel bottom and sides, and forming a sediment deposit behind each dam. These two factors would allow vegetation to become established on the channel banks and bottom, which would add long-term stability to the channel. The accumulated sediment would also raise the gully bottom and the alluvial water table, and act as an alluvial aquifer. Consequently, the present flow regimen would be attenuated and a more extensive riparian zone established.

Assuming the needed materials can be locally purchased, porous check dams would be preferred over non-porous check dams. Both dam types would ultimately stabilize the gully, however, both the head of flow over the spillway and the dynamic and hydrostatic forces against the porous check dam are less. This is a result of part of the flow being released through the structure. Consequently, porous check dams can withstand higher flows than non-porous check dams, and the risk of failure, due to flooding, is reduced. Assuming that the presently active knickpoints or headcuts on site 1 don't migrate significantly before project construction, approximately 27 check dams would be needed to rehabilitate the gully system. The lowermost dam on each gully would be placed near the gully mouth, where the channel geometry approximates that of a stable channel reach. This would help prevent lateral channel migration and the maintanance of a stable base level. The remaining check dams would be installed so the sediment deposit, behind each dam, reaches the toe of the next upstream dam. The size and extent of each sediment deposit is influenced by the dam height, gully gradient, flow velocity, and the physical characteristics of the sediment. Depending on these factors, studies have shown the sediment deposit gradient to vary from 30 to 60 percent (mean of 45 percent) of the original gully gradient. Exceptions to this rule of check dam spacing would occur where large headcuts or knickpoints exist. This may require more closely spaced check dams to ensure that the sediment deposits reach the headcut or knickpoint rim. The longitudinal profile, in Appendix 4, shows the proposed placement of the 27 check dams.

Typical construction plans for the proposed type of check dams can be found in figures 4A and 4B. The single fence check dams should be used only when the dam height is two feet or less. These structures consist of a wire-mesh fence, fastened to steel fence

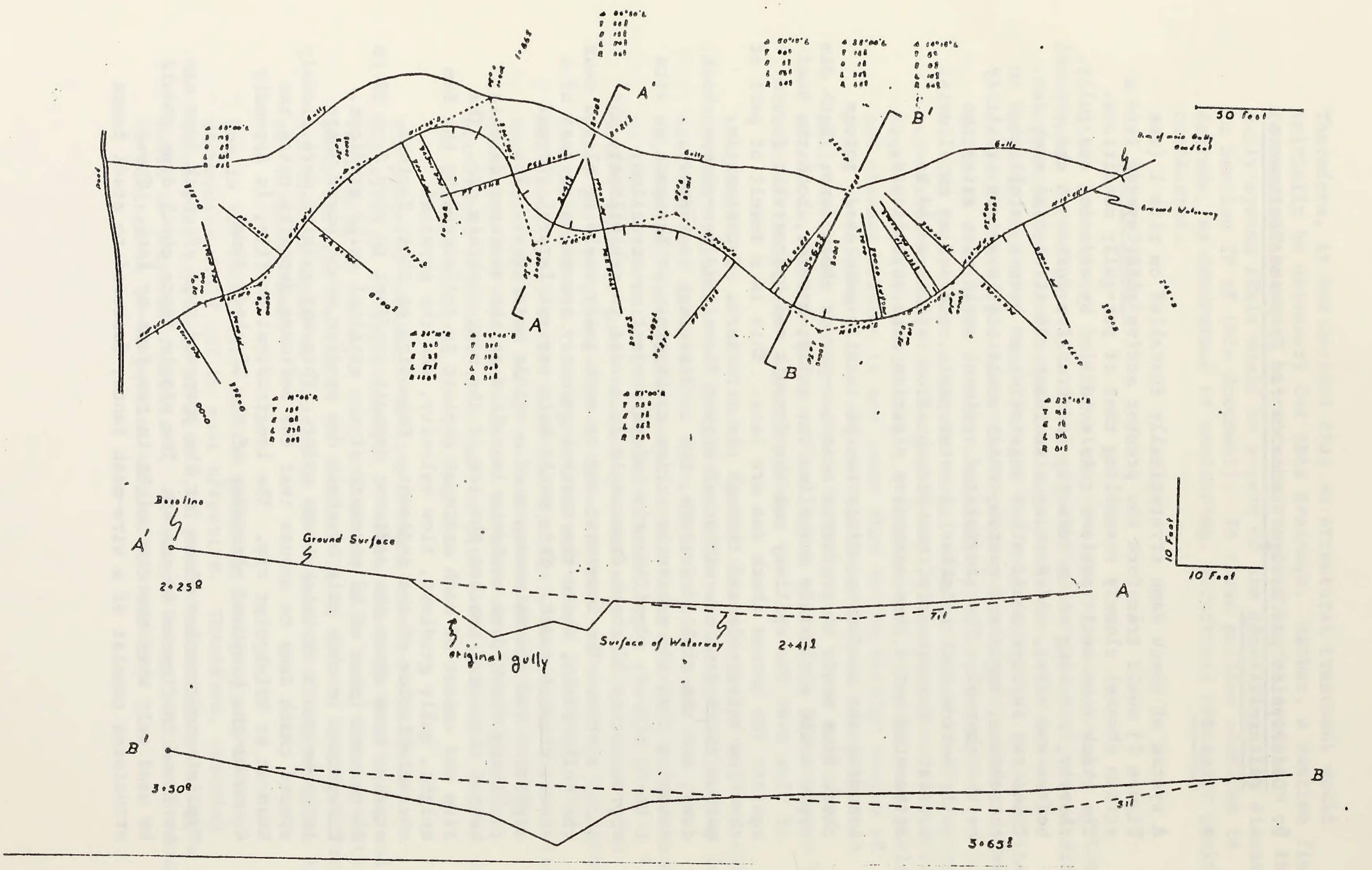


FIGURE 3. PLAN AND PROFILE OF A TYPICAL GRASSED WATERWAY
(TAKEN FROM USDA-FOREST SERVICE RESEARCH PAPER RM-40)

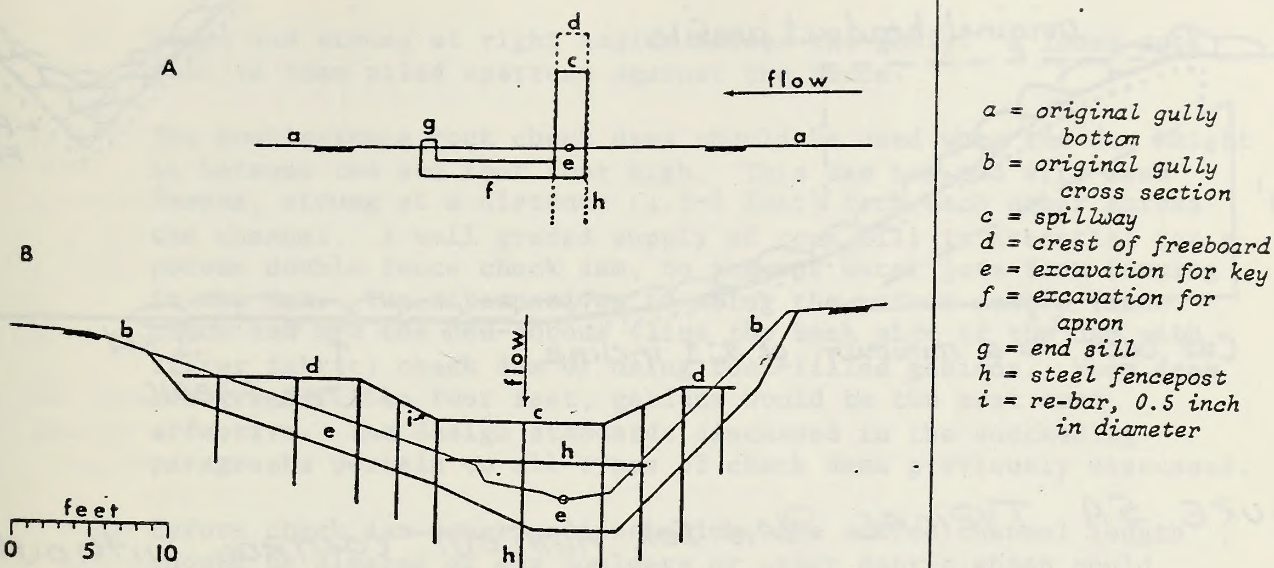


FIGURE 4A.* TYPICAl CONSTRUCTION PlANS FOR A DOUBLE-FENCE ROCK CHECK DAM
A. Section of DAM PARAllel to centerline of Gully
B. Section of DAM At the CROSS section of Gully

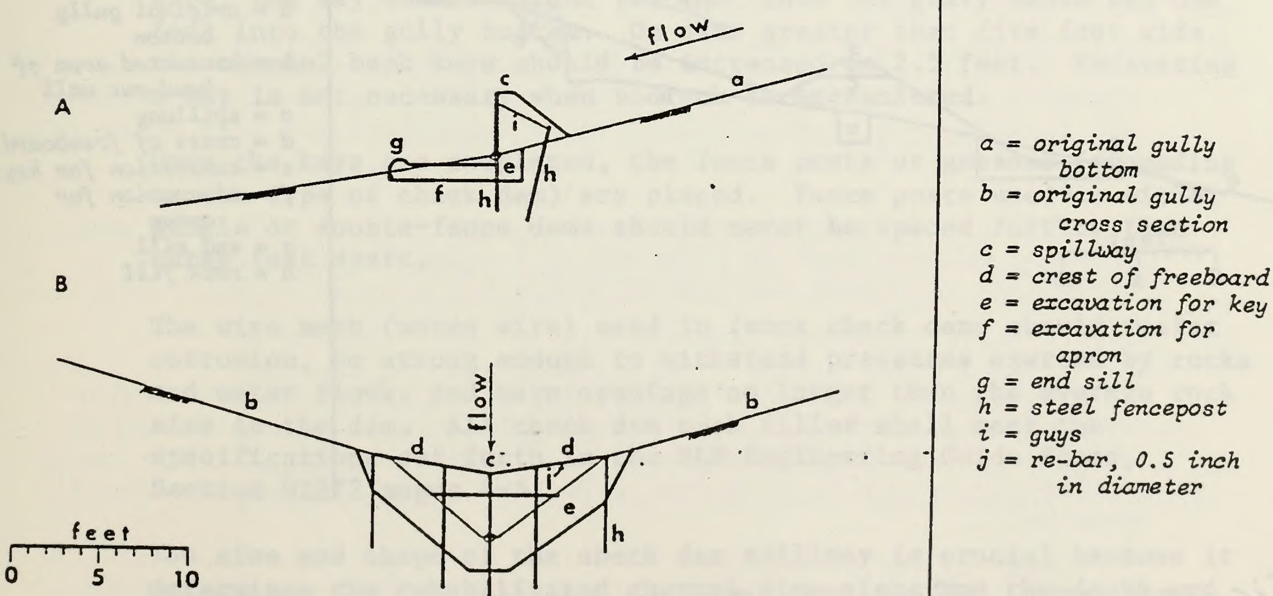


FIGURE 4B.* TYPICAL CONSTRUCTION PlANS FOR A SINGLE-FENCE ROCK CHECK DAM
A. Section of DAM PARAllel to centerline of Gully
B. Section of DAM AT THE CROSS SECTION OF Gully

* Figures 4A AND 4B taken FROM US Forest SERVICE RESEARCH PAPER RM-20.

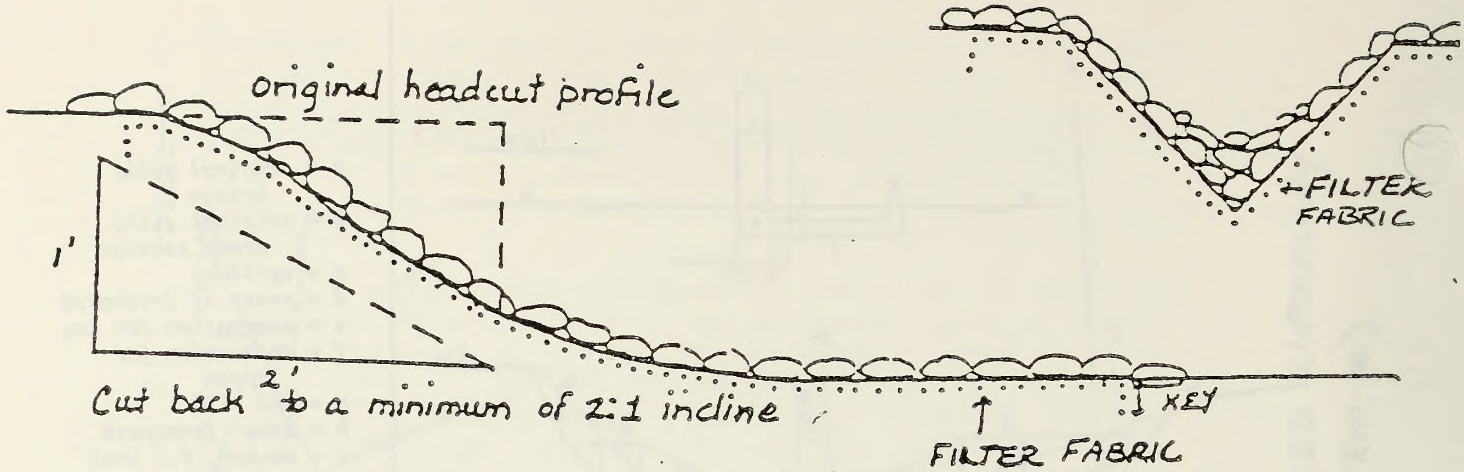


FIGURE 5A. TYPICAL PLAN FOR HEADCUT CONTROL without the USE OF A CHECK DAM

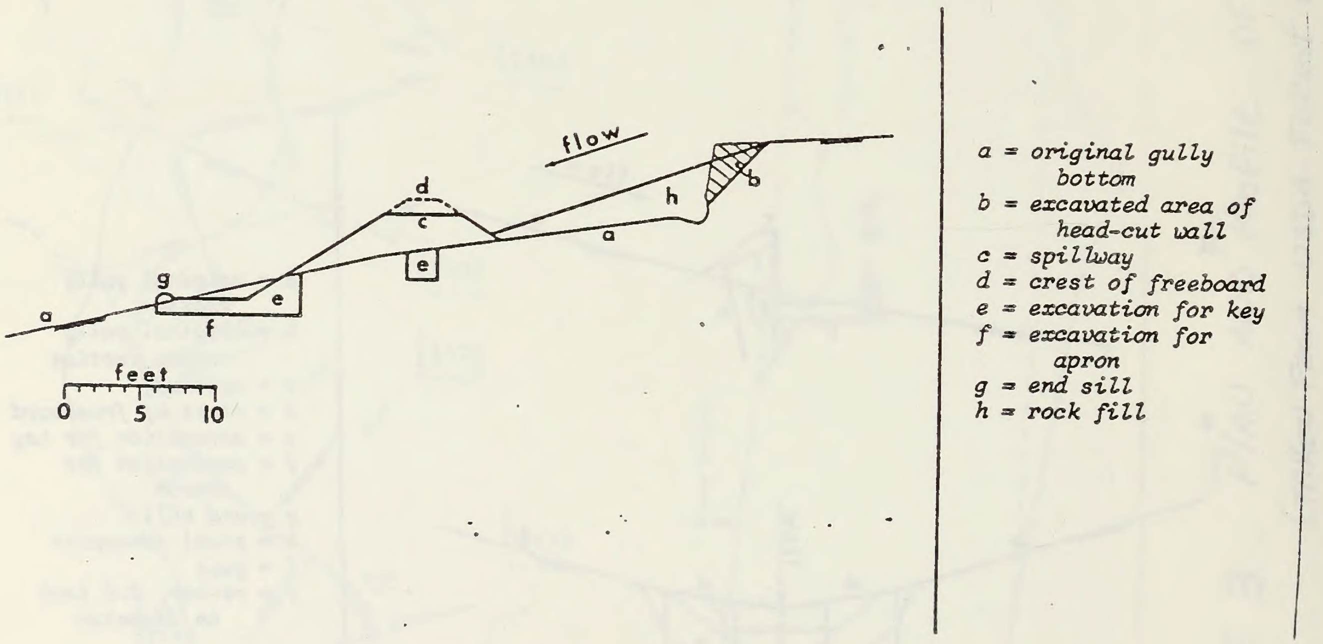


FIGURE 5B. TYPICAL PLAN FOR HEADCUT CONTROl USING A CHECK DAM. (TAKEN FROM U.S. FOREST SERVICE RESEARCH PAPER RM-20).

posts and strung at right angles across the gully. A loose rock fill is then piled upstream against the fence.

The double-fence rock check dams should be used when the dam height is between two and four feet high. This dam has two wire-mesh fences, strung at a distance (1.5-2 feet) from each other across the channel. A well graded supply of rock fill is essential for a porous double fence check dam, to prevent water jets from forming in the dam. Two alternatives to using the porous double-fence check dam are the non-porous (line the back side of the dam with filter fabric) check dam or using rock-filled gabions. When dams are greater than four feet, gabions would be the most cost effective. The design standards discussed in the succeeding paragraphs pertain to all types of check dams previously discussed.

Before check dam construction begins, the entire channel length should be cleared of any boulders or other debris which could obstruct flow and threaten to initiate lateral channel migration.

Check dams should be laid out so the line of discharge from the spillway is parallel to the centerline of the gully immediately below the structure. In addition, it is essential that the check dam be located in a straight channel reach and situated so the upstream direction of flow is perpendicular to the dam. Before check dam construction begins, the gully walls should be reduced to the angle of repose for a distance (at least twice the dam height) up and down stream from the dam.

The first step in check dam construction is excavating a key into the channel banks and bottom. On check dams less than five feet wide, the key should extend two feet into the gully banks and one foot into the gully bottom. On dams greater than five feet wide the channel bank keys should be increased to 2.5 feet. Excavating a key is not necessary when bedrock is encountered.

Once the keys are completed, the fence posts or gabions (depending on the type of check dam) are placed. Fence posts used in either single or double-fence dams should never be spaced further than three feet apart.

The wire mesh (woven wire) used in fence check dams should resist corrosion, be strong enough to withstand pressures exerted by rocks and water flows, and have openings no larger than the average rock size in the dam. All check dam rock filler shall meet the specifications set forth in the BLM Engineering Guide Specs, Section 02272 pages 4-5.

The size and shape of the check dam spillway is crucial because it determines the rehabilitated channel dimensions and the depth and extent of the sediment deposit behind the check dam. In order to reclaim the gully to natural (pre-gully) conditions, the spillways would be designed to safely handle the bankfull discharge of the natural channel. Previous studies have shown this flow rate to be equivalent to the flood with a 2-5 year recurrence interval. An indirect flow measurement, calculated on an ungullied reach of site 1, showed the bankfull discharge to be approximately 20 cubic feet per second (see Appendix 1). Several different spillway dimensions would handle 20 cfs, however, to maximize dam height and sediment depositon, the spillway should be as flat (to a one foot minimum) and broad as possible. The maximum allowable width of some spillways may be limited by existing channel conditions.

Aprons (see Figure 4A and 4B) would be constructed of rock (see BLM Engineering Guide Specs. - Section 02274 pages 1-4), in the channel directly downstream from each check dam. The aprons would extend at least 1.5-2 times the spillway height downstream. At the downstream end of the apron, a rock sill (see Figure 4A and 4B) would be built no more than five inches high as measured from the channel bottom to the top of the sill.

The gully banks directly downstream from each dam would be riprapped with rock and reinforced with wire mesh. Generally this bank protection would be equivalent to the upper edges of the freeboard of the dam but this height can decrease with increasing distance for the dam. This bank protection need not extend any further downstream than the apron.

To check the advance of active knickpoints or headcuts, the rim of either must be below the expected sediment grade from the check dam immediately downstream (see Figure 5B). If this is not possible, the knickpoint or headcut would be cut back to a 2:1 slope and rocked as shown in Figure 5A.

The spillover capacity (the flood event which the project would be designed to withstand) is approximately 100 cubic-feet per second and is discussed in more detail under the Hydrologic Risk Analysis Section, page 17.

The sediment deposits located at the mouth of each gully, on site 1, would be excavated to reconstruct a channel with dimensions sufficient to handle the bankful discharge without experiencing erosion.

A standard Type D design 4-strand barbed wire livestock exclosure measuring 275 feet by 250 feet (approximately 1.5 acres) would be constructed around the seep area at the head of site 1. This would protect this fragile site from livestock trampling and subsequent erosion.

Water for livestock use would be piped from the stock pond to a trough placed out of the riparian zone using wildlife funding. The water trough would have 1 or 2 escape ramps for animals that might fall into the trough.

2. Feasibility and Risk Analysis For Site 1

a. Feasibility

The proposed project would be economically feasible since it would reduce loss of productive soil and degradation of water quality on public lands. The restoration of historically valuable riparian habitat is also of primary importance. The additional benefits to livestock, wildlife, and recreational use (small game hunting) add to the economic viability of this project. No physical site factors preclude the implementation of this project or the attainment of the project objectives.

The construction of this project would not cause conflicts with other land uses. Similar projects have been constructed for controlling erosion and sedimentation with added benefits being the restoration of riparian habitat.

b. Hydrologic Risk Analysis

The purpose of the hydrologic risk analysis is to weigh the initial project construction cost against the cost of project failure (environmental consequences, rebuilding costs, etc.) from flood events, and try to minimize both. On project site 1 this is accomplished by using the estimated project life and an acceptable probability level of project failure, to determine the design flood event.

Over time, check dams settle and impound sediment, making them and the stream channel more stable. Consequently, check dams are most prone to fail from flood events during the first few seasons after construction. The sediment yield on project site 1 is high, due to active gully erosion, and should produce a stable check dam system within five years after construction.

Both on-site and off-site impacts would result from project failure. Downstream impacts would primarily amount to an accelerated sediment yield. On-site impacts would be the loss of project construction dollars, continued gully erosion, and the loss of riparian habitat. Taking these impacts into consideration, it was decided that a 20 percent risk of project failure (80 percent probability of no failure) over the five year project life, was acceptable. To determine the project design flood event, the following equation was used:

$$T = \frac{1}{1 - \sqrt[N]{P}}$$

T=Return Period in Years
P=Probability of no failure (80%)
N=Project Life (5 years)

$$T = \frac{1}{1 - \sqrt[5]{0.80}}$$

$T = 23 \approx 25$ year flood event

Assuming that the 25 year flood event approximates the peak flow from the 25 year storm (see Table 1 in Appendix II), the project design flood event would equal 100 cubic feet per second (cfs).

Therefore, project 1 should be designed with a safe flood capacity (this should not be confused with the spillway capacity) of 100 cfs. This can, in part, be accomplished by designing each structure and the surrounding area to dissapate the flood flow energy as much as possible, avoiding the formation of secondary or multiple channels. Concentration of primary flow energy, however, should stay in the main channel.

3. Site 2

As already stated, site 2 would initially be monitored. However, if structures are needed at a later date, they would be similar to the check dams and headcut treatments being proposed for site 1, but not as extensive. A watershed analysis would be completed if structures are proposed.

4. Site 3

The proposal on site 3 includes a series of check dams (approximately 35-40) similar to those proposed for site 1. However, since site 3 has a larger drainage area and bankfull stream channel, the check dams would be larger. To accelerate the raising of the alluvial water table, in trying to achieve the riparian habitat improvement objective, check dams would be spaced closer than those on site 1 for any given gully gradient.

A 1.2 mile stretch of an infrequently used, non-essential BLM spur road off Six Mile Lane would be closed and water barred. The road would be ripped and seeded with a standard mix of adapted grass species if deemed necessary. This would be accomplished immediately following the construction of the ckeck dams.

Short stretches of Six Mile Lane County Road may need to be relocated or water barred to accomplish project objectives (This work will be coordinated with the Gunnison County Road Department).

If monitoring indicates that livestock are detrimentally impacting the attainment of project objectives, a livestock exclosure may be constructed to more accurately assess this impact.

5. Site 4

The primary purpose of the grassed waterway, proposed for site 4, would be to increase irrigation to the alluvium, and to enhance and extend the present boundary of the riparian zone. The waterway would also promote gully stabilization on this site.

The waterway (see Figure 3) should be constructed shortly after the start of the growing season to establish vegetation as soon as possible. Seeding the waterway, with quick establishing plant species, after construction, is a must.

The project would involve the construction of a new watercourse with a reduced slope gradient and hydraulically inefficent cross-sections (shallow and broad). Both approaches change the flow regimen and decrease the erosive energies of water flow. The flat cross-sections favor the establishment of vegetation which is essential for the project to be successful. By using gentle meanders in the waterway, the channel length can be incresed and the channel gradient decreased over that of the original gully.

Short segments of Six Mile Lane County Road may need to be relocated or water barred to accomplish project objectives. (This will be coordinated with the Gunnison County Road Department).

III. Environmental Assessment (CO-037-EA5-002)

A. Chapter 1 - Purpose and Need

The primary purpose of the first phase of the Long Gulch project is to reduce channel entrenchment and headcutting and rehabilitate an actively eroding tributary (Site 1) of this watershed. In addition, downstream sediment yields will be reduced and portions of the riparian zone restored. Ancillary goals are to decrease downstream peak flows, increase vegetative watershed cover and forage for livestock and wildlife, improve habitat for wildlife and provide seasonal water for livestock and wildlife.

Gullying of drainage systems and the resultant loss of important riparian habitat and increased sedimentation are a widespread problem on public land throughout the West. The Bureau of Land Management (BLM) is directed by Federal statutes and executive orders (see Section I.D., Activity Plan) to maintain or improve watershed condition and soil productivity on those lands it administers. The BLM is also required to comply with state and local water quality regulations.

B. Chapter 2 - Description of the Alternatives Including the Proposed Action

1. Alternative 1 - Check Dams and Headcut Treatment Proposed Action

See Section II.C.1. - Problem Identification and Proposed Treatments, Site 1, and II.C.2. - Description and Design Standards for Proposed Treatments, Site 1.

2. Alternative 2 - Headcut Treatment

This alternative proposes only the treatment of the knickpoints and headcuts (see Figure 5A) on Site 1. Headcuts and knickpoints would be riprapped with rock and filter fabric.

The primary objective of this alternative would be gully stabilization. Gully rehabilitation would not be realized under this alternative. The structures would be periodically monitored and maintenance would be performed as needed.

3. Alternative 3 - No Action Alternative

This alternative would mean that no sediment control structures would be built or other sediment control techniques used to stabilize site 1. The knickpoints would continue to advance upstream resulting in further loss of sediment, lowering of the alluvial water table and loss of riparian habitat.

C. Chapter 3 - Affected Environment

1. Climate
   See Section II.A.2.

2. Topography and Geology
   See Section II.A.3.

3. Soils
   See Section II.A.4.

4. Water Resources
   See Section II.A.5.

5. Vegetation
   See Section II.A.6.

6. Wildlife
   See Section II.A.7.

7. Recreation, Visual Resources
   See Section II.A.8.

8. Cultural Resources
   See Section II.A.9.

D. Chapter 4 - Environmental Consequences

1. Proposed Action

a. Climate, Air Quality, Geology, Topography, Minerals, Cultural Features, Paleontology, Socioeconomics, Land Use, Wilderness, Prime and Unique Farmlands, Areas of Critical Environmental Concern, Wild and Scenic Rivers, or Floodplains and Wetlands. None of the above elements would be affected.

b. Soil

Soil disturbance due to construction would result in a short-term increase in erosion rates. However, long-term erosion would be decreased due to increased watershed cover.

c. Water

Sediment yield would be decreased and thus water quality improved for both the short term and long term. Sediment would be trapped behind the porous check dams as the stream flows through and over them. Approximately 1,500 tons of sediment would be deposited during the 5 year storage life of the project. After this period additional decreases in sediment yield would occur due to the healing of headcuts and knickpoints and stabilization of streambanks.

Downstream flood control would also occur due to the reduction in peak runoff rates in the drainageway. The alluvial ground water table would be raised and the intermittent flow regime would be attenuated.

Construction of a 1.5 acre livestock exclosure around a fragile seep would make that area unavailable for livestock forage. However, this is mitigated by overall inceases in forage anticipated on the remainder of the project area and piping water for livestock to a trough placed outside the riparian zone.

d. Vegetation

Vegetation along a two to ten foot strip on either side of the gully would be disturbed by check dam construction and laying back of the gully banks to a 1:1 slope on either side of the check dams. Long-term vegetation production would be increased due to raising of the water table and gully stabilization.

e. Wildlife

Short-term disturbance from construction activity would occur. In the long term, restoration of the riparian zone along portions of the drainageway would increase brood rearing habitat for sage grouse. Deer and elk benefits would be modest since they do not make heavy use of the drainageway. Numerous non-game birds and mammals would greatly benefit from the increase in riparian habitat, especially if tree plantings are implemented to increase the habitat diversity.

f. Recreation, Visual Resources

Improved habitat for sage grouse and other small game would provide an increased opportunity for hunting and related activities. Construction of the check dams would temporarily result in a visual intrusion on the drainageway. However, it would only be visible from the mouth of this tributary to Long Gulch or from the power line road where it crosses the tributary. The visual impact would be lessened as vegetation is reestablished on the disturbed areas.

g. Unavoidable Adverse Environmental Impacts

Short-term increases in erosion rate would occur as well as short term vegetation disturbance. Wildlife would also be disturbed during construction activities. In addition the visual character of the area would be changed.

h. Relationship Between Short-Term Use and Long-Range Productivity

The Long Gulch watershed is currently used for spring, summer, and fall cattle grazing, wildlife and recreational usage. This project would enhance cattle and wildlife usage by increasing forage, riparian habitat, and water availability.

i. Irreversible or Irretrievable Commitment of Resources

There would be no irreversible or irretrievable commitment of resources.

j. Cumulative Impacts

There would be no cumulative impacts.

k. Critical Elements

As indicated in the previous impact discussion, the proposed action does not impact any critical elements. The proposed projects are in conformance with the Gunnison Basin Management Framework Plan, 1979.

2. Alternative 2

a. Climate, Air Quality, Geology, Topography, Minerals, Cultural Features, Paleontology, Socioeconomics, Land Use, Wilderness, Prime and Unique Farmlands, Areas of Critical Environmental Concern, Wild and Scenic Rivers, Floodplains and Wetlands, Recreation or Visual Resources. None of the above elements would be affected.

b. Soil

Soil disturbance due to construction would result in a short-term increase in erosion rates in the immediate area of the knickpoints and headcuts. However, long-term erosion would be slightly decreased due to stabilizing the knickpoints and headcuts. The decrease in long-term erosion would be much less than for alternative 1.

c. Water

Construction would cause short-term sediment yield increases. Long-term sediment yield would be decreased and water quality improved to a lesser extent than for the preferred alternative. Treatment of the headcuts would help stabilize them, but bank sloughing and bed scouring would still contribute to sedimentation. Downstream flood damage would still occur. The alluvial ground water table would not be raised, nor would the intermittent flow regime be attenuated.

d. Vegetation

Short-term vegetation disturbance would occur due to construction. Long-term vegetation production would not be altered.

e. Wildlife

Short-term disturbance would ocur due to construction activity. No long-term changes would occur.

f. Unavoidable Adverse Environmental Impacts

Short-term adverse impacts to sediment yield, erosion rate, vegetation, and wildlife would occur due to construction activities.

g. Relationship Between Short-Term Use and Long-Range Productivity

The current area usage is spring, summer and fall cattle grazing, wildlife and recreation use. This alternative would not affect these uses.

h. Irreversible or Irretrievable Commitment of Resources

There would be no irreversible or irretrievable commitment of resources.

i. Cumulative Impacts

There would be no cumulative impacts.

j. Critical Elements

As indicated in the previous impact discussion, this alternative does not impact any critical elements. This alternative is in conformance with the Gunnison Basin Management Framework Plan, 1979.

3. No Action Alternative

No short-term impacts from construction would occur. High intensity storms and snow melt runoff would result in continued upstream migration of knickpoints and headcuts. Accelerated soil erosion, high sediment yields, loss of riparian habitat, and flood damage downstream would continue. Forage for livestock and wildlife habitat would be lost in proportion to the soil loss resulting from upstream migration of knickpoints and handcuts. The visual quality of the channel zone would continue to be degraded.

E. Chapter 5 - Consultation and Coordination

See Watershed Activity Plan, Section V.

F. Chapter 6 - List of Preparers

Prepared by:

Signature	Date	Title
Dennis M. Murphy	3/5/85	UBRA Hydrologist
[signature]	3/5/85	Dist. Soil Scientist

Reviewed by:

Signature	Date	Title
[signature]	3/6/85	Range Conservationist
[signature]	3-5-85	Wildlife Biologist
Tom Baird	8 Mar 85	Engineer
[signature]	3/8/85	Landscape Architect
[signature]	3/6/85	Economist
[signature]	7 Mar 85	Environmental Coord.
[signature]	3-28-85	Archeologist
[signature]	3/6/85	Realty Specialist
[signature]	3/20/85	Recreation Planner
[signature]	3/5/85	Fisheries Biologist

G. Cost Analysis

1. Assumptions

a. $\overline{X}$ annual accelerated sediment yield which would be retained on site = 300 tons per year for five years.

b. Benefit of on-site erosion or sediment yield reduction - $6 per ton.

c. Increase in $\overline{X}$ annual vegetation production would be 1,500 pounds per acre per year, or 2 AUMs per acre per year for 20 years.

d. Benefit of an AUM is $8.

e. Depreciation Rate/Opportunity Cost/Interest Rate = 8.375.

2. Computations

Cost of Project = $15,000

Sediment Storage Capacity of Project = 1,500 tons retained over five years.

Total benefits of sediment retention or on-site erosion reduction ammortized over five years = $7,116.

Increase in livestock AUMs = 200 AUMs over 20 years.

Total benefits of increased livestock AUMs ammortized over 20 years = $764.

Total benefits of project = $7,880

Ratio of benefits to costs = 0.525.

The above ratio of benefits to costs does not include the numerous intangible benefits of this project. Restoration of historic riparian zones has a high intrinsic value since this important vegetation type is critical for many wildlife species, and increased plant diversity, and visual landscape diversity. The attenuation of water flow will also help disperse livestock use. The visual quality of the drainageway would also be improved.

IV. Monitoring and Maintenance

A. Monitoring

Monitoring is a vital part of this watershed project in order to determine if the project objectives are being met. Monitoring the early phases of this project would also help determine the techniques and methods to be used in implementing the latter phases of the project. At a minimum, monitoring would include:

1. Periodic measurement of cross sectional profiles at permanent sites strategically located along the channel.

2. Permanent pace point transects to measure changes in cover and key livestock forage species.

3. Utilization studies to ensure compliance with recommended key species utilization levels.

A more detailed monitoring plan would be developed after project implementation and referenced in this activity plan.

B. Maintenance

A routine maintenance inspection would be conducted once every year and/or after the occurrence of any storm equal to or greater than the 25 year event. If repairs are needed on any portion of the project, funds would be requested through the annual work plan process.

If livestock are determined to be causing damage to any portion of the project, requests may be made to fence these areas, excluding them from grazing.

V. Consultation and Coordination

1. Colorado State Water Engineers Office

2. USDA - Soil Conservation Service

3. Colorado Division of Wildlife

4. Gunnison County Road Department.

VI. Appendices

APPENDIX #1

Spillway Calculations For Project Site #1

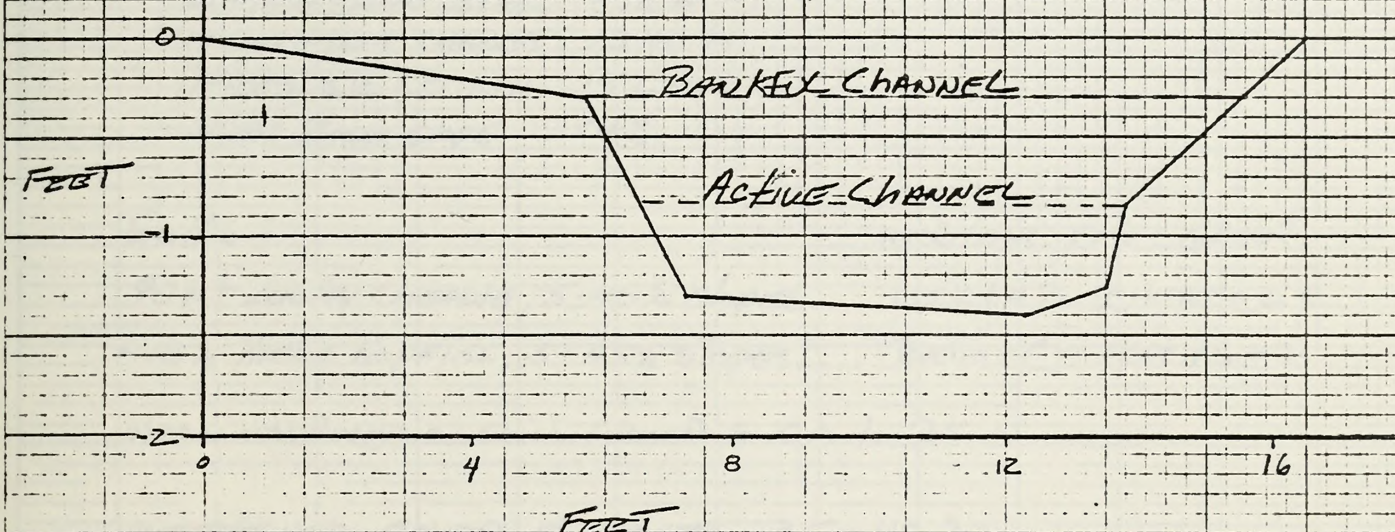


FIG. 1 X-SEC OF STABLE CHANNEL BELOW GULLY SYSTEM ON SITE #1 - LONG GULCH GULLY REHAB.

BANKFULL CHANNEL - HYDRAULIC PARAMETERS:

X-SECTIONAL AREA = 8.0 ft^2
CHANNEL SLOPE = 0.014 ft/ft.
WETTED PERIMETER = 10.6 ft.
HYDRALIC RADIUS = 0.75
n coef. (GRAVELLY BOTTOM, LOAMY BANKS) = 0.06

MANNINGS:

$$\text{DISCHARGE} = \frac{8(1.486)(0.014)^{\frac{1}{2}}(0.75)^{2/3}}{0.06} = 19\ ft^3/sec.$$

Spillway Sizing For Bankful Discharge

Spillway ≈ Rectangular Weir, where Disharge (Q) equals constant - C × weir length - L × weir height - $H^{3/2}$

$Q = CLH^{3/2}$ Assumption - C = 3
minimum spillway height = 1 ft.

$19 = 3L1^{3/2}$

$L = 19 \div 3 = 6.3$ ' Rounded up to 7 ft'

Spillway Size = 7 ft. wide × 1 ft deep

APPENDIX 2

WATERSHED ANALYSIS - PROJECT SITE #1

WATERSHED PARAMETERS:

WATERSHED SIZE 2.2 mi^2
ELEVATIONAL CHANGE 1340 ft.
HYDRAULIC LENGTH 15230 ft.
MEAN BASIN SLOPE 44%

Soils: HYDROLOGIC SOIL GROUP

90%+ Lucky Cheadle, 5-45% slopes LUCKY = B CHEADLE = C

<10% Parlin Hopkins, 5-45% slopes PARLIN = C HOPKINS = B

MEAN HYDROLOGIC SOIL GROUP = C⁻ to B⁺

WATERSHED COVER ESTIMATE 35-40%
RANGE CONDITION - FAIR

CURVE NUMBER ESTIMATE = 78
(SCS Technical Release #55, pg 22, figure 5.3)

TABLE I

PRECIPITATION AND RUNOFF ESTIMATES

RECURRENCE INTERVAL (YEARS) 6 HR. DURATION	PRECIPITATION (INCHES)	PEAK FLOW (ft3/sec.)	RUNOFF VOLUME (AC-FT.)
2	0.8	10	2
5	1.1	35	10
10	1.3	63	18
25	1.5	100	27
50	1.8	168	44
100	2.0	222	57

10 Squares to the Inch

Appendix 3

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Uncompahgre Basin Resource Area
2505 South Townsend Avenue
Montrose, Colorado 81401

IN REPLY
REFER TO:

JAN 25 1985

Memorandum

To: Dennis Murphy, UBRA Hydrologist

From: Lin Fehlmann, Water Rights Coordinator

Subject: Long Gulch Sediment Control and Riparian Habitat Improvement Project

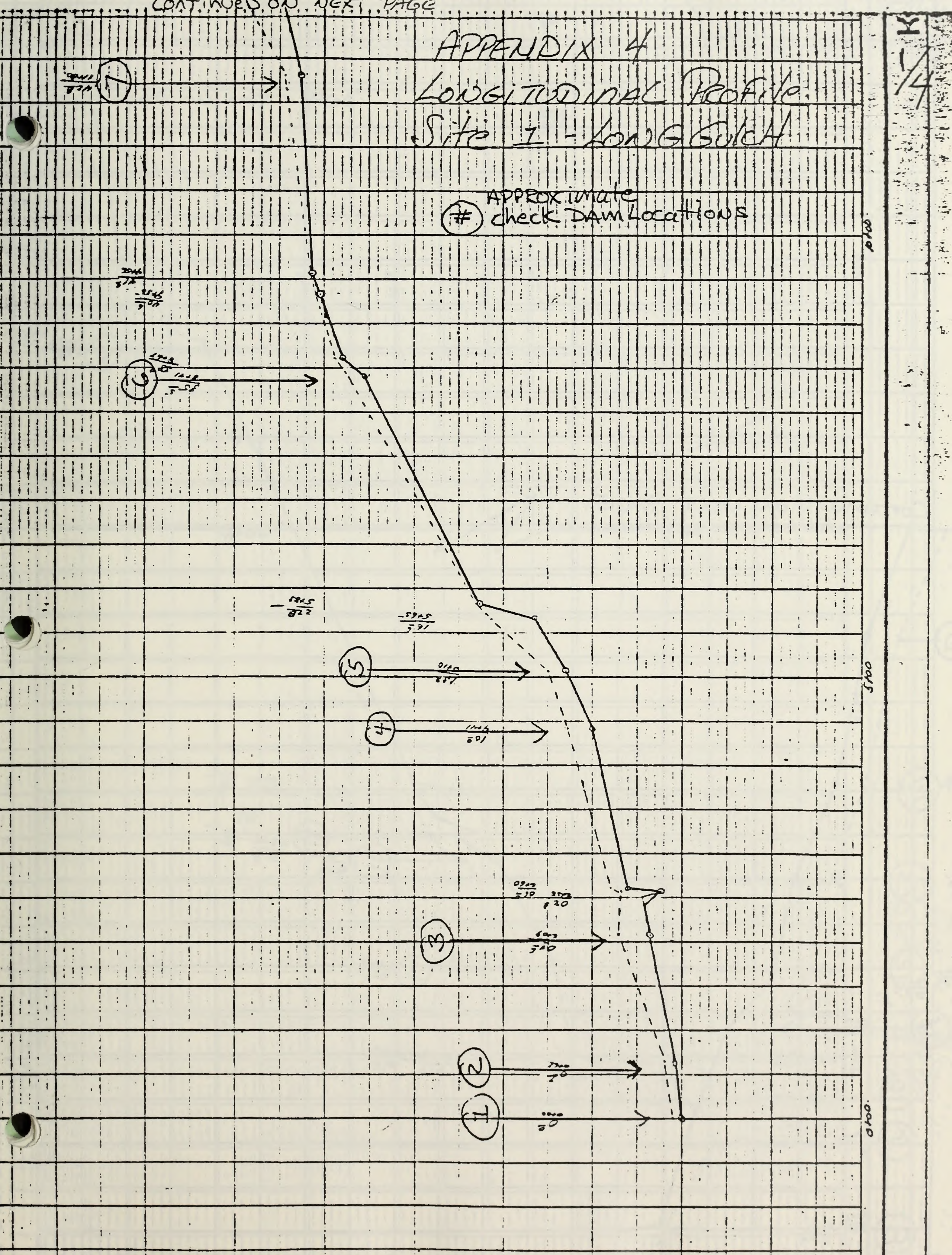
On January 25, 1985 I visited with Ralph Kelling, Division Engineer for Water Division 4, concerning the proposed erosion control project on Long Gulch. After Searching the records, we found no downstream water users that would be injured by the proposed erosion control structures. Mr. Kelling felt that a decree on these structures was unnecessary, as the water supply was of such short duration. He recommended that we go ahead with our plans to protect the watercourses.

Lin Fehlmann

APPENDIX 4

Longitudinal Profile

Site 1 - Long Gulch



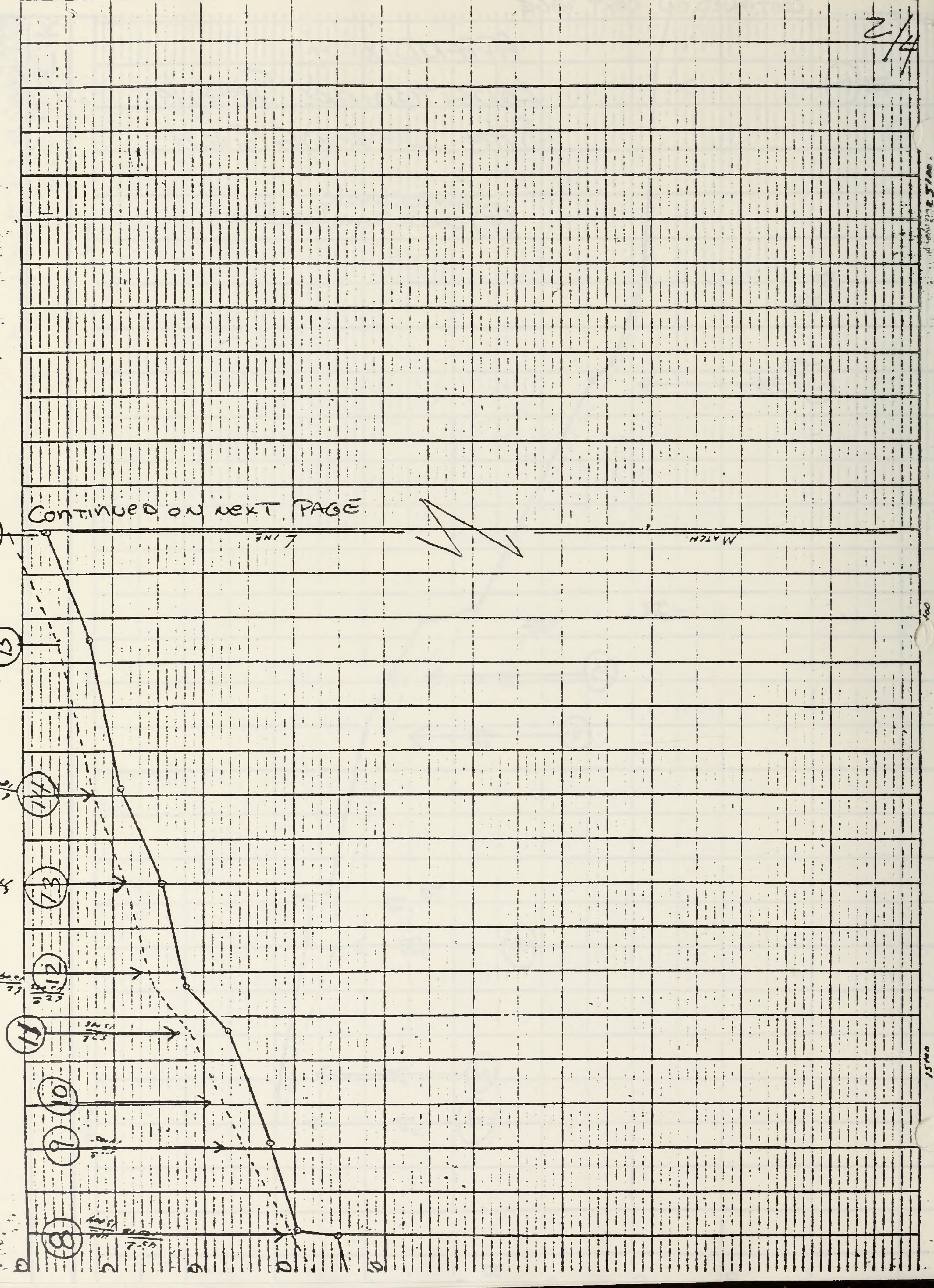
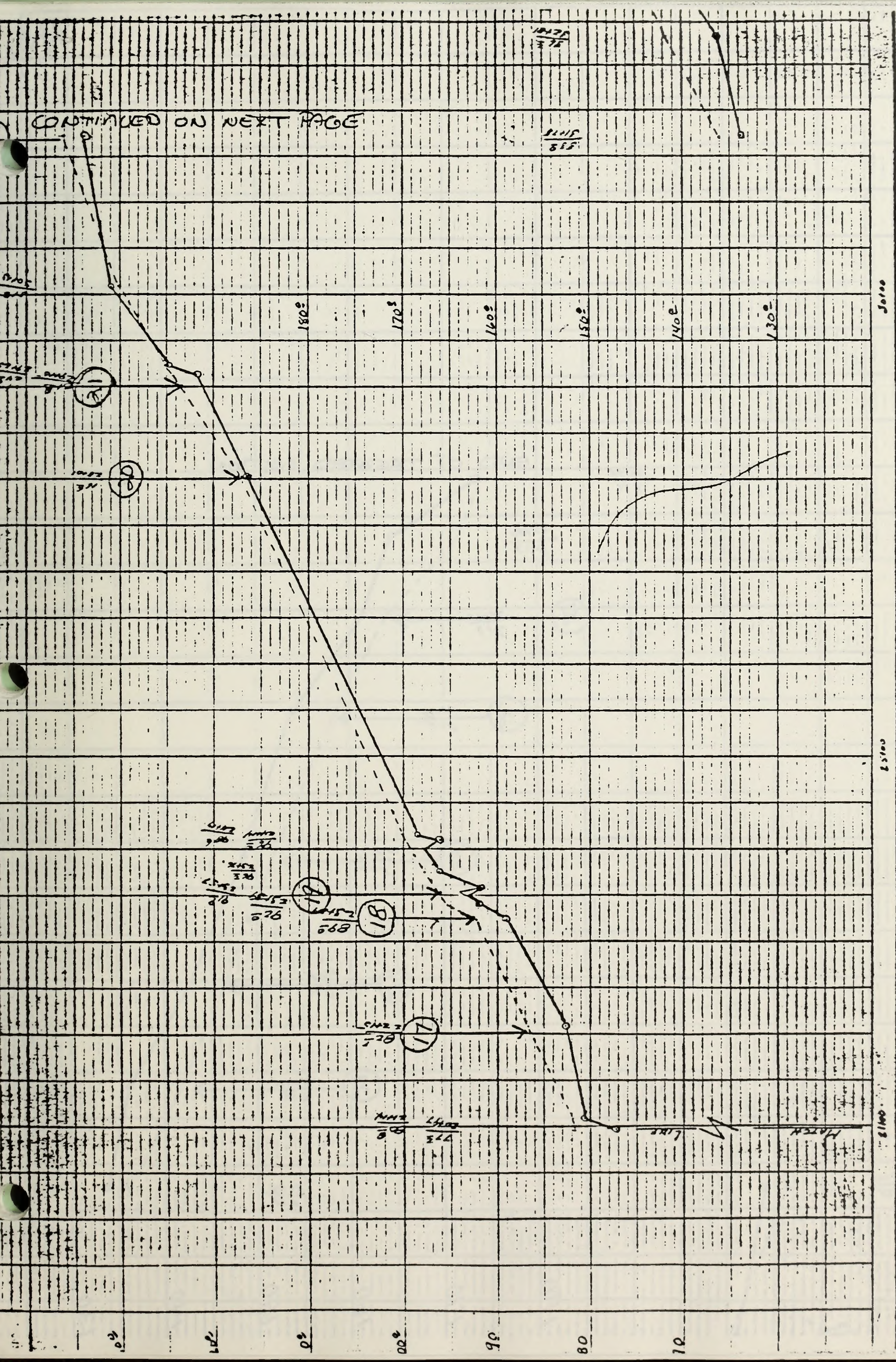
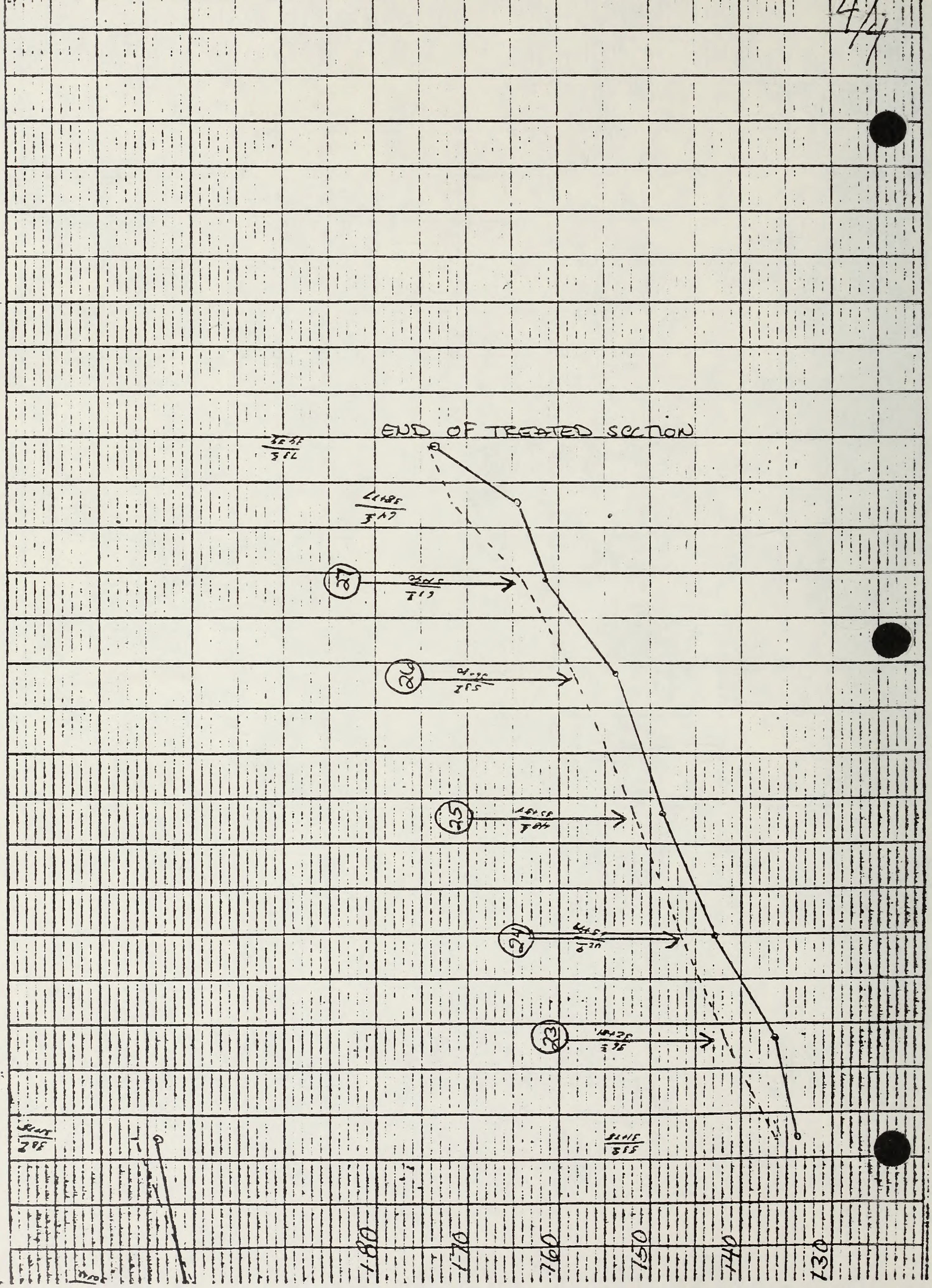


PLATE 1. PLAN-PROFILE


CONTINUED ON NEXT PAGE
180°
170°
160°
150°
140°
130°


4/4
END OF TREATED SECTION
27
26
25
24
23
180
170
160
150
140
130

AIR RESOURCES

Course 7000.1
Instructors: Archer, Wagner

INTRODUCTION TO AIR RESOURCE MANAGEMENT

Objectives:

1. Describe program roles and responsibilities in Air Resource Management.
2. Review management and technical issues in Air Resource Management.
3. Review techniques available to obtain and incorporate climatic data into management decisions.
4. Identify information and data required to perform necessary air quality-impact analyses.
5. Identify sources of technical assistance available in a particular area of concern.

TOPIC OUTLINE:

I. Legal Aspects and Management Roles

A. Air as a Resource (climate, meteorology, air quality)

1. Management (Philosophy, organization)
2. Authorities (FLPMA, CAA, NEPA, etc.)

B. Agency Cooperation

1. Federal Land Managers
2. Regulatory Agencies (EPA, States)
3. Others (NWS, private groups, state climatologists)

C. Air Quality Regulations (list of acronyms)

1. NAAQS (nonattainment, maintenance plans)
2. PSD (increments, visibility, AQRV's)
Video Tape (8 min.) - Dale Robertson, FLM Roles

II. Management Issues

A. Impact Assessments

B. Land Use Plans (inventory, conflict resolution)

C. Lease Stipulations

D. Multi-Use Support

E. Regulatory Requirements (sip, PSD permit review, standards redesignation)

F. Effects (ADRV's, visibility, acid deposition, smoke management)
Video Tape (30 min.) - Atmospheric Deposition

III. Technical Issues

A. Monitoring (meteorology, air quality)

B. Modeling (tapas, nomograph)

C. Information Sources (BLM/EPA training, video tapes, journals, texts)

IV. Case Studies

A. Climate Related

1. Resource Management Needs and the IAMS Program

2. Climate Inputs to the RMP Process (modeling, monitoring)

B. Air Quality Planning

1. Land Use Plans - Dispersion Potential Mapping

2. Simple Screening vs. Complex Modeling

3. Chevron Shale Oil Project (changed proposed development)

C. Federal Agency Coordination

1. Uintah Basin Synfuel EIS

2. Alton Coal Field - NPS/OSM/BLM (VRM vs. visibility)

3. Revising National Visibility Regulations

D. State Agency Coordination

1. Revising State Visibility Regulations

2. Woodsmoke - Firewood Sales

3. Smoke Management - Wilderness Fire Management

4. Redesignation - Wilderness Act vs. CAA
Video Tape (15 min.) - Brent Bradford, State Implementation Plans

V. Summary

BIOGRAPHICAL SKETCHES

Scott F. Archer - Physical Scientist (Air Resource Specialist), USDI-BLM, Colorado State Office, Denver, Colorado, FTS 564-7122, commercial (303) 294-7122.

Since 1981, Scott has served the Bureau of Land Management by providing meteorologic and air quality management direction in the areas of monitoring, modeling, environmental impact assessment, training, contract administration, and policy development implementation. He has conducted air resource impact evaluations for over 30 environmental assessments and environmental impact statements including: categorical exclusion reviews for monitoring sites, area-wide resource management plans, wilderness review, preference right lease applications, regional coal leasing assessments, and major oil shale development projects. From 1978 to 1981, Scott coordinated visibility monitoring research throughout the southwest under contract to the U.S. Environmental Protection Agency in Las Vegas, Nevada. Prior to that, he worked intermittently for the National Park Service in Flagstaff, Arizona, and conducted undergraduate air quality research at Grand Canyon National Park.

Scott received his Bachelor of Science degrees in Chemistry, Environmental Science, and Criminalistics from Northern Arizona University.

William W. Wagner - Air Resource Specialist, USDI-BLM, Utah State Office, Salt Lake City, Utah, FTS 588-3125, commercial (801) 524-3125.

Bill is presently the Air Resource Specialist with the Utah State Office, BLM, in Salt Lake Cilty, Utah. He has been in the position since 1975. From 1969 to 1975 he was on the Research Staff of the University of Utah as a Radiation Biologist in the Department of Radiological Health. From 1963 to 1969, Bill was a Research Assistant, Department of Radiological Health, University of Utah, and from 1960 to 1963 a Research Agronomist, California Chemical Company. From 1955 to 1960 he was a Pilot and Instructor with the Strategic Air Command, USAF.

Bill received a BS degree (1953) and an MS degree (1955) in Agronomy at Utah State University. He received a Ph.D. degree in Radiation Biology from the University of Utah in 1972.

He is the author of publications in the general area of Agronomy, Radiation Biology, and Air Quality, and presently holds a Adjunct Associate Professor appointment at Brigham Young University.

BIOGRAPHICAL SKETCHES

Scott F. Archer - Physical Scientist (Air Resource Specialist), USDI-BLM, Colorado State Office, Denver, Colorado, FTS 564-7122, commercial (303) 294-7122.

Since 1981, Scott has served the Bureau of Land Management by providing meteorologic and air quality management direction in the areas of monitoring, modeling, environmental impact assessment, analysis, contract administration, and policy development implementation. He has conducted air resource impact evaluations for over 30 environmental assessments and environmental impact statements including: categorical pre-design reviews for monitoring sites, area-wide resource management plans, wilderness review, geothermal right lease applications, regional coal leasing assessments, and major oil shale development [illegible]. From 1978 to 1981, Scott coordinated visibility monitoring research throughout the southwest under contract to the U.S. Environmental Protection Agency in Las Vegas, Nevada. Prior to that, he worked [illegible] for the National Park Service in Flagstaff, Arizona, and conducted undergraduate air quality research in Grand Canyon National Park.

Scott received his Bachelor of Science degrees in Chemistry, Environmental Science, and [illegible] from Northern Arizona University.

William W. Wagner - Air Resource Specialist, USDI-BLM, Utah State Office, Salt Lake City, Utah, FTS 588-3125, commercial (801) 524-3125.

Bill is presently the Air Resource Specialist with the Utah State Office, BLM, in Salt Lake City, Utah. He has been in the position since 1979. From 1969 to 1979 he was on the research staff of the University of Utah as a Radiation Biologist in the Department of Radiological Health. From 1963 to 1969, Bill was a Research Associate, Department of Radiological Health, University of Utah, and from 1960 to 1963 a Research Agronomist, California Chemical Company. From 1955 to 1960 he was a Pilot and Instructor with the Strategic Air Command, USAF.

Bill received a BS degree (1955) and an MS degree (1960) in Agronomy at Utah State University. He received a Ph.D. degree in Radiation Biology from the University of Utah in 1972.

He is the author of publications in the general area of Agronomy, Radiation Biology, and Air Quality, and presently holds a Adjunct Associate Professor appointment in Brigham Young University.

BLM Air Resource Management

The CAA and the associated air quality regulations and standards are the primary tools for the protection of air quality. However, the Clean Air Act does not necessarily have within its provisions the protection that we, as FLMs, may find necessary to protect certain of the resources we manage which might be impacted by air quality. In this case, we must look to other statutes in addition to the Clean Air Act for the level of air quality protection that we see as necessary for the protection of other resources that we manage. Acid deposition, for example, is not presently regulated by the CAA and acid rain has the potential for significantly impacting both non-biological and biological resources.

As FLMs, we must coordinate closely and continually with the air quality regulating agencies (EPA and the states) to assure that they are aware of our concerns regarding air quality and potential impacts to our other resources.

The majority of the lands managed by FLMs (whether BLM, USFS, NPS, or FWS) are generally distant from the centers of heavy population and industrial development. These lands are, therefore, in air quality attainment areas and are subject to the provisions of the PSD which are established for the protection of air quality that is presently better than the NAAQS. Management of air quality over those lands must look to the NAAQS as an upper limit of air pollution and not as a goal to be achieved.

THe PSDRs have limitations. For example:

1. PSD does not provide relief from emissions from existing sources.

   Baseline air quality is established by the first application for a PSD permit for a "MEF" (defined as emitting 100 T/yr. or 250 T/y depending upon the source type). PSD then sets allowable incremental increases in air pollution above this background or baseline level.

2. PSD incremental limitations speak only to two air pollutants; SO_2 and TSP.

3. The PSDRs set out both Class I air quality areas (the highest level of air quality protection) and Class II areas. The majority of lands managed by the FLMs are within Class II areas and that includes the BLM, USFS, NPS, AND FWS. Managers of Class I areas are required to be notified of proposed developments of major air polluting emitting facilities potentially impacting Class I areas, but no such requirement exists for managers of Class II areas.

4. Within the Class II lands which make up the majority Federally-managed lands are wilderness areas, proposed wilderness areas, wilderness study areas which may be proposed and subsequently designated as wilderness. They also contain wild and scenic rivers, national recreational areas, research natural areas, areas of critical environmental concern, areas of special interest or concern from the standpoint of scenic values, recreational values, and critical biological habitat which may be sensitive to air quality impacts from existing air pollution or an increase in the levels of air pollution.

The CAA and the associated air quality regulations and standards are the primary tools for the protection of air quality. However, the Clean Air Act does not necessarily have within its provisions the protection that we, as FLMs, may find necessary to protect certain of the resources we manage which might be impacted by air quality. In this case, we must look to other statutes in addition to the Clean Air Act for the level of air quality protection that we see as necessary for the protection of other resources that we manage. Acid deposition, for example, is not presently regulated by the CAA and acid rain has the potential for significantly impacting both non-biological and biological resources.

As FLMs, we must coordinate closely and continually with the air quality regulating agencies (EPA and the states) to assure that they are aware of our concerns regarding air quality and potential impacts to our other resources.

The majority of the lands managed by FLMs (whether BLM, USFS, NPS, or FWS) are generally distant from the sources of heavy population and industrial development. These lands are, therefore, in air quality attainment areas and are subject to the provisions of the PSD which are established for the protection of air quality that is presently better than the NAAQS. Management of air quality over these lands must look to the NAAQS as an upper limit of air pollution and not as a goal to be achieved.

The PSDRs have limitations. For example:

1. PSD does not provide relief from emissions from existing sources.

   Baseline air quality is established by the first application for a PSD permit for a "MSS" (defined as emitting 100 TPY, or 250 TPY depending upon the source type). PSD then sets allowable incremental increases in air pollution above this background or baseline level.

2. PSD incremental limitations speak only to two air pollutants: SO_2 and TSP.

3. The PSDRs set out both Class I air quality areas (the highest level of air quality protection) and Class II areas. The majority of lands managed by the FLMs are within Class II areas and that includes the BLM, USFS, NPS, AND FWS. Managers of Class I areas are required to be notified of proposed developments of major air polluting emitting facilities, potentially impacting Class I areas, but no such requirement exists for managers of Class II areas.

4. Within the Class II lands which make up the majority federally-managed lands are wilderness areas, proposed wilderness areas, wilderness study areas which may be proposed and subsequently designated as wilderness. They also contain wild and scenic rivers, national recreational areas, research natural areas, areas of critical environmental concern, areas of special interest or concern from the standpoint of scenic values, recreational values, and critical biological habitat which may be sensitive to air quality impacts from existing air pollution or an increase in the levels of air pollution.

The concerned FLM, who recognizes air as an important resource and who has an aggressive and responsive ARM program, has available to him (or her) other statutes which can be used in support of air quality protection and protection of other resources.

For example:

1. The FLM enabling legislation such as:

   BLM's FLPMA - which mandates the protection of the "air and atmosphere" in BLM's multiple use and sustained yield management responsibilities.

   USFS NFMA - which mandates the "protection and enhancement of air quality"

2. NEPA

   The NEPA requires an analysis of the potential significant impacts from major federal actions. If the major federal action includes a major emitting facility, air quality impacts will be a significant issue and require an analysis. The PSD also requires an analysis of MEFs. There are similarities and important differences in these two analyses.

3. There are also statutes that require protection of resources such as scenic values, areas of critical environmental concern, T&E species, and wilderness.

   a. The T&E Species Act speaks to the protection, preservation, and enhancement of species and species' habitat and the FLM should be aware of the implications that air quality and air pollution impacts have on these resources.

   b. The Wilderness Act speaks to the preservation of wilderness values and provides goals and objectives for maintaining those values.

      Wilderness areas occur in both Class I and Class II areas. In the case of wilderness, the PSD provision for the assessment of BACT is common to both Class I and Class II PSD areas. BACT provides the FLM the opportunity to meet the wilderness goals and objectives of wilderness areas of protection from man-caused changes by minimizing man-caused effects from air pollution emissions.

In summary:

- The CAA and related reguations, standards, and implementation plans are the primary tools in the protection of air quality.

- The CAA does have limitations for the FLM charged with the responsibility of managing multiple resources.

- Other statues provide additional means of protecting air quality and impacts to other managed resources from air pollution.

DRAFT

7300 Air Resources
Manual Section Outline
(Revised August 16, 1985)

.01 Purpose
.02 Objectives
.03 Authority - S. Coloff
.04 Responsibility - S. Coloff
.05 Definitions - W. Wagner
.06 Policy - S. Coloff
.07 Coordination - W. Wagner

.1 Air Resources Program (S. Coloff)
 .11 Background
 .12 Description of Air Resource
 .13 Purpose
 .14 Air Resource Program Description
  A. Functional Elements
  B. Functional Responsibilities
  C. Technical Skills
  D. Program Organization

.2 Air Resource Management Activities (W. Wagner)
 .21 Purpose
 .22 Types of Processes (S. Archer)
  A. Land Use Planning Activities
   1. Procedures
   2. Coordination Requirements

  B. Wilderness (W. Wagner)
   1. Procedures
   2. Prescribed Parameters of Discretionary Authority
   3. Coordination

  C. Leases, Withdrawals, Rights-of-Way, Exchanges (S. Archer)
   1. Procedures
   2. Coordination

  D. Environmental Impact Statements (EIS) and Assessments (EA) (W. Wagner)
   1. Procedures
   2. Coordination

  E. Prevention of Significant Air Quality Deterioration (W. Wagner)
   1. Procedures
   2. Coordination

  F. Redesignation (W. Wagner)
   1. Procedures
   2. Coordination

G. State Implementation Plans (SIP) (C. Anderson)
1. Procedure
2. Coordination

H. Smoke Management (S. Coloff)
1. Procedures
2. Prescribed Parameters of Discretionary Authority and Responsibility
3. Coordination

.3 Air Resource Inventory (C. Anderson)
.31 Purpose and Objectives
.32 Procedures
.33 Reporting and Archiving
.34 Coordination Requirements

.4 Air Resource Monitoring (S. Archer)
.41 Purpose and Objectives
.42 Procedures
.43 Reporting Requirements
.44 Coordination Requirements

.5 Air Resource Modeling (A. Riebau)
.51 Purpose and Objectives
.52 Procedures
.53 Reporting Requirements
.54 Coordination Requirements

.6 Air Resource Training and Education (S. Archer)
.61 Purpose and Objectives
.62 Procedures
.63 Reporting Requirements
.64 Coordination Requirements

7300 - Air Resources

.01 Purpose. This section sets forth the general policy, objectives, management structure, and management responsibilities of the Air Resource Management Program. This section also provides a background discussion of the nature of the air resource, description of the air resource program, and the foundation for air resource management.

.02 Objectives.

A. Provide information and technical assistance on air quality, meteorology, climate, and other air resource information to support and guide Bureau management actions including resource management planning, environmental analyses, rights-of-way, withdrawal and lease actions, ~~planning~~, smoke management, and other land management activities.

B. Monitor, inventory, model, predict and evaluate air quality and climate conditions and trends that affect, result from, or otherwise influence land management activities or planning.

C. Achieve and maintain air quality standards in cooperation with other Federal land management agencies and Federal, State, and local agencies responsible for maintaining air quality.

.03 Authority. Air resource management responsibilities are authorized under various laws and executive orders, including Federal Land Policy and Management Act, Clean Air Act as amended, and the National Environmental Policy Act. (See BLM Manual Section 7000.)

.04 Responsibility.

A. The Director and Associate Director are responsible for:

1. Establishing Bureauwide objectives, formulating and analyzing national level policies, and setting national priorities for the conduct of the air resources program;

2. Preparing, evaluating, and revising Bureau Manuals, Handbooks, and Technical References to maintain a current system of policy documentation and program guidance;

3. Providing liaison at the national level with other Federal agencies and organizations . . .

4. Ensuring internal coordination between the Air Resources Program and other Bureau Programs.

B. The Service Center Director is responsible for providing technical support to the Headquarters Office and Field Offices by:

1. Responding to Field Office requests for technical assistance and/or training;

2. Developing, testing, evaluating, and making recommendations to the Headquarters Office on the applicability of new technologies for the collection, storage and retrieval, analysis and interpretation, and application of air resource data;

3. Provide assistance and conduct air modeling to support resource management and planning analysis. In addition, evaluate and adapt air resource modeling technologies to support Bureau programs;

4. Preparing air resource handbooks, technical notes and references, and other field-oriented guidance at the direction of the Headquarters Office;

5. Providing liaison with research agencies, educational institutions, and professional organizations to maintain a "state-of-the-art" level of knowledge in air resources.

C. BIFC Director. (reserved)

D. State Directors are responsible for achieving the Bureau's air resource program objectives (.02) within their respective States by:

1. Interpreting Bureauwide air resource policies, setting State air resource program priorities, and preparing supplemental program directives for Statewide application;

2. Providing liaison with other Federal agencies, State agencies, user groups, and adjoining BLM State Offices to ensure a coordinated air resources program;

3. Evaluating Statewide air resource program effectiveness through periodic review of support activities and interagency coordination;

4. Provide training in order to maintain the necessary level of technical expertise required to meet management responsibilities;

5. Provide technical equipment and facilities necessary to accomplish State air resource program objectives.

D. District Managers are responsible for achieving Bureau and State air resource program objectives within their respective District boundaries by:

1. Interpreting Bureau and State air resource policies, setting District air resource program priorities, and preparing supplemental program directives and guidelines for District-wide application;

2. Cooperating with other Federal, State, and local agencies, user groups, and other BLM Offices as may be appropriate to ensure a coordinated air resources program;

3. Evaluating District-wide air resource program effectiveness by periodically reviewing and evaluating District work accomplishments, including technical adequacy and compliance with Bureau, State, and District policies;

4. Maintaining sufficient technical expertise within the District organization to ensure that air resource issues are identified and addressed;

5. Conduct air and climate monitoring as may be necessary to accomplish State air resource program objectives.

E. Resource Area Managers are responsible for achieving Bureau, State, and District water resource program objectives within their respective Resource Area boundaries by:

1. Identifying and addressing air resource issues and air resource needs;

2. Conducting air and climate monitoring as may be necessary to accomplish State air resource program objectives.

.05 Definitions

Air Resource - The air and atmospheric component of the ecosystem whose quality (air quality) and characteristics (meteorology and climate) the BLM influences by its management activities or utilizes in the development of analyses leading to management decisions on public lands. As a management activity, the air resource includes the consideration climate, meteorology and air quality.

Air Quality - The quality of the atmosphere as determined by the concentration of air pollutants, visibility, odors, sound, and other energy forms transmitted through the atmosphere.

Air Quality Related Values (AQRV) - Those attributes of a Class I air quality area important to the functioning of the area for the purposes for which it was established and preserved and which can be affected by air quality. AQRVs include but are not limited to visibility, flora, fauna, ecologic, historic, and cultural characteristics.

<u>Climate</u> - The composite or generalization of weather conditions of a region, such as temperature, pressure, humidity, precipitation, sunshine, cloudiness, and winds throughout the year, averaged over a series of years.

<u>Meteorology</u> - The science dealing with atmospheric phenomena and their variations such as stability, wind speed, wind direction, temperature etc. Use of the term in this document relates most generally to dispersion characteristics of the atmosphere related to the movement of air pollutants.

<u>Prevention of Significant Deterioration</u> (PSD) - An air quality management and permit process, specified in Part C of the Clean Air Act of 1977, designed to ensure that air quality in designated "clean air" areas does not significantly deteriorate beyond allowable increments of air quality or impact adversely on air quality related values, while maintaining a margin for future industrial growth.

<u>State Implementation Plan</u> - A document, developed by the State government, approved by EPA, which provides for the implementation, maintenance, and enforcement of air quality laws, standards, regulations, programs, and air pollution control strategies.

.06 <u>Policy</u>

A. The Bureau of Land Management shall manage the public lands in a manner that will protect the quality of the air resource consistent with the multiple use concept by ensuring compliance with the regulations, standards, and applicable requirements of the Clean Air Act, as amended; the Federal Land Policy and Management Act of 1976; applicable State regulations and implementation plans; and other applicable laws, regulations, and directives.

B. The Bureau of Land Management recognizes air as a resource deserving of full consideration with all other resources and uses on public lands. The air resource must be considered and incorporated into multiple-use management programs in accordance with the definition of multiple use as set forth in the Federal Land Policy and Management Act of 1976. Air quality and atmospheric values must be considered on an area-by-area basis through application of multiple-use concept, taking full account of the value and importance of the various resources present.

C. The significance of the air resource and atmospheric values relative to the other resources and uses of the area must be determined on a periodic basis or as may be necessary to evaluate new or changing uses of the public lands.

D. The Bureau must consult and coordinate with the State on the management of existing and future consumption of allowable increments of air quality degradation so as to provide for the protection of air quality and ensure the multiple use of other resources on the public lands.

E. The air resources program must provide information on air quality, atmospheric values, climate, and other air resources information needed to incorporate consideration of air resources into Bureau planning, environmental analysis, rights-of-way actions, exchanges, withdrawal, lease actions, hazardous materials management, smoke management, and other land-use and resource management activities and decisions.

F. The Bureau must maintain a professional staff and technical expertise as necessary throughout the Bureau to carry out the air resource management responsibilities related to planning, monitoring, evaluation, coordination, modeling, impact analysis, smoke management, training, promoting the understanding of air quality issues, and other matters necessary to implement the air resource policy of the Bureau.

G. The Bureau must cooperate with the other Federal land management agencies and with Federal, State, and local control agencies to assist in maintaining air quality standards, and to review proposed rules affecting air quality standards, and to review proposed rules affecting air quality and revisions to State implementation plans and State redesignations of air quality classifications of Bureau lands.

.07 Coordination

A. Early and effective coordination with other BLM resource activities and responsibilities is one of the primary objectives of the Air Resource Management Program. Effective coordination will maximize opportunities for information transfer on climate, meteorology, and air quality to assist and improve BLM management activities. Early coordination and assistance will serve to minimize potential conflicts with other management opportunities so that air quality issues do not become constraints to BLM's multiple use management responsibilities.

B. The Bureau will coordinate with other agencies and groups which have responsibilities for or are affected by air resource management actions including land management agencies, Federal, State, and local control agencies and other resource oriented user groups to assist in the preparation and review of land-use plans, issuance of permits, proposed rule changes affecting air quality, revisions of State implementation plans, and State air quality reclassifications.

.1 Air Resource Program

.11 . Background

BLM land management actions in some circumstances can have a significant effect on the air resources and in turn, air resources limitation can potentially limit BLM management actions; thus, BLM shares in the responsibility for management of the air resource with other authorities. Primary management responsibility rests with the States and the Environmental Protection Agency. The Bureau's role in air resource management is complex, involving interagency coordination, participation in State air quality related implementation plans and processes, monitoring, impact analysis, and advocacy in some situations.

.12 Description of the Air Resource

A. The properties and characteristics of the air resource have biologically fundamental and sometimes crucial relationships in the productivity and management of resources and aesthetic values of the public lands such as wilderness areas, forestlands, rangelands, fish and wildlife and their habitat, watershed, archaeological and historical values, recreational and natural scenic values.

1. Air is a dynamic, mobile, constantly changing resource that readily transcends geographic and political boundaries.

2. Air is a renewable resource within the limits of the climate and other natural processes to recycle and cleanse the air.

3. Air is a consumable resource within limits of air quality standards and prevention of significant deterioration regulations.

B. It is increasingly important for resource managers and field personnel to understand and use more and more climate/weather information in resource management. Climate is the driving force for hydrologic, biologic and ecologic processes. No other single factor has greater influence and bearing on renewable resource management. Climate as a technical discipline can, if used effectively, increase the benefit, productivity, and success of many Bureau activities.

.13 Purpose The Air Resource Program is the primary management method by which the Bureau implements the air resource management policy (Section 06) and supports related stewardship and land management responsibilities.

.14 Air Resource Program Description The Air Resource Program is composed of four major parts: (1) air resource program functional elements, (2) Washington Office, State/District Office, DSC, and BIFC responsibilities, (3) technical skills, (4) program organization.

A. Air Resource Program Functional Elements

1. Monitoring and Inventory Collection of data and information as necessary to determine, evaluate, and analyze air resource conditions and trends on the public lands and outer continental shelf, including air quality, air quality increments, climate, meteorology, sound, wind, and other energy forms transmitted through the atmosphere.

2. Technical Assistance Provide technical assistance, consultation, information, and training to other Bureau programs requiring consideration of air resources in Bureau planning, preparation of environmental documents, rights-of-way actions, withdrawal, lease actions, smoke management, hazardous materials assessments, and other land-use management activities and decisions.

3. Guidance Develop air resource management guidance and procedures for management activities on public lands to fulfill air resource policy.

4. Intergovernmental Coordination Participate in air resource planning, implementation, permit review, redesignation, rulemaking, and other decisionmaking processes of other Federal, State, and local agencies to ensure BLM concerns, views and needs are properly considered.

B. Functional Responsibilities

1. Washington Office

a. Development of air resource policy and program goals and objectives;

b. Review new, proposed, and existing regulations and laws affecting Bureau activities;

c. Develop budget, conduct planning, and develop strategies to implement programs;

d. Coordinate with other governmental agencies;

e. Establish training goals and standards;

f. Advocate air quality protection and control;

g. Provide overall program direction, coordination, and evaluation.

2. Boise Interagency Fire Center (reserved)

3. Denver Service Center (EIS/EA support)

a.

b.

4. State and District Office

The State and District Office level is the key operational level of the Bureau's air resource management program. The responsibilities of the State and District Offices to implement the air resources program of the Bureau includes the following general activities:

a. Conduct air quality, climate, and other air resource inventories and monitoring;

b. Assure BLM activities are consistent with Federal, State, and local air quality standards;

c. Coordinate BLM program plans and activities with State air quality agencies;

d. Review State implementation plans (SIP) and recommend revisions and changes to the SIP as necessary to meet BLM management needs.

e. Evaluate consumption and existing use of air quality increments and determine influence on existing and future programs and activities;

f. Provide technical support and consultation to other State Office and District Office programs;

g. Incorporate climate, meteorology and air quality considerations into planning processes, including prescribed fire and smoke management.

h. Conduct air quality modeling, special air quality monitoring, and evaluations;

i. Assure that the appropriate air quality control and protection methods and emission and ambient air quality levels are contained in lease stipulations and other Bureau actions requiring protection of air quality and air quality related values; and

j. Conduct air quality training programs.

C. Technical Skills

1. The technical skills required to carry out the major elements of the air resource program are found in the technical disciplines of; (1) air quality; (2) meteorology/biochemistry; (3) air pollution control; and (4) air quality modeling.

2. The skills represented by these disciplines are those necessary to carry out fully the requirements of applicable laws, standards, and regulations.

3. Throughout the Bureau, air resource workload and requirements for certain technical skills varies considerably from time to time and from State Office to State Office.

D. Program Organization

1. The State Office is normally the most appropriate organizational level for the air quality specialists because of the far reaching nature of the air resource, the need for close coordination with State government, and the support role of the air resources program.

2. Air resource management involves large land areas usually much greater than Resource Areas or Districts, thus Bureau coordination with State agencies and Federal agencies is better accomplished from State Office usually co-located in State capitols.

.2 <u>Air Resource Management Activities</u>

.21 <u>Purpose</u> This section describes the process and activities through which the bureau carries out its Air Resource Management responsibilities and incorporates Air Resource Management into the Bureau planning process, programs, and management activities including land use planning, wilderness study, leases, withdrawals, rights-of-way, environmental analyses and impact statements, and smoke management as discussed in the following sections.

.22 <u>Types of Processes</u>

A. <u>Land Use Planning Activities</u>

1. <u>Procedures</u>

a. The air resource program will provide information (i.e., alternative management situations, monitored data, etc.) necessary for developing management and/or activity plans which include Management Situation Analyses, Resource Management Plans, and Management Framework Plans.

b. Early in each management planning process (typically when identifying the existing management situation), the air resource management program will determine those air resource factors which require, limit, or influence particular Bureau management actions.

c. The air resource management program will be fully integrated with other multiple use resource programs in order to identify:

(1) conflicting, limited, or restricted areas such as PSD Class I or nonattainment areas.

(2) allowable resource uses and threshold levels such as PSD increments, hazardous pollutant emission levels, and/or climatic limitations.

(3) air resource characteristics, goals, and objectives sought.

(4) protective measures and control practices (e.g., lease stipulations) required to preserve or enhance air resource values.

(5) sensitive areas requiring more detailed activity planning to assess potential impacts.

(6) air resource monitoring and modeling requirements.

2. Coordination Requirements

Early coordination with Bureau personnel, as well as outside agencies, is necessary for timely, balanced integration of air resource management considerations into multiple-use planning activities. This requires coordination with the planning team and responsible Bureau officials, as well as affected Federal, State, and local agencies, and Bureau specialists as necessary.

B. Wilderness Areas

1. Procedure

a. Wilderness values are made up of a number of resources including air quality. The air resource and air quality factors of BLM wilderness areas will be managed in such a way and to the extent that will protect their wilderness character and leave them unimpaired for future use and enjoyment as wilderness.

b. The Bureau will continue to manage wilderness study areas (WSA's) as Class II air quality areas. Coordination with the State will be maintained to assure that the Class II air quality classification will continue to assure that suitability of the WSA as a wilderness area is not unduly or permanently impaired and to afford environmental protection.

c. If a State reclassifies any BLM managed wilderness area to Class I air quality, the Bureau shall exercise its affirmative responsibility to protect the air quality related values (including visibility) within the Class I area. Air quality reclassification is the prerogative of the States and it must follow a process mandated by the Clean Air Act Amendments of 1977 involving a study of health, environmental, economic, social, and energy effects, a public hearing, and a report to the Environmental Protection Agency. BLM shall participate in this State initiated process where BLM lands are involved.

2. <u>Prescribed Parameters of Discretionary Authorized Responsibility</u>

a. The Federal Land Manager must exercise affirmative responsibility to protect air quality and air quality related values in Class I areas under his management (Clean Air Act as amended August 1977).

b. The Federal Land Policy and Management Act, Section 603(c) reads in part that during the period of review of such (WSA) areas and until Congress has determined otherwise, the Secretary shall continue to manage such areas according to his authority under this Act and other applicable laws in a manner so as not to impair the suitability of such areas for preservation as wilderness. FLPMA Section 603(c) also requires in managing the public lands that the Secretary shall by regulation or otherwise take any action required to prevent unnecessary or undue degradation of the lands and their resources or to afford environmental protection.

3. Coordination Requirements

a. Air resource specialists will coordinate with the BLM wilderness program for a case by case determination of air quality related values and where air quality related values may be of concern.

b. Air resource specialists will coordinate with the appropriate State and Federal regulatory agencies in exercising BLM's affirmative responsibility to protect the air quality related values (including visibility) within any Class I area it manages.

C. Leases, Withdrawals, Rights-of-Way, Exchanges

1. Procedures

a. BLM will include in all land transfer instruments, enforceable stipulations designed to ensure compliance with all applicable State, Federal, and local regulations, implementation plans, or standards.

b. BLM will ensure that holders of transfer agreements will adopt practices which minimize air pollution where necessary. Supplemental measures might include, but are not limited to control of non-regulated pollutants, supplemental pollution control, special management or industrial practices, or contingency plans triggered by meteorological conditions.

c. BLM will not undertake any land transfer instruments unless the applicants can demonstrate, to the satisfaction of the relevant approving authority, that the action will not circumvent ambient air quality standards. For example, BLM will not grant a lease if the lessee intends to exclude public access so that the air resource over the leased land would not be considered "ambient air" as defined in State or Federal standards, and thus not be subject to those standards.

d. Where necessary, BLM will include stipulations requiring the applicant to gather data, or to allow access to transferred lands to BLM or other agencies in order to gather data.

e. BLM will adhere to the discretionary authority parameters detailed in Section 301(c) of FLPMA, and Section 176(c(of the Clean Air Act. Specifically:

(1) FLPMA Section 302(c) states, in part: "The Secretary shall insert in any instrument providing for the use, occupancy, or development of the public lands a provision authorizing revocation or suspension, after notice and hearing, of such instrument upon a final administrative finding of a violation of any term or condition of the instrument, including but not limited to, terms and conditions requiring compliance with regulations under Acts applicable to the public lands and compliance with applicable State or Federal air or water quality standard or implementation plan: . . . ."

(2) The Clean Air Act, Section 176(c) states, in part: "No department, agency, or instrumentality of the Federal Government shall (1) engage in, (2) support in any way or provide financial assistance for, (3) license or permit, or (4) approve any activity which does not conform to a (state implementation) plan after it has been

approved and promulgated under Section 110. ... The assurance of conformity to such a plan shall be an affirmative responsibility of the head of such department, agency or instrumentality."

2. Coordination Requirements

a. BLM will coordinate any enforcement actions undertaken for regulation noncompliance with the appropriate regulatory authority (i.e., the U.S. Environmental Protection Agency and/or State government.)

b. BLM will take an active role in the development and review process for air quality regulations by State, Federal, and local agencies in order to ensure that BLM stipulations are consistent with those regulations.

D. Environmental Impact Statements (EIS) and Assessments (EA)

1 Procedures It is the policy of the Bureau to fully consider if air quality is a concern in each specific EIS or EA as required by National Environmental Policy Act (NEPA). Determination of concern will be made through the review of description of the proposed action, scoping meetings, and discussions with BLM air resource specialists. It is further the policy of the Bureau to

fully coordinate the EA and EIS air resource analysis and conclusions with other affected, responsible, or concerned agencies, organizations, and/or individuals.

The air quality analyses performed are for the purpose of meeting the broader environmental analysis requirements and concerns of NEPA and not for more specific regulatory purposes as those performed by the State or EPA. The scope and depth of analysis will be dictated by the nature of the proposed action to be addressed in the NEPA process. Because the air resource does not adhere to administrative or physical boundaries, the extent of the impact area to be addressed may often be broader than more topographically defined resources such as soil, vegetation, etc.

The air resource analysis will also provide appropriate climatological and meteorological analysis in sufficient detail to address the proposed action.

2. Coordination

The air resource specialists will participate with the analysis teams on those statements and assessments which have air quality as potential issues. Early coordination with other resource team members where resource interaction would occur such as socio-economics to assure time effective analysis development and analysis compatibility.

E. Prevention of Significant Air Quality Deterioration

1. Procedures It is the policy of the Bureau to take an active coordination role with the State in the State's responsibility for managing the existing use and future consumption of allowable increments of air quality degradation in a manner that will provide for the protection of air quality as well as the multiple use and development of other resources. BLM will manage its lands consistent with the current PSD classification. BLM will analyze management options for their effect on PSD increment consumption and incre- ment remaining for other uses and effect on future management options. It is the responsibility of BLM to identify potential conflicts in resource use and air quality limitations.

2. Coordination Redesignation is a process within the PSD program that could have signifi- cant implications to BLM multiple use management. It is, therefore, the policy of BLM to begin early coordination with the redesignating authority to assure BLM's present and future multiple use management responsibilities are adequately considered.

The BLM will meet its affirmative responsibility to protect the air quality related values (including visibility) of any BLM managed lands within a Class I area and to consider in consultation with the administrator of EPA whether a proposed major emitting facility will have an adverse impact on such values.

BLM should also coordinate with the State and EPA to review permit applications within Class II areas which bear on Bureau management activities.

F. Redesignation

1. Procedures

2. Coordination

State

Redesignation Authority

Indian

State

G. State Implementation Plan

1. Program Procedure

a. The BLM shall actively participate in the development and revisions of the State Implementation Plan (SIP) that will affect the planning and management activities of the BLM. This involvement includes but is not limited coordination with the State agency responsible for developing the SIP.

b. BLM managers and specialists must be aware that Section 176(c) of the Clean Air Act as amended states that no Federal agency shall (1) engage in, (2) support in any way or provide financial assistance for, (3) license or permit, or (4) approve, any activity which does not conform to the SIP.

c. Areas that do not meet National Ambient standards, called nonattainment areas, require special consideration when planning and implementing BLM activities that may impact air quality in these areas.

2. Coordination

a. Coordination will be done internally in BLM to assure that SIP requirements are considered in all BLM activities.

b. Coordination will be done with other Federal, State, and local agencies when these agencies are involved with our activities or they have the lead role. The time frame for this coordination is critical for actions that other agencies have the lead and a rigid time schedule. These actions include but are not limited to reclassification of areas, revision of existing standards, and propagation of new standards.

H. Smoke Management

1. Procedure The purpose of smoke management is to minimize air quality and visibility impairment of smoke from prescribed burning on smoke sensitive areas by identifying and avoiding smoke sensitive areas, reduce emissions, and dispense smoke well.

a. The continued and expanded use of prescribed fire as a basic management technique for maintaining and enhancing productivity of public forest and rangelands in dependent upon the management of smoke from prescribed fires.

b. Prescribed fires will be planned and conducted to minimize the impact of smoke by combining favorable meteorological transport and dispersion conditions with prescribed techniques to reduce smoke emissions.

c. Smoke management will be included in all prescribed burn plans where smoke sensitive areas may be impacted by emissions from the prescribed burn.

d. Air modeling, or other predictive methods and best available meteorological and forecast information will be used to determine potential smoke impacts.

e. Smoke management activities and planning will be conducted in compliance with State, local, and Federal smoke management programs, regulations and standards, and in full cooperation with State, local authorities, other Federal agencies, and the private sector to collectively reduce the impact of smoke on public health and welfare.

2. Prescribed Parameters of Discretionary Authority and Responsibility

Prescribed fire managers should exercise personal and legal responsibility to assure the success of smoke management programs by voluntarily curtailing burning if, in their opinion, the airshed is becoming overloaded with smoke, or local weather factors are likely to create smoke problems even though no burning restrictions have been issued.

3. Coordination

Assist fire management in assessing smoke impacts, coordinate smoke impact assessments with local central authorities.

.3 Inventory

.31 Purpose and Objectives

This section describes the purpose and objectives of air resources inventory in the BLM. The purpose of an air resource inventory is to provide air resource data to meet BLM program, planning, and management activity needs. The objectives are to provide, on a timely basis, the necessary data to establish existing air resource conditions and determine air resource trends for incorporation into Bureau programs, plans, and management decisions.

.32 Procedures

The BLM will inventory air resource data as needed to meet BLM program management needs. The inventory will include but not be limited to climate, meteorology, air quality, and air quality effects data.

The BLM will use existing valid air resource data and air resource data sources whenever possible. These sources include but are not limited to NOAA, EPA, other Federal and State agencies, and universities.

Any inventory done as part of an established network shall be reported and archived according to the procedures of that network.

.33 Reporting and Archiving

The BLM shall maintain inventory data. The method of reporting and archiving will be determined on a case by case basis. As procedures are established for reporting and archiving, the existing data shall be included in the new procedures as applicable.

.34 Coordination

The BLM will coordinate with State and Federal agencies and other sources in acquiring and sharing air resource data.

The BLM will determine air resource data user needs and the appropriate format for air resource data utilization.

.4 Air Resource Monitoring

.41 Purpose and Objectives

BLM will conduct air resource monitoring when necessary to:

A. obtain useful data describing the air resource to support numerous Bureau activities (i.e., Resource Management Plans, reclamation plans, capability analyses, etc.).

B. cooperate with other data user groups to the fullest extent possible, limiting duplication of efforts and program costs.

C. develop new monitoring techniques, if necessary, for implementation of Bureau activities.

D. support multi-agency monitoring programs where it is in the Bureau's or national interest.

.42 Procedures

A. The Bureau will monitor air resource parameters (e.g., meteorology, climate, and air quality) only where adequate, valid, usable information is not available from other sources. Air resource monitoring will be conducted in coordination with other data user groups whenever feasible.

B. Essential air resource monitoring will be initiated by the Bureau to:

1. support other multiple use resource programs.

2. carry out a variety of management actions, such as management planning, Environmental Impact Statements and Environmental Assessments, Air Quality regulatory requirements, land use agreement stipulation enforcement, etc.

3. determine air resource impacts to and/or effects on BLM resources due to Bureau or outside generated emission sources.

C. The Bureau may cooperatively participate in external air resource monitoring programs (i.e., National Atmospheric Deposition Program, Weather Service network, etc.) where it is in the Bureau's or national interest.

D. All air resource monitoring must be conducted based upon a quality assurance program and methods appropriate for the intended use of the data.

E. Standard monitoring methodology (e.g., U.S. Environmental Protection Agency reference or equivalent air quality methods, National Weather Service methods, or other standardization as needed to ensure uniformity in monitoring activities) should be applied except under special circumstances.

.43 <u>Reporting Requirements</u>

A. Air resource monitoring data are to be reported to and archived at least annually.

B. Brief descriptions of the quality assurance procedures applied when collecting monitoring data are to accompany the data inventory.

C. Validated air resource monitoring data collected on a cooperative basis will be reported to and shared with cooperative users without reservation.

.44 Coordination Requirements

A. Air resource monitoring will be conducted cooperatively with other data user groups whenever feasible.

B. Prior to implementing a cooperative monitoring program, specific purpose, objectives, authority, scope, responsibility, deliverable items, reporting, and funding requirements will be delineated and agreed to by all cooperative parties.

C. Monitoring data indicating stipulation violations shall be reported to the responsible regulatory authority for appropriate action as soon as possible.

.5 Air Resource Modeling

.51 Purpose and Objectives

A. Regulatory Modeling Air resource modeling is often one of the most complex, data-intensive tools which the Federal Land Manager must use to support program activities. Air quality modeling can be simplified into three types. The first type is modeling to receive an approved emissions permit from a designated regulatory authority. This modeling requires extensive meteorological data, relatively complete conceptualized project emissions by amount and species, and primarily addresses the limitations of the PSD increment or ambient standards in localized areas. The Bureau must have at its disposal modeling tools and expertise to conduct detailed reviews of this type of modeling to ensure that the best interests of the public's trust are forwarded through responsible management.

B. <u>Modeling for NEPA Analyses</u> The second type of modeling which must be used by the Federal Land Manager is performed to support land management decisions by projection of air resource consequences. This type of modeling generally addresses consequences over large geographic areas from projects whose emissions rates by amount and species are less precisely known. Extensive meteorological data sets are often lacking and analyses are designed by best scientific judgment to result in believable and defensible worst case potential impacts for NEPA disclosure documents.

C. <u>Resource Management Support Modeling</u> The third type of modeling is carried on by the agency internally to site monitoring equipment, delineate areas of critical environmental concerns, assist resource management planning, and provide support to other resource activities. This type of modeling can be made up of various elements of the other two but in essence, is completed to increase knowledge of the natural systems the Bureau manages. Often this type of modeling may be completed as input to other resource assessment models such as range forage production models or wildlife population dynamics models.

D. Legislative Backdrop While the first type of modeling concerns the stipulations of the Clean Air Act, the second type of modeling is firmly grounded in the requirements of the National Environmental Policy Act, the Federal Land Policy and Management Act, the Wilderness Act, and the Clean Air Act itself. The third type of modeling is not necessarily directly driven by legislation, but is often the only tool available to make wise resource management decisions. These decisions themselves may be driven directly by various statutes or executive orders. Thus, under the requirements of legislation, the BLM and other Federal Land Managers must assume responsibility for completion of scientifically defensible analyses. BLM specialists must have the modeling capability and technical and expertise to correctly conduct or supervise this type of modeling to guarantee that legislative responsibilities are met.

.62 Program Procedures

A. Modeling Activities After recognizing air resource modeling as an indispensable tool and element of air resource management, it is the policy of the Bureau to fully and correctly integrate air resource modeling into its management activities. Bureau air resource modeling must be conducted so as to be technically defensible to support the best interest of the public and the agency. Technical defensibility will be achieved through state-of-the-science modeling tools and professional expertise.

1. It is also the policy of the Bureau to develop modeling tools and professional expertise to support this policy by:

(a) Increasing the timeliness and technical excellence of Bureau studies while reducing costs by using "in-house" modeling capabilities to compliment the Bureau's unique legislated responsibilities as a Federal Land Manager.

(b) Developing uniform modeling guidelines, presenting standard approaches tempered by professional judgment on the scope of analysis, project funding, and data availability. The goal of these guidelines shall be to enhance consistency and technical supportability of Bureau studies.

(c) Consulting qualified Bureau personnel to determine if modeling is required and to review proposed methodology and analysis results.

2. This may also necessitate the development of state-of-the-science models and procedures, where none are otherwise available, designed to support Bureau activities including, but not limited to:

(a) Developing alternatives for management actions which assure, to the best possible extent, compliance with State Implementation Plans and other legislated air resource considerations.

(b) Developing lease tract ranking strategies and decisions.

(c) Determining lease stipulations.

(d) Supporting smoke management programs.

(e) Siting monitoring equipment.

(f) Conducting detailed reviews, if necessary, of industrial applicant's emissions permit applications.

(g) Determining geographic areas of crucial management concern including such topics as hydrogen sulfide risk areas, winter feeding grounds, and public nuisance due to air resource impacts.

(h) Providing climatological information for range, wildlife and watershed management decisions, as appropriate.

(i) Determining appropriate methodology for ensuring modeling consistency, supportability, and repeatability.

.53 Reporting Requirements Although air resources has a body of jargon which succinctly expresses complex technical concepts, Bureau air resource modeling information transmittals (such as technical reports and EIS sections) will be written to be understandable to as general an audience as is practical. Modeling analyses shall be provided in a timely manner.

.54 Coordination Requirements Due to the often complex and sometimes controversial nature of air resource analyses, close and early coordination with Federal, State, local, and private agencies and individuals will be usually indispensable. The sensitive nature of gathering appropriate date and choosing assumptions and models to complete a modeling analysis may necessitate the involvement of a qualified BLM air resources specialist.

.6 Air Resource Training and Education

.61 Purpose and Objectives

A. In order to fully integrate Air Resource Management considerations throughout the Bureau, and as one of the most recent programs to be implemented by the Bureau, there is a special need for Air Resource Management training of both personnel who routinely conduct air resource activities and the Bureau as a whole (particularly other program specialists and management). In order to accomplish these training needs, the Air Resource Specialists will to conduct conferences, workshops, and specialized training (such as Environmental Impact Analysis training, etc.). Particular emphasis is needed to identify and implement the unique Air Resource Management responsibilities.

B. Training of the specialists is necessary to maintain "state-of-the-art" technical awareness, both to properly manage the resource and to effectively interact with resource user groups (i.e., industry and environmentalists). The Bureau will make training resources available in order to maintain the necessary level of technical expertise required to meet management responsibilities (including budgetary considerations).

C. Given the limited availability of specialized training within the Bureau, and also from other Federal agencies, the Bureau will make outside training sources available where applicable (especially when the private sector is the only available source). The Bureau may also utilize workshops, conferences, meetings, and other training techniques (e.g., self instructional courses) in order to meet training objectives.

.62 Procedures

Instruments of agreement (e.g., cooperative agreements) and normal procurement procedures will be needed to implement the Air Resource Management training program.

.63 Reporting Requirements

Existing reporting requirements will be followed through the training management program.

.64 Coordination Requirements

All training activities and educational materials will be conducted and/or coordinated through existing training and librarial management programs, particularly to present training to other Bureau employees (nonspecialists).

C. Given the limited availability of specialized training within the Bureau, and also from other Federal agencies, the Bureau will make outside training sources available where applicable (especially when the private sector is the only available source). The Bureau may also utilize workshops, conferences, meetings, and other training techniques (e.g., self instructional courses) in order to meet training objectives.

.62 Procedures.

Instruments of agreement (e.g., cooperative agreements) and normal procurement procedures will be needed to implement the Air Resource Management training program.

.63 Reporting Requirements.

Existing reporting requirements will be followed through the training management program.

.64 Coordination Requirements.

All training activities and educational materials will be conducted and/or coordinated through existing training and internal management programs, particularly to present training to other Bureau employees (nonspecialists).

BLM Air Resource Staff

Mr. Russ Hansen (Air Contact) U.S. Bureau of Land Management Alaska State Office 701 'C' Street, Box 13 Anchorage, AK 99513	(907) 271-5069
Mr. Dan McGlothlin (Air Coordinator) U.S. Bureau of Land Management Arizona State Office 3707 North 7th Street Phoenix, AZ 85014	FTS 261-5512 (602) 241-5512
Mr. Phil Sielaff (Climate Coordinator) U.S. Bureau of Land Management Boise Interagency Fire Center 3905 Vista Avenue Boise, ID 83705	FTS 554-9446 (208) 334-9446
Ms. Lois Payne (Air Coordinator) U.S. Bureau of Land Management California State Office 2800 Cottage Way Sacramento, CA 95825	FTS 460-4725 (916) 970-4725
Mr. Scott Archer (Air Specialist) U.S. Bureau of Land Management Colorado State Office 2020 Arapahoe Street Denver, CO 80205	FTS 564-7122 (303) 294-7122
Mr. Lee Stevens (Air Specialist) U.S. Bureau of Land Management Colorado Oil Shale Project Office P.O. Box 580 Grand Junction, CO 81502	FTS 323-0379 (303) 245-6700
Mr. Tom Hewitt (Air Contact) U.S. Bureau of Land Management Eastern States Office 350 South Pickett Street Alexandria, VA 22304	FTS 274-0070 (703) 274-0070 (All States bordering and East of the Mississippi River)
Mr. Steve Ellis (Air Coordinator) U.S. Bureau of Land Management Idaho State Office 3380 Americana Terrace Boise, ID 83706	FTS 554-9516 (208) 334-9516
Mr. Harlan Hayes (Air Coordinator) U.S. Bureau of Land Management Montana State Office P.O. Box 36800 Billings, MT 59107	FTS 585-6474 (406) 657-6474 (Also North and South Dakota)

BLM Air Resource Staff (cont'd)

Mr. Jim McGlothlin (Air Contact) U.S. Bureau of Land Management Nevada State Office P.O. Box 12000 Reno, NV 89520	FTS 470-5455 (702) 784-5455
Mr. Chris Anderson (Air Specialist) U.S. Bureau of Land Management New Mexico State Office P.O. Box 1449 Santa Fe, NM 87501	FTS 476-6565 (505) 988-6565 (Also Kansas, Texas, and Oklahoma)
Mr. Bill Brookes (Climate Coordinator) Dr. Bob Clark (Smoke Coordinator) U.S. Bureau of Land Management Oregon State Office P.O. Box 2965 Portland, OR 97208	FTS 429-2253 (503) 231-2253 (Also Washington)
Dr. Bill Wagner (Air Specialist) U.S. Bureau of Land Management Utah State Office 324 South State Street Salt Lake City, UT 84111	FTS 588-3125 (801) 524-3125
Mr. Al Riebau (Air Specialist) U.S. Bureau of Land Management Wyoming State Office P.O. Box 1828 Cheyenne, WY 82001	FTS 328-2068 (307) 772-2068 (Also Nebraska)
Mr. Stan Coloff (Air Specialist) U.S. Bureau of Land Management Washington Office (WO-222) Room 909, Premier Building 18th & 'C' Streets, N.W. Washington, DC 20240	FTS 653-9210 (202) 653-9210

FS Air Resource Staff

Ronald L. Russell (Rge/WS) Forest Service Northern Region (R01A) P.O. Box 7669 Missoula, MT 59807	FTS 585-3233 (406) 329-3233 (MT, N ID, NW SD)
Dennis V. Haddow (A & FM) Forest Service Rocky Mountain Region (R02A) P.O. Box 25127 Lakewood, CO 80225	FTS 776-9562 (303) 236-9562 (CO, KS, NE, SD, E WY)
Toby Hanes (S/W) Forest Service Southwestern Region (R03A) 517 Gold Ave., SW Albuquerque, NM 87102	FTS 474-1835 (505) 766-1835 (AZ & NM)
Clifford R. Benoit (S/W) Forest Service Intermountain Region (R04A) 324 25th Street Ogden, UT 84401	FTS 586-5594 (801) 625-5594 (S ID, NV, UT, W WY)
Bob Doty (WS) Forest Service Pacific Southwest Region (R05A) 630 Sansome Street San Francisco, CA 94111	FTS 556-1564 (415) 556-1564 (CA & HI)
Charlotte Hopper (A & FM) Forest Service Pacific Northwest Region (R06A) P.O. Box 3623 Portland, OR 97208	FTS 423-5434 (503) 211-5434 (OR & WA)
Keith R. McLaughlin (SW & A) Forest Service Southern Region (R08A) 1720 Peachtree Road, NW Atlanta, GA 30367	FTS 257-2692 (404) 881-2692 (All states from TX east and KY/VA south)
Harry Parrott (L WS & M) Forest Service Eastern Region (R09A) 633 West Wisconsin Avenue Milwaukee, WI 53203	FTS 362-3342 (414) 291-3342 (All states from MO/MN east and IL/MD north)
Tom Sheehy (LM & WS) Forest Service Alaska Region (R10A) P.O. Box 1628 Juneau, AK 99802	(907) 586-7247 (AK only)

FS Air Resource Staff Cont'd

James G. Byrne (WS & A)
Forest Service
Washington Office (W01B)
P.O. Box 2417
Washington, DC 20013

FTS 235-8096
(703) 235-8096

Richard W. Fisher (WS & A)
Douglas G. Fox (AQ & AS Res)
Forest Service (S28A)
Rocky Mountain Forest
and Range Experiment Station
240 West Prospect Street
Fort Collins, CO 80526

FTS 323-1232
FTS 323-1231
(303) 224-1231

David V. Sandberg (F & A Res)
Forest Service
Forestry Sciences Laboratory (R06FOSA)
4507 University Way, NE
Seattle, WA 98105

FTS 399-7815

Charles K. McMahon (Smoke Chemistry)
Forest Service
Southern Forest Fire Laboratory
Rt. 1, Box 182-A
Dry Branch, GA 31020

FTS 238-0204
(912) 744-0220

NPS Air Resource Staff

Dr. William Anderson Mr. David Sherman National Park Service National Capitol Regional Office 1100 Ohio Drive, S.W. Washington, DC 20242	FTS 426-6660
Ms. Mary Foley National Park Service North Atlantic Regional Office 15 State Street Boston, MA 02109	FTS 223-7765
Mr. John Karish National Park Service Mid-Atlantic Region 209-B Ferguson Building University Park, PA 16802	FTS 597-7974
Mr. Ken Hulick National Park Service Southeast Regional Office 75 Spring Street Atlanta, GA 30303	FTS 242-4916
Dr. Michael Ruggerio National Park Service Midwest Regional Office 1709 Jackson Street Omaha, NE 68102	FTS 864-3438
Mr. Cecil Lewis National Park Service Rocky Mountain Regional Office P.O. Box 25287 Denver, CO 80225	FTS 236-8647
Dr. Keith Yarborough National Park Service Southwest Regional Office P.O. Box 728 Santa Fe, NM 87501	FTS 476-6412
Ms. Shirley M. Clark National Park Service Pacific Northwest Regional Office 2001 6th Avenue Seattle, WA 98121	FTS 399-4235

<u>NPS Air Resource Staff Cont'd</u>

Mr. Don Christensen National Park Service Western Regional Office P.O. Box 36063 San Francisco, CA 94102	FTS 556-8373
Dr. Gary Ahlstrand National Park Service Alaska Regional Office 2525 Gambell Street, Room 206 Anchorage, AK 99503	(907) 271-4239
National Park Service Air Quality Division P.O. Box 25287 Denver, CO 80225	
John Christiano, Division Chief Betty Frantum, Program Assistant	(303) 236-8765
Mark Scruggs, Research Branch Chief Jim Bennett, Ecologist Don Henderson, Research Meteorologist Ken Stolte, Biologist Vacant, Monitoring Specialist	(303) 236-8770
Christine Shaver, Policy Branch Chief Erik Hauge, Env. Specialist D. Brian Mitchell, Env. Proct. Spec. Darwin Morse, Env. Proct. Spec. David Joseph, Env. Proct. Spec.	(303) 236-8761
Miguel Flores, Permit Review Branch Chief John Bunyak, Env. Engineer Deborah Mangis, Env. Specialist Gail Brown, Computer Specialist	(303) 236-8765
Molly Ross, Staff Assistant Debby Peck, Program Analyst National Park Service Air Quality Division 18th and 'C' Streets, NW Washington, DC 20240	FTS 343-4911 FTS 343-3293
William C. Malm, Research Physicist National Park Service Air Quality Division 301 South Howes, Room 343 Fort Collins, CO 80521	(303) 221-5341

BR

IN REPLY REFER TO

CO-933
7700

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
1037 20th STREET
DENVER, CO 80202

FYI - Scott

October 7, 1982

Information Memorandum No. CO-83-4
Expires: 9/30/84

To: District Managers

From: State Director, Colorado

Subject: Air Resource Management Audio-Visual Training Aids

Several audio-visual training aids have been assembled in the State Office to assist field personnel in understanding air resource management issues. The enclosed list identifies available video tape and slide/cassette programs with brief descriptions of each program's content. With the exception of the "Visibility" video tape, all programs are general in nature and appropriate for viewing by all Bureau personnel. Several presentations also have support documentation to assist the viewers.

These programs are available on loan from Linda Lewis, Employee Development Specialist, FTS 327-2347. Questions concerning technical content should be directed to Scott Archer, Air Quality Specialist, FTS 327-3264.

Bob Moore

Associate

Enclosures

U.S. Department of the Interior
Bureau of Land Management
Washington, DC 20240 (202) 653-9210

AIR RESOURCE MANAGEMENT: An Introductory Session
1 Tape (35 Minutes); 1981

AIR RESOURCE MANAGEMENT

Prepared by BLM's Washington Office (Lands & Renewable Resources Staff), this program provides a two part introduction for all Bureau personnel on Air Resource Management concepts, terminology and acronyms of this new area of management responsibility. Part 1 reviews the legal requirements and foundation for air resource management and the roles and responsibilities shared by BLM, state governments, the EPA and other Federal land managers. Part 2 examines various categories of air pollution sources on public lands and discusses how climate and meteorology affect the transport and concentration of air pollutants. An outline accompanies the video tape defining terms and describing management concepts.

Appalachian Community Service Network
1200 New Hampshire Ave., NW. Suite 240
Washington, DC 20036 (202) 331-8100

CLEAN AIR AND THE PARKS
2 Tapes (60 Minutes each); 1981

COPYRIGHTED MATERIAL
NOT FOR PUBLIC RELEASE

CLEAN AIR AND THE PARKS

Produced by the National Parks and Conservation Association and originally aired live on March 29, 1981, this program examines several controversial air quality issues including Clean Air Act revisions, visibility, acid rain, and other aspects of the PSD program. Barbara Brown (National Park Service) presents a half hour general overview with additional comments by scientists Drs. William Malm, Gary Glass and John Skelly. A 1½ hour panel discussion follows, including call-in session questions, hosted by Paul Pritchard (NPCA Executive Director) and including Richard Ayers (Clean Air Coalition), Paul Kaplow (Arco), Edward Macias (Washington University), George Rejhon (Canadian Embassy), Paul Stolpman (EPA, Office of Policy Analysis), and Jack Taylor (Edison Electric Institute).

WVIA-TV Public Braodcasting Center
Old Boston Road, Jenkins Township
Pittston, PA 18640 (717) 344-1244

H.R. 6161 - AN ACT OF CONGRESS
1 Tape (60 Minutes); 1980?

H.R. 6161

AN ACT OF CONGRESS

Produced by Guggenheim Productions, Inc., under grants by the National Endowment for the Humanities and Westinghouse Electric Corp., and aired May 27, 1982 on WETA-TV, this program examines how the Clean Air Act was amended in 1977. The program focuses on changes to vehicle emission levels and deadlines for compliance, but also demonstrates the basic process followed for other sections of the amendment. H.R. 6161 is followed through sub- and full-committee hearings, through the House Rules committee and to a floor vote, and final passage by the House and Senate. Principle Congressmen involved include Paul Rogers (D-FL) representing health and environment interests, with John Dingell (D-MI) and James Broyhill (R-NC) representing automobile industry interests. THE REGULATORS - OUR INVISIBLE GOVERNMENT provides an interesting follow-up to this program.

WVIA-TV Public Broadcasting Center
Old Boston Road, Jenkins Township
Pittston, PA 18640 (717) 344-1244

THE REGULATORS - OUR INVISIBLE GOVERNMENT
1 Tape (50 Minutes); 1982

THE REGULATORS

OUR INVISIBLE GOVERNMENT

Produced by ROBERT PIERCE/Films, Inc., under grans by Bendix Corp. and the Office of Environmental Education (US Dept. of Education), and aired May 28, 1982 on WETA-TV, this program "explains how the laws of Congress are translated by an army of little known bureaucrats into regulations effecting every american's life and livelihood." Section 169A of the 1977 Clean Air Act Amendments is followed through development, review and final implementation, three years after Congress passed the law concerning air pollution in pristine areas. Principle persons involved include Gordon Anderson (photographer and environmentalist) who originally presented the problem to Congress, David Hawkins (EPA, Chief of Air Pollution Programs) responsible for developing the regulations, Barbara Brown (NPS, Chief of Air Quality) representing the National Park Service, and Johnnie Pearson (EPA, Standards and Implementation) who wrote the regulations. H.R. 6161 - AN ACT OF CONGRESS provides an interesting introduction to this program. A film guide accompanies the video tape to assist in viewing.

New England Interstate Water
  Pollution Control Commission
607 Boylston Street
Boston, MA 02116 (617) 437-1524

A CAUSE FOR ALARM: Acid Precipitation in the Northeast
Slide/Cassette Tape (26 Minutes); 1981

A CAUSE FOR ALARM

Produced by the New England Interstate Water Pollution Control Commission and Northeast States for Coordinated Air Use Management, this program examines the complex issues of acid precipitation (acid rain), particularly in the Northeast. Issues addressed include: definitions of acidity, pH, and alkalinity and buffering capacity; identification of sources, chemical processes and long range transport involved in acid rain; and impacts to aquatic and terrestrial ecosystems, drinking water, manmade structures, visibility and human health. An introductory brochure and program script accompany the slide/tape program to assist in viewing.

U.S. Environmental Protection Agency
Air Pollution Training Institute
Research Triangle Park, NC 27771 (919) 541-2498

VISIBILITY
1 Tape (58 Minutes); 1979?

VISIBILITY

Produced by EPA's Air Pollution training institute, this program provides a very technical introduction to visibility monitoring and interpretation. Dr. William C. Malm (USEPA/EMSL-Las Vegas) and Dr. Ken O'Dell (Northern Arizona University) discuss human perceptions of visibility and the factors which influence them. Major topics include measurement of vista contrast, visual range, and color. The speakers conduct demonstrations of air pollution effects on visibility. An outline accompanies the video tape defining terms and describing measurement/interpretation concepts.

Valley Vision Television
Box 8718
Aspen, CO 81612 (303) 923-5591

ON THE AIR
1 Tape (29:34 Minutes);1982

ON THE AIR

Produced by Mary Mann of Valley Vision Television and aired on KRMA-TV October 1, 1982, this program examines issues surrounding the reauthorization of the Clean Air Act and the resulting impacts to Western Colorado. The program focuses on the costs of polluting clean versus the need to reduce foreign oil dependence and spur economic growth. Issues examined include visibility, acid rain, and budget cuts within the EPA. Includes interviews with Steve Durham (EPA), John Firor (Formerly with the Nat'l Center for Atmospheric Research), Dennis Haddow (USFS), Bobby Hall (American Petroleum Institute), Gary Hart (Senator-CO), Anne Gorsuch (EPA), Kathleen Sullivan (Colorado State Representative), James Watt (Secretary of the Interior), Timothy Wirth (Congressman-CO), Bob Yuhnke (Environmental Defense Fund), and others.

MANAGER RELATIONS

Course 7000.1
Instructor: Huff

MANAGER - SPECIALIST PANEL

Objectives

1. Identify common communication barriers between specialists/ professionals and their managers - and to be able to do something about it.

2. Identify common elements of an "ideal" soil and water program, and how to move from "today" to ideal.

3. Identify common perceptions of "professional behavior," and how to behave in a "professional manner."

Panel Members

Thomas J.Allen, Associate State Director, Arizona
Ben F. Collins, District Manager, Las Vegas
John A. Kwiatkowski, Deputy State Director, Lands and Renewable Resources, Montana
Robert D. Roudabush, Area Manager, Vermillion RA

Moderator: Dick Huff, Colorado State Office

Topic Outline

A. The soil and water program - results of the participant questionnaire

Briefing and clarification/consensus seeking format

1:00 p.m.

1. Elements of an ideal program
2. Today's program
3. Ways to move from today to ideal

B. Specialist/manager communications - results of Course 7000-3 participant questionnaire

1:20 p.m.

1. Problem solving and roles
2. Multiple-use awareness and values
3. Interpersonal skills
4. Speaking and writing skills

C. Professionalism and discretionary effort (and organization culture)

1:40 p.m.

Lecture/Discussion Format

1. Phenomena of "discretionary effort" in professional jobs
2. The "professionally motivating" climate
3. Is "professional behavior" a social or a technical question?
4. Disdain for policy, standards and administrivia
5. What does a BLM professional look like?
6. Autonomy of, and control over, professionals
7. Power and influence of professionals
8. Norms and shared values of a professional community v. a community of managers
9. Professionalism as a self-concept
10. Zealots, idealists and realists

D. Panel presentations

Lecture/Discussion Format

2:00 p.m.

Opening comments by each panel member of 10 min. duration each.

Topics to be covered are:
(The order of sub-topics is the speaker's discretion)

1. Suggestions for enhancing communication between specialists and managers, with respect to:

    a. multiple-use decisionmaking values
    b. interpersonal expectations
    c. problem-solving methodology
    d. speaking and writing competencies

2. Professional behavior expectations:

   a. What's ok and not ok?
   b. What does a "professional" look like?
   c. Suggestions for enhancing professional immage

3. Soil and water program expectations:

   a. What does a "good" program look like?
   b. What does the program look like today?
   c. Suggestions for enhancing the program

<u>2:30 p.m.</u> - Break

E. <u>Interaction with the manager panel</u>

<u>3:00 p.m.</u> - <u>Facilitated panel discussion format</u>

F. <u>Program Summary</u>

<u>4:00 p.m.</u>

<u>Briefing/Clarification/Discussion Format</u>

I will be recording the salient points of the panel presentations and ensuing discussion and will review these with the group for the purpose of having an "end product" with the following 2 parts:

1. "Ideal" soil and water program, where program is "today," and how to get to the ideal.

2. Summary of dialog about communications and professionalism, and recommendations for what to do "back home."

Parting comments by panel members and course director (Jackson).

Introduction: Richard M. Huff
Organization Development Specialist
Colorado State Office

For: Bureauwide Soil and Water Training Course (7000-1)
Phoenix Training Center, April 21-May 2, 1986

My current practice since 1980 centers on communication and decisionmaking processes, the dynamics of organizational change, and leadership development. My preferred method of aiding managers and employees in accomplishing organizational and individual goals is a team-building format with natural work groups. I believe that real and lasting change takes hard work, more time than expected, and a certain degree of pain. I value the behavior of a leader over that of a process manager and I value the behavior of individuals with a mature knowledge of self. My bottom-line goal is to improve the interpersonal and organizational conflict managing behavior of a multiple-use (multiple conflict) Bureau.

My past-life background is as a Forester for U.S. Forest Service (USFS) and Bureau of Land Management (BLM), in Montana, Idaho, and Western and Eastern Oregon, from 1959-1969.

My current-life background began with Interior's Departmental Management Training Program and has encompassed Management and Program Analysis, Training and Employee Development, a myriad of interrelated Administrative functions, and lastly in the area I enjoy the most-Organization Development.

My educational associations have been with the University of Minnesota, Oregon State University, George Washington University, and the University of Northern Colorado. My graduate specialty is Organization Behavior.

My military past-life is with the 11th and 82nd Airborne Divisions and the 5th and 19th Special Forces Groups.

I am an avid gardener, bushwhacking backpacker and the father of one 24 year old son, and 3 daughters age 21, 19, and 17.

Richard M. Huff
Organization Development Specialist
Bureau of Land Management
Colorado State Office
Denver, Colorado 80202
FTS 564-7094
Comm. (303) 294-7094

Professionalism, Discretionary Effort, and Organization Culture

Discussion Outline

Bureau Course 7000-1

Phoenix Training Center

May 1, 1986

I. Discretionary Effort

The words identify a concept which points out the difference between the maximum amount of effort and care a professional individual could bring to the job, and the minimum amount of effort required to avoid being penalized or fined. In short, it is that portion of one's work effort over which the individual has the greatest control.

A. Some Emerging "Truth"

1. The amount of discretionary effort permissable in job structures has greatly increased in the past ten years.

2. Due to a widespread "commitment gap," many high-discretion professionals are, by their own admission, holding back effort from their jobs, giving less than they are capable of giving, and less than they are, in principle, willing to give.

3. There is widespread "conventional wisdom" that attributes this gap to a failure in the American "work ethic."

4. This commitment gap surfaces at a time when American is struggling to maintain economic viability.

B. Some Conclusions

1. It is unlikely that the U.S. can revive its economic vitality without addressing the commitment gap among the community of technical professions.

2. The conventional wisdom of a deteriorating work ethic among professionals is badly off-target. The work ethic is strong and may indeed be growing stronger.

3. The real cause lies not with new cultural values or erosion of a work ethic entirely, but rather with a striking failure of managers to support and reinforce a professionally motivating climate.

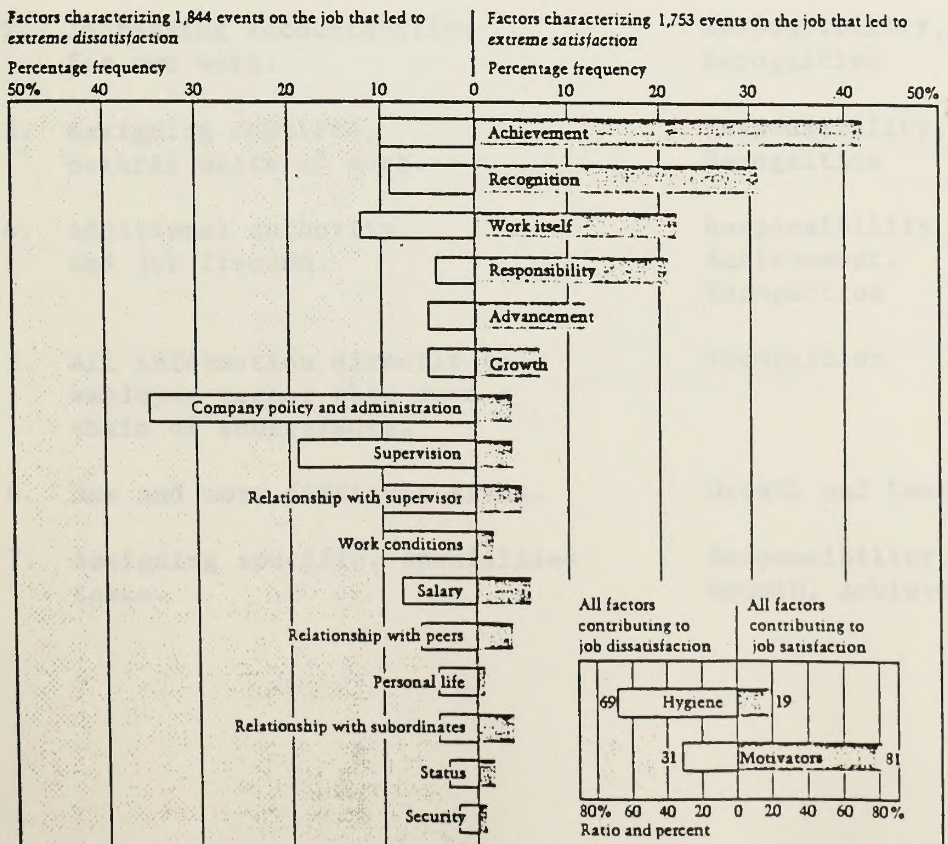
I feel that this is an area which has important and direct implication for how the Bureau manages its' professional workforce. What de-motivator's are likely to generate a "commitment gap" among technical professionals in the Bureau of Land Management (BLM), and what can we change to enhance productivity? With this rather easily understood concept we can begin, at every level, and with all employees, to find practical solutions.

II. Professional Motivating Climate, or Culture

I include these two words, climate and culture, in the subtitle, because I believe strongly that they are largely synonymous. I believe that the "climate" of any organization and of its myriad substructures is a function of what people believe and how they behave in response to their beliefs. This also is the prevailing definition of organization culture. "The Way Things Are Around Here," again synonymous with "culture," is the ultimate determiner of task, structure, and strategy. The "climate," or "culture" is how we define our jobs, what goals we set and how we set them, how we relate to our publics, how we make decisions, how we organize, coordinate, and communicate, how we allocate scarce resources and so on. These are all reflections of our shared or conflicting values, bias and assumptions, which determine how we cope, adapt and talk to each other.

A. Climate Motivators and De-Motivators

The following exhibit displays the primary factors to consider in striving for a job climate which would be professionally motivating.



Others which are not included in this particular set of studies, but which are immensley significant are:

1. Opporunities for internal professional peer association (communication).
2. Opportunities for external professional peer association (societies, access to Journals).
3. Efforts by the employer to "sound off" about the professional competence of its' technical workforce (tub thumping).

B. Horizontal Job Loading (De-Motivating, but well intentioned actions).

1. Challenging employees to produce more "widgets." (Zero times zero = zero)

2. Adding meaningless, routine, and tasks. (Zero plus zero = zero)

3. Rotating assignments in a number of equally mundane jobs. (Substitute one zero for another zero)

4. Removing difficult tasks to free time for more but less challenging tasks. (Subtraction in the hope of achieving addition)

C. Vertical Job Loading (Motivators most of the time)

Action	Motivator
1. Remove some controls, retain accountability.	Responsibility, Personal Achievement.
2. Increasing accountability for own work.	Responsibility, Recognition
3. Assigning complete, natural units of work.	Responsibility, Recognition
4. Additional authority and job freedom.	Responsibility, Achievement, Recognition
5. All information directly to employee rather than down a chain of supervisors.	Recognition
6. New and more difficult tasks.	Growth and Learning
7. Assigning specific, specialized tasks.	Responsibility, Growth, Achievement

III. Professional Behavior.

It is becoming more evident that so-called "professional behavior" has less to do with technical norms for method and technique than with social norms of the culture such as how to dress, how to talk, and so on, as well as what degree of dissidence over policy and practice are permissible internally or externally. There is no well understood set of expectations in the Bureau that are regularly, and openly articulated.

IV. Autonomy, Control, Power, and Influence.

Some goals seem to be diametrically opposed. To grant greater autonomy to a profession is to run the risk of the manager losing control, setting up a classic struggle for power and influence in the organization. Strong disciplinary affiliations among professions can indeed foster goal driven behavior not in the interest of the organizations mission.

The challenge for the professional manager is to redefine expectations of "control" and controlling behavior. The key point is coordinating, not controlling. The behavioral expectation is to understand and coordinate the nature of the work, but not to control specific activities.

Values frequently clash over administrative requirements and measurement of performance. The professional excellence of both the manager and the technician can be measured by their ability to productively resolve these types of conflicts.

V. How It All Plays Out.

Professionalism is, in large part, a self-concept irrespective of climate or other factors. Some GS-3 Clerk-Typists have an easily visible aura of professionalism, and some GS-13 Technical Professionals are immature in the extreme. So, we now introduce the notion of personal maturity to the concept of professionalism. Our self-concept is the script we follow in our professional lives.

The bottom line is that it may be unimportant whether or not a particular occupational specialty is a "true" profession or not, but rather how the individual views him or herself and is treated by peers and supervisors. The question then reduces to whether or not the work is carried out "in a professional manner" - a far more valid and meaningful measurement.

A
Study
of
Manager - Specialist
Communications

<u>Source</u>

Participants
and
Supervisors of Participants
at
Bureauwide Course No. 7000-7
Watershed Rehabilitation
May and December 1983, and December 1984
Phoenix Training Center

November 1985

Table of Contents

Section

Section A

Data Tabulation

DATA TABULATION - PART I

Bureauwide training course 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center

Pre-Training Survey of Attendees

A. What is unclear about your manager's information needs?

No. of Responses	(N=72)
3	- Everything is unclear.
2	- Manager's technical background is unclear.
12	- The level of detail needed is unclear.
11	- My manager's needs are clear.
2	- I don't know, I don't get any feedback.
5	- The needs vary a lot, hard to keep clear.
2	- Information needs on geologic vs. accelerated erosion.
1	- Information needs about stream barriers.
3	- Information needs for manager's goals.
1	- Issue is convincing managers that information is essential.
1	- Information needs about inventories.
1	- Information needs about vegetative manipulation.
2	- The manager doesn't want any information.
1	- I don't know, I have never asked the question.
3	- What benefit/cost data are needed.
2	- Information needs about applicable laws and Bureau policy.
3	- Information needs about political values.
1	- Role of BLM, OSM, MLRB, and industry.
1	- Will we adhere to guidelines or not.
1	- Information needs about effects on fisheries.
3	- What is the manager's real interest level.
1	- Issue may be my own lack of expertise.
1	- How to display work accomplishments.
1	- Information needs about effects of drilling, mining, and construction.
8	- No response to this question.

B. What are the major communication barriers with your manager?

No. of Responses	(N=72)
10	- Lack of management interest.
2	- Communications incompetence of managers.
4	- Technical incompetence of managers.
16	- Lack of technical background of managers.

8	- Predetermined courses of action by managers.
1	- Most barriers are between divisions and areas.
6	- Level of detail needed.
2	- Rarely have any problems.
2	- My technical competence.
4	- My briefing skills.
1	- Political influences.
3	- My communications skills.
4	- Technical jargon.
2	- The search for specific yes or no answers in grey areas.
2	- Lack of a multiple-use concept by many managers.
3	- No response to this question.

C. What is unclear about the decisionmaking role and process of your manager?

No. of Responses	(N=72)
17	- I am clear on the role of my manager.
2	- Who decides about negative impacts?
1	- Who decides about support of best management practices (BMP's)?
2	- Whose values really affect decisions?
12	- I cannot tell where politics and/or values enter.
1	- Everything is unclear.
4	- Is it his decision or the decision of his boss?
1	- The role of BLM is unclear.
4	- Role is clear, but won't make a decision.
5	- I am unclear about the support I can expect.
1	- What forces are involved?
2	- How users can get decisions changed.
2	- How manager can ignore watershed concerns.
1	- How resource interrelationships are handled.
1	- How can managers make decisions without data?
2	- How impartial can the manager be?
1	- Unclear on weight given to cost.
1	- Not sure where all his input comes from.
1	- How they can use watershed funds for non-watershed projects.
2	- There seems to be no accountability.
9	- No response to this question.

D. What would you like to do better in communicating with managers?

No. of Responses	(N-72)
8	- Describe problems relative to degree to impact.
2	- Describe data from inventories and research.

1	- Relationship of data to clean water laws.
3	- Provide recommendations for mitigating impacts.
2	- How hydrological concepts are interrelated.
4	- How the data fit into decisionmaking processes.
6	- Provide understandable data.
8	- Find out what the manager wants.
5	- Convey the importance of hydrologic analysis.
7	- Be more precise in expressing opinions.
1	- Tell manager what my goals are and my expertise.
1	- Prepare displays of progress and accomplishments.
11	- Develop and present alternatives.
5	- Be more persuasive and convincing.
4	- Basic, easy-to-use, valid, predictive models.
2	- A watershed workshop won't help.
2	- No response to this question.

DATA TABULATION - PART II

Bureauwide course 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

Pre-Training Survey of Attendees

A. Relative Seriousness, manager being unclear on technical data needs:

No. of Responses	(N=72)
9	- Serious Problem
23	- Often a problem
19	- Seldom a problem
10	- No problem
11	- No response

COMMENTS:

No. of Responses	(N=72)
2	- Manager doesn't want the facts.
4	- Manager is sometimes too impatient to collect data.
2	- So far this is no problem.
3	- Input accepted only because required by policy.
2	- We have to continually rejustify data gathering.
1	- We don't provide enough site-specific data.
1	- Manager feels studies are non-productive.

No. of Responses	
3	- Manager has no commitment to watershed management.
2	- Manager has no idea how to use the data.
2	- Decisions are pre-determined, why bother?
50	- No comment.

B. Relative seriousness, manager unclear of format for displaying and discussing alternatives.

No. of Responses	(N=72)
5	- Serious problem
13	- Often a problem
31	- Seldom a problem
10	- No problem
13	- No response

COMMENTS:

No. of Responses	(N=72)
3	- Manager doesn't want to discuss alternatives.
6	- Have had no trouble with pros and cons.
1	- We use the RMP format.
1	- Should activity plan precede RMP?
61	- No comment.

C. Relative seriousness, predetermined point of view of manager:

No. of Responses	(N=72)
15	- Serious problem
21	- Often a problem
9	- Seldom a problem
9	- No problem
18	- No response

COMMENTS:

No. of Responses	(N=72)
3	- Usually politically or budget driven.
2	- Not resistance — outright rejection.
3	- Usually open to all points of view.
1	- Some specialists have oversold the program.
3	- Seldom open to new ideas.

3		- At times the decision has already been made.
1		- "Dominant" programs overshadow watershed.
56		- No comment.

D. Relative seriousness, manager insensitive to emotional needs in communication.

No. of Responses	(N=72)
3	- Serious problem
14	- Often a problem
29	- Seldom a problem
11	- No problem
15	- No response

COMMENTS:

No. of Responses	(N=72)
1	- Haven't had a problem.
4	- Sometimes is "phony"; not really included.
1	- Usually listens attentively.
66	- No comment.

E. Relative seriousness. Manager not clear on briefing format needs and desires.

No. of Responses	(N=72)
3	- Serious problem
6	- Often a problem
29	- Seldom a problem
21	- No problem
13	- No response

COMMENTS:

No. of Responses	(N=72)
1	- RMP format needs consistency.
2	- No real awareness of briefing techniques in our office.
3	- Most managers don't seem to care.
66	- No comment.

F. Relative seriousness. Manager providing adequate information on influence of outside pressures.

No. of Responses	(N=72)
4	- Serious problem
18	- Often a problem
21	- Seldom a problem
9	- No problem
20	- No response

COMMENTS:

No. of Responses	(N=72)
1	- This is a major stumbling block.
1	- Time available is most often the problem.
70	- No comment.

G. Relative seriousness. Manager doesn't understand the complexity if the specialist role.

No. of Responses	(N=72)
13	- Serious problem
25	- Often a problem
8	- Seldom a problem
10	- No problem
16	- No response

COMMENTS:

No. of Responses	(N=72)
2	- Becomes obvious at PIPR review time.
3	- Manager takes differenfes in opinion personally.
6	- Manager not really interested.
3	- I am perceived as an adversary.
1	- Has not been a serious problem with good communication.
1	- We keep losing positions in SWA program.
1	- Manager wants quick and easy solutions only.
3	- Manager cannot relate to complexity of water issues.
50	- No comment.

DATA TABULATION - PART III

Bureauwide Training Course 7000-7, May and December 1983, and December 1984; Watershed Rehabilitation; Phoenix Training Center.

Pre-Training Survey of Attendees:

Question: Do you have any other comments?

No. of Responses	(N=72)
1	- We lack direction in the S&W program.
2	- Inventory funding is inadequate.
1	- There is no consistency in enforcing 3809 regulations.
1	- We have done a lot in the past 5 years.
5	- Communications (lack of) is the real issue.
1	- Best managers make decisions based on resource needs.
1	- Poor managers make purely political decisions.
3	- We don't spend our 4341 money wisely.
57	- No response to this question.

DATA TABULATION - PART IV

Bureauwide course 7000-7, May and December 1983 and December 1984, Watershed Rehabilitation, Phoenix Training Center.

Pre-Training Survey of Managers

A. In your situation, are you more of a decisionmaker regarding watershed issues, or are you an influencer of other decisionmakers?

No. of Responses	(N=73)
5	- Realistically, all decisionmakers are influencers and are in turn influenced. I am both.
30	- Primarily an influencer of other decisionmakers.
31	- Primarily a decisionmaker.
1	- Line managers are the decisionmakers—internally, the staff are influencers.
1	- This may depend on the controversial nature or scope.
1	- Managers articulate policy to staffs who make recommendations for decisions.
4	- No response to this question.

B. What are the major communication barriers with your specialist(s)?

No. of Responses	(N=73)
7	- Complexity of the terminology.
21	- Inability of specialist to present results of analysis in non-technical fashion.
6	- Influence of political pressure.
7	- Specialist's skill and knowledge in communications.
9	- Specialist's ability to "sell" the program.
2	- Specialist's ability to display the background material.
2	- Specialist's ability to quantify predicted losses.
5	- Specialist's ability to organize a presentation.
1	- Physical distances between offices.
1	- Turnover and continual policy changes.
1	- Mixed-up organizational roles.
5	- Specialist's unwillingness to accept decisions.
11	- No response to this question.

C. What would you like resource specialists to understand about your decisionmaking role and process?

No. of Responses	(N=73)
12	- Decisions are seldom about single actions, but are series of actions over time and influenced by many outside factions.
11	- Realize that tradeoffs are made involving numerous resource values.
13	- The need to understand relationships with other resources and the social and political impacts.
1	- Quality decisions are directly related to quality staff input.
3	- They have to push--not wait for someone to point out their problems for them.
1	- They make recommendations and managers make decisions.
1	- There is a need to have greater awareness of administrative commitments.
4	- Policy, political, and budget constraints affect decisions.
1	- One speciality is seldom a controlling factor.
2	- There are numerous sides to any issue.
1	- Not all recommendations will be accepted.
2	- What is "best" may not be attainable.
1	- Not all managers are inept.
1	- That nothing beats timely communication.
2	- Data has to be simplified.

5	- Learn how to summarize data to plain-talk style.
1	- Display alternatives accurately.
3	- Keep data base objective and leave subjective opinions out.
1	- A real need for completed staff work.
2	- Do their homework and present the best case, then support manager's decision.
5	- No response to this question.

D. <u>As a result of this workshop, what is one improvement you would like to see in the nature of communication with specialists?</u>

<u>No. of Responses</u>	(N=73)
6	- The specialist needs to provide sound data even if he/she does not approve of political or public pressure influences.
1	- A clearer definition of watershed program goals in relation to overall resource management.
2	- Prepare less technical presentations.
3	- An understanding that hydrology is not a world unto itself.
1	- Be more sensitive to necessary time frames.
3	- Make transition from total advocacy to multiple-use concept.
5	- Recognize their staff role and support decisions.
1	- Be sensitive to timing and reality of political and public pressures.
7	- How to show what problems exist and how to solve them.
1	- Be sensitive to other priorities.
3	- Avoid using meaningless, broad statements.
1	- Learn how to display "degree of risk."
3	- Need to be familiar with other resources also.
5	- Involve management early in their discussions.
6	- A greater appreciation for multiple-use decisions.
1	- Provide better analysis with mitigations of more consumptive uses.
1	- An appreciation of the budget process.
3	- Offer alternatives.
5	- More complete multi-disciplinary staff work.
1	- Display proven field experiences--not just academic theory.
3	- Ability to openly discuss conflicts.
2	- Be more assertive--not so much "poor me."
9	- No responses to this question.

E. What information do you need from Resource Specialists to facilitate effective decisionmaking.

No. of Responses	(N=73)
2	- Expand my understanding of hydrologic processes.
1	- Specialist needs to understand contract administration and project layout.
1	- What is condition of the resource, problem areas, priority of treatment, impact of available alternatives.
6	- The problem, the magnitude, and alternatives.
1	- Feasibility of project plans.
1	- AWP commitments, funding, progress, purpose, need, and options.
8	- Keep me informed and current.
12	- Specific recommendations with sound rationale.
1	- Research and studies add little to my decisionmaking.
1	- Limiting factors.
1	- Most effective and effecient methods.
1	- Water quality and quantity, structures, off-site benefits.
5	- Alternatives and sensitive and unusual cases.
1	- Information needed to make decisions. Some data takes time to gather. This is OK as long as the plan is OK.
3	- Feedback on what is going on.
1	- Need current law, regulations, and policy.
1	- Input to coordinated resource management plans.
1	- Water rights and vegetative conversion.
4	- Conflicts, agreements, inventories, and problems.
21	- No response to this question.

DATA TABULATION - PART V

Bureauwide course 7000-7, May and December 1983 and December 1984, Watershed Rehabilitation, Phoenix Training Center

Pre-Training Survey of Managers

A. Relative seriousness, specialist presents information that is too technical.

No. of Responses	(N=73)
2	- Serious problem
25	- Often a problem
41	- Seldom a problem
3	- No problem
2	- No response

COMMENTS:

No. of Responses	(N=73)
1	- Some technical jargon is necessary.
1	- Varies with specialists.
1	- Mainly with hydrology in test well contracts.
5	- I don't have time to digest technical jargon.
2	- Specialists only think they are too technical.
1	- Explain some of the terminology in written reports.
3	- Explain soils nomenclature.
1	- Mostly not applicable to the situation.
1	- Mostly with EIS's.
1	- Design EA's and summaries for laymen.
1	- Doesn't fit into total district operation.
1	- Most specialists do a good job.
54	- No comment.

B. Relative seriousness, specialist does not use a good format for displaying and discussing atlernatives.

No. of Responses	(N=73)
5	- Serious problem
43	- Often a problem
21	- Seldom a problem
2	- No response

COMMENTS:

No. of Responses	(N=73)
5	- Too often is a single approach for all problems.
2	- Often because of a lack of time.
1	- Does it, but doesn't provide to decisionmaker.
2	- I ask for alternatives.
3	- Often specialists fail to consider possible alternatives.
3	- Too subjective.
2	- Specialists have little field experience.
1	- Common for specialists in narrow field.
1	- Incomplete staff work.
4	- Specialists strive to be decisionmakers.
49	- No comment.

C. Relative seriousness, specialist predetermined point of view.

No. of Responses	(N=72)
6	- Serious problem
42	- Often a problem
20	- Seldom a problem
3	- No problem
2	- No response

COMMENTS:

No. of Responses	(N=73)
1	- Big problem when defensiveness takes over.
4	- Specialists need to be better team members.
10	- Same comments as in "B" relative to few, if any, practical alternatives.
58	- No comment.

D. Relative seriousness, specialist insensitive to emotional needs in communication.

No. of Responses	(N=73)
5	- Serious problem
15	- Often a problem
40	- Seldom a problem
8	- No problem
5	- No response

COMMENTS:

No. of Responses	(N=73)
6	- Some specialists persist in tunnel vision.
2	- They need to try walking in another's shoes.
65	- No comment.

E. Relative seriousness, specialist not skilled in briefing techniques.

No. of Responses	(N=73)
3	- Serious problem
24	- Often a problem
36	- Seldom a problem
8	- No problem
2	- No response

COMMENTS:

No. of Responses	(N=73)
1	- Photography is usually available.
2	- Time may be more of a problem than skill.
1	- Poor pre-planning by specialist and manager.
2	- A picture is worth a thousand arguments.
2	- Improve quality of visual aids, not quantity.
1	- Watershed program is no longer action-oriented.
2	- If data could be displayed quickly and accurately it would help.
1	- Too much detail.
2	- Transfer of ideas is easier if done graphically.
1	- Anything is ok as long as it is understandable.
58	- No comment.

F. Relative seriousness, specialist does not provide adequate arguments to use in multiple use/political conflicts.

No. of Responses	(N=73)
2	- Serious problem
33	- Often a problem
29	- Seldom a problem
6	- No problem
3	- No response

COMMENTS:

No. of Responses	(N=73)
1	- Usually a cost-to-significance analysis is missing.
3	- Absence of predicting consequences.
2	- Problems should be worked out in advance.
1	- Power/political conflicts seldom relate to hydrologic data.
4	- This is incomplete staff work.
1	- This is the managers responsibility.
47	- No comment.

G. Relative seriousness, specialist doesn't understand my decision-making process/role.

No. of Responses	(N=73)
6	- Serious problem
36	- Often a problem
25	- Seldom a problem
4	- No problem
2	- No response

COMMENTS:

No. of Responses	(N=73)
5	- Specialists need to understand the delicate balance.
7	- Some specialists do not support decisions when made.
4	- Specialists need to understand the interdependence of activity budgets.
3	- Managers must communicate rationale for decisions.
54	- No comment.

DATA TABULATION PART VI

Bureauwide Training Course 7000-7, May and December 1983, and December 1984 Watershed Rehabilitation, Phoenix Training Center.

Pre-Training Survey of Managers

Other Comments by Managers:

No. of Responses	(N=73)
4	- Briefing techniques and aids are very important
3	- Problem solving skill is essential
1	- Communicate, don't "snow"
1	- Always try to see the "big picture"
1	- Specialists need to understand the budget process
5	- BLM has a lot of excellent specialists
3	- BLM needs to resurrect a field-oriented S&W program
1	- Cannot put enough emphasis on communications
2	- Need conflict resolution and group facilitation skills
2	- Needs training in rehab plans and activity plans
1	- Managers need ability to teach quality staff work
2	- Teach specialists what completed staff work consist of
47	- No response

Section B

Data Summary

DATA SUMMARY PART I

Bureauwide Course 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation; Phoenix Training Center.

Pre-Training Survey of Managers and Supervisors

A. SUMMARY OF RELATED NUMERICAL RESPONSES.

Section A, Parts II and V

Questions asked of Managers and Specialists	Serious Problem	Often a Problem	Seldom a Problem	Not a Problem	No Response
Managers - "Data are too Technical"	3	34	56	4	3
Specialists - "Data needs unclear"	13	32	26	14	15
Managers - "Problem analysis lacking"	7	59	28	3	3
Specialists - "Needs are unclear"	0	20	43	17	20
Managers - "Predetermined point of view"	8	58	27	4	3
Specialists - "Predetermined point of view"	21	30	12	12	25
Managers - "Insensitive to needs"	7	20	55	11	7
Specialists - "Insensitive to needs"	4	20	40	15	21
Managers - "Briefing skills lacking"	4	33	49	11	3
Specialists - "Needs are clear"	4	8	40	30	18
Managers - "Naive to outside pressures"	3	45	40	8	4
Specialists - "Information not provided	5	25	30	12	28
Managers - "Doesn't understand my role"	8	49	34	6	3
Specialists - "Doesn't under-stand my role"	18	35	11	14	22

B. COMPOSIT CATEGORIES OF RELATED NUMERICAL RESPONSES.

Section A, Parts II and V

Category		Percent of Total Responses: Serious or some concern	Little or no concern	No response
I. Briefing skills and expectations.	a. Managers	37	60	3
	b. Specialists	28	55	17
	c. Composit	33	58	9
II. Problem-solving skills, attitudes and expectations.	a. Managers	60	37	3
	b. Specialists	35	41	24
	c. Composit	48	39	13
III. Quality of communication, and interaction.	a. Managers	27	66	7
	b. Specialists	24	56	20
	c. Composit	26	61	13
IV. Role understanding and expectations.	a. Managers	58	40	2
	b. Specialists	53	25	22
	c. Composit	55	32	13

C. COMPOSIT CATEGORIES OF RELATED NARRATIVE RESPONSES

Section A, Parts I-B and IV-B (Barriers to Communication)

	Category	Percent of Total Responses: Concerned Managers	Percent of Total Responses: Concerned Specialists
I.	Barriers Related to Briefing Skills and Expectations.	49	20
II.	Barriers Related to Problem-solving Skills and Expectations.	18	13
III.	Barriers Related to Quality of Communication, Interaction, and Attitudes.	15	24
IV.	Barriers Related to Technical Knowledge, Skills and Ability.	0	34
V.	Barriers Related to Organization Structure and Dispersed Office Locations.	3	4
VI.	No Responses to this Question.	15	5

D. COMPOSIT CATEGORIES OF RELATED NARRATIVE RESPONSES

Section A, Part I-C and IV-C (Decisionmaking Role and Process)

		Percent of Total Responses	
	Category	Concerned Managers	Concerned Specialists
I.	Concerns Related to Personal Values and Attitudes.	7	56
II.	Concerns Related to Role Clarity and Acceptance.	7	9
III.	Concerns Related to Problem-solving Skills and Expectations.	32	10
IV.	Concerns Related to Multiple-Use Relationships.	48	9
V.	No Response to this Question.	6	16

E. COMPOSIT CATEGORIES OF RELATED NARRATIVE RESPONSES

Section A, Part I-D and IV-D, (What Needs to Improve)

Category		Percent of Total Responses: Concerned Managers	Percent of Total Responses: Concerned Specialists
I.	Related to Improved Briefing Techniques	8	24
II.	Related to Improved Interpersonal Skills	8	18
III.	Related to Improved Role Understanding	7	17
IV.	Related to Sharing of Values and Expectations	12	0
V.	Related to Improved Technical Skills	2	8
VI.	Related to Improved Organizational and Multiple Use Awareness.	22	4
VII.	Related to Improved Problem-solving Skills	29	26
VIII.	No Response to this Question.	12	3

DATA SUMMARY PART II

Bureauwide training Course No. 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

A. Attendee Narrative Responses, Section A, Part I-A; What is (or is not) known about managers information needs?

A total of 64 responses from 72 attendees are shown in this section. Of the 64 responses, 53 indicate areas of concern. These are summarized into six categories shown.

Percent of responses concerned attendees	Category
15	Concerns related to technical issues.
43	Concerns related to values, roles and goals.
5	Concerns related to multiple use concepts.
24	Concerns related to briefing issues.
6	Concerns related to interpersonal issues.
7	Concerns related to problem-solving issues.

B. Manager Narrative Responses, Section A, Part IV-A; as to decisionmaking or influencing decisionmakers.

This question will be dropped from future pre-training questionnaires for course 7000-7. The data adds little to the intent of the pre-training survey. It does however, provide an insight to role perceptions of managers. The data are summarized into four categories shown below:

Percent of Responses	Category
45	A decisionmaker
41	An influencer of decision makers
8	Both a decisionmaker and an influencer
6	No response to the question.

Unfortunately, it was not practical at the time to identify the organizational location of the managers who responded. If we had done so, we could have compared the perceived role as shown in the responses, with the Bureaus' role expectations of the managers position title, job series, and location in the organization structure.

C. Manager narrative responses, Part IV-E; What are the information needs of managers.

A total of 52 responses from 73 managers are shown in this section. Of the 52 responses, 50 indicate specific needs. These are summarized into five categories shown below:

Percent of Responses	Category
8	Related to technical issues.
24	Related to problem definition and impact(s).
40	Related to alternative solutions.
16	Related to cost/benefit and AWP.
12	Related to policy and resource planning.

Section C

Data Analysis

Data Analysis Part I

Bureauwide Training Course No. 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

A. Narrative Responses (Section B, Part II-A)

The data indicates rather clearly that 73 percent of all attendees, and 83 percent of attendees responding to this question are, for one specific reason or another, not on the same "wave length" with their respective manager.

This is a significant percentage, given the notion that effective communication between the resource specialist and the manager is essential to effective multiple-use decisionmaking in our decentralized organization structure. The quality and timeliness of this interaction is the backbone of rational, defensible decisions.

In this first question, the primary areas of non-communication are shown clearly, and are a clue to the actions which could be taken to begin to increase leader-follower effectiveness.

The category of briefing skills is one which cannot be entirely addressed by training alone. The manager and the specialist must both possess some skill in this area, to arrive at a decision as how to best present certain types of data and to manage group behavior. But, the most significant action to be taken is for the manager and specialist to share their expectations and knowledge of format, technique, and level of detail.

The category referred to as "multiple-use concepts" indicates a lack of sufficient time being spent by managers in sharing their knowledge of resource interrelationships, policy, and power/political influences. This is not to say, however, that the specialist does not have an equal responsibility for self-learning. The organization expectations of a resource specialist in this Bureau seldom include the "purist" mode (no offense intended), which may be more appropriate to research-based organizations. The real world of multiple-use decisionmaking on public lands, by necessity, must recognize the real world of conflicting values and resource needs which are ever present.

Another category is related to values and goals. As introduced above, the conflict of individual values not only applies to conflicting user "publics," but among the decisionmakers themselves. The absence of sharing this information on a continuous basis, as an integral part of a participative problem-solving process, is usually the root cause of most leader-follower discontent over technical and policy issues.

The category of technical issues is representative of the major focus for the technical content of course 7000-7. In this question, 15 percent of attendees responding chose to hold the manager accountable for

communicating technical information needs. If the manager doesn't know what is needed for decisionmaking, then it is unlikely the specialist will ever be content. This is a continuing circle of discontent that can only be resolved by open, two-way communications.

The category of interpersonal issues is the expression of greatly deteriorated leader-follower relationships. It would be difficult to surmise cause and effect without first hand knowledge of both parties involved.

The final category of problem-solving issues relates to the methodology of problem-solving itself and to decisionmaking. This is an area where skill building for both the specialist and the manager would likely be productive. In this area, the development and analysis of alternative solutions seems to be the greatest concern.

B. <u>Narrative Responses</u> (Section B, Part II-C)

Combining four of the five categories, this shows that 92 percent of Manager responses are concerned with problem-solving and decisionmaking in one fashion or another. Similarly combining four of six categories from Section B, Part II-A show that 79 percent of attendee responses are concerned with the same issues.

The methodology of problem-solving and decisionmaking, and the briefing techniques associated with displaying the results of these thought processes, are some part of the concern expressed in the data. These are areas of skill and knowledge and acquired experience. Of far greater significance, are the references to roles, goals, values, and interpersonal relationships. These four issues are perhaps separate academically but inseparable in their effect on the quality and timeliness of decisionmaking.

<u>Data Analysis Part II</u>

Bureauwide Training Course No. 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

<u>Narrative Responses</u> (Section B, Part I-E)

These data which addresses what areas managers and specialist would like to see improved, are summarized into seven (7) categories.

Presuming that percentage distribution of responses may be an indication of priority of concern. The top four categories are as follows:

Priority of Concern	Managers	Specialists
1.	Problem-solving	Problem-solving
2.	Multiple-use awareness	Briefing Techniques

3.	Values	Interpersonal skills
4.	Briefing techniques	Roles

Agreeing on the top category is a good start. Unfortunately, the agreement is about the most easily solved communication skill issue. Presuming that role considerations and briefing techniques are an integral part of problem-solving concerns and that values are the real issue in concerns for multiple-use awareness, then each side of the formula has three priorities, two of which are held in common. There are now four issues in common which could be listed as follows:

1. Problem-solving skills and role considerations.
2. Multiple-use awareness and values considerations.
3. Interpersonal communication skills.
4. Briefing skills and techniques.

Briefing skills and techniques and improved interpersonal communication skills can perhaps be favorably impacted through various formal training ventures. The effects of role ambiguity and value conflicts as they relate to multiple-use problem-solving and decisionmaking are far more difficult to not only diagnose, but to work on and improve upon. The first two fit into one training agenda, and the latter two fit into a category which, historically, can only be improved through the "working on work" techniques centered around participative group processes.

Data Analysis Part III

Bureauwide Training Course No. 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

Narrative Responses (Section B, Part I-C)

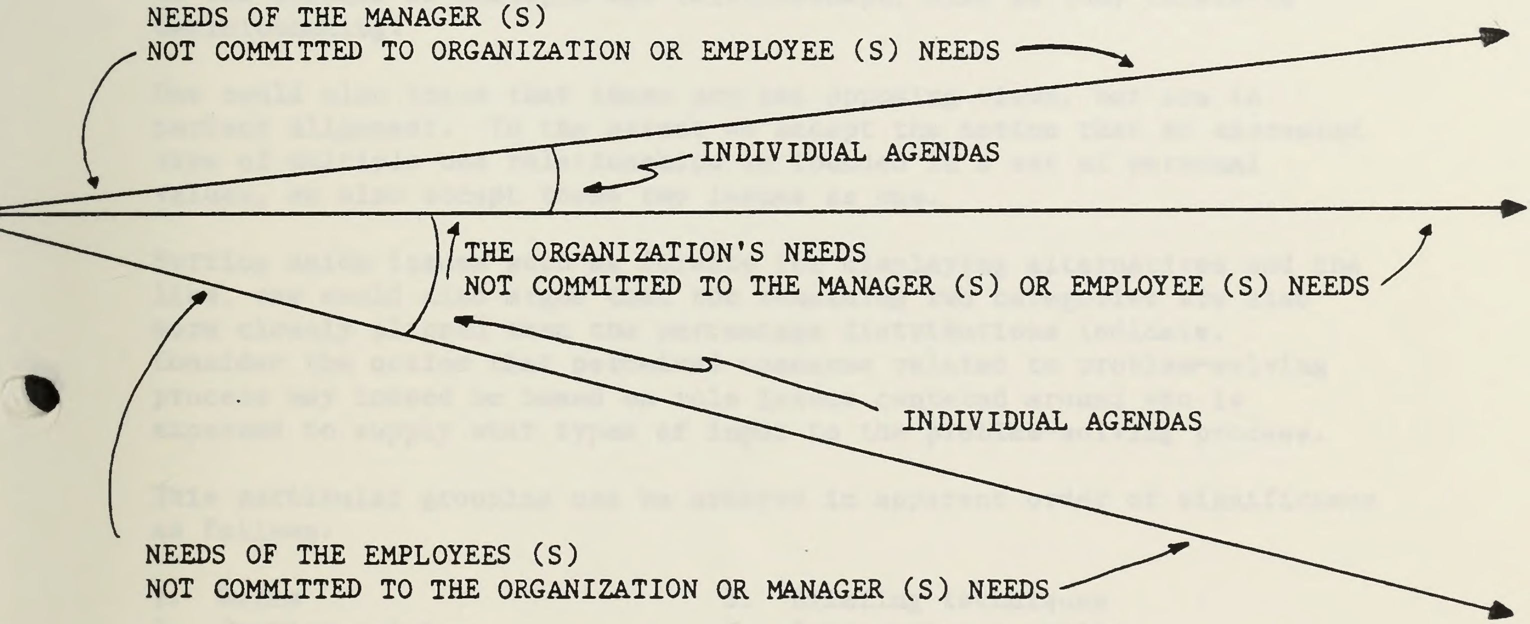
These data which addresses perceived barriers to communications, are summarized into five primary categories.

The percentage of specialists expressing a perception of barriers is rather evenly spread among four of the five categories. This spread, in relation to its distribution, shows some disimilarity with the common categories of Section A, Part I-B. For example, Section B, Part I-C shows that 34 percent of concerned specialists pointed to barriers associated with technical issues, but Section A, Part I-B indicates that only approximately 17 percent of respondents were unclear about technical issues. It would be my judgment that this combination points to value differences over technical issues being the more significant "barrier." The apparent lack of communication is evidenced by the fact that 0 percent of managers felt this was a barrier.

Of significance also, is the concern by managers (49 percent) for briefing skills and format. Specialists, however, show only 20 percent of respondents indicating that this is an area of concern.

The disparity in responses for the remaining categories indicate a considerable gap in the expectations of managers and specialists, and to the extent they are communicating, they may be communicating about the wrong issues.

The following illustration is of a basic vector model. The model shows a commonly found disparity in understanding and commitment. It would be safe to assume that attempts to communicate on any issue not held in common need would result in even further frustration.



Data Analysis Part IV

Bureauwide Training Course No. 7000-7, May and December 1983 and December 1984; Watershed Rehabilitation, Phoenix Training Center.

Narrative Responses (Section B, Part I-D)

These data which addresses perceived concerns about roles and decisionmaking, are summarized into four categories.

The significant point to raise in this comparison is that the distribution of concerned managers is virtually 180% opposite from that of specialists. For example, the greatest apparent concern of specialists is confusion over the personal values and attitudes of the managers, as these factors relate to decisionmaking. On the other hand, the greatest apparent concern of managers is the specialists sensitivity to the balance of multiple-use relationships, also as they relate to decisionmaking.

One could also argue that these are not opposing views, but are in perfect alignment. To the extent we accept the notion that an expressed view of multiple-use relationships is founded in a set of personal values, we also accept these two issues as one.

Setting aside issues such as formats for displaying alternatives and the like, one could also argue that the remaining two categories are also more closely aligned than the percentage distributions indicate. Consider the notion that perceived concerns related to problem-solving process may indeed be based on role issues centered around who is expected to supply what types of input to the problem-solving process.

This particular grouping can be arrayed in apparent order of significance as follows:

1. Roles
2. Problem-solving
3. Briefing techniques
4. Interpersonal skills

Section D

Summary and Recommendations

Part I. Summary

Bureauwide Training Course No. 7000-7, May and December 1983, and December 1984; Watershed Rehabilitation, Phoenix Training Center.

The responses to the questionnaire arrayed in various narrative and tabular displays, point to a well substantiated set of four conclusions concerning manager-specialist communication.

The first, and by far the most significant conclusion, is that managers and specialists are experiencing the greatest frustration because they are not successfully communicating about the "right" issues. They are not conversing in a common language from common values and expectations, nor are they conversing frequently enough.

The second, is that managers and specialists are experiencing frustration with each others interpersonal competence about as much as might be expected.

The third, is that managers and specialists are experiencing a lesser degree of frustration over purely technical issues than might have been predicted.

The fourth, is what managers and specialists are experiencing the least degree of frustration over appropriate briefing skills and techniques.

In relation to the first assumption, those issues about which the greatest frustration level is evident are:

1. Communicating to each other, personal values and bias associated with multiple-use on public lands, especially as they relate to tradeoffs of "ideal" situations for any given renewable or non-renewable resource.

2. Communicating to each other, personal values and bias associated with the influence of political and pressure-group forces on multiple-use decisionmaking.

3. Communicating to each other, perceived role, values, and bias associated with the problem solving and decisionmaking processes, as the issue relates to problem definition and providing a range of creative alternatives.

As mentioned previously, the primary issue is not of intensive skill building, although certainly this does come into play, but rather an issue of a commitment to openly communicating ideas, values, and expectations. As we find so often in dealing with communication problems, it is the underlying values and expectations of involved individuals which seldom, if ever, are shared by parties in conflict. The key then is to share these things early and continuously, so that they become real and legitimate and not part of a set of false assumptions. This is the basic premise in building a sound relationship which approaches the conflicts inherent to multiple-use decisionmaking with a creative, positive, and productive attitude.

Part II - Recommendations

Bureauwide Training Course No. 7000-7, May and December 1983, and December 1984; Watershed Rehabilitation, Phoenix Training Center.

Five basic recommendations are suggested below, as well as a brief explanation of how the subjects were presented in course 7000-7.

1. Briefing Skills and Techniques

Certainly the first recommendation is for managers and specialists to share with each other their preferences and needs in this area. Each should acquire a basic level of skill in public speaking and briefing techniques. To me, this is critical for virtually every technical, supervisory, and managerial position in the Bureau. Many low-cost courses are on the market and Toastmasters International is highly recommended. In-house instructor capability exists in some states.

For course 7000-7, this issue was only briefly addressed in the time available, and was practiced through the group presentation phase the last day of the program. Feedback from the manager audience was particularly helpful.

2. Interpersonal Competence

There is little that could be accomplished in this area in such a short time frame as is available in the 7000-7 course. In addition, this type of course segment is far less effective than addressing the subject in a one or two-day concentrated program or as part of a teambuilding program.

To me, this is also critical for every employee. The key is awareness of your own bias, your own interpersonal needs, your own unique style, and your impact on others, discovered through learning and practicing the art of feedback.

For course 7000-7, this issue was addressed in a brief segment on feedback and the use of several brief instruments to open the door to interpersonal communication awareness.

For back-home application, I suggest a long-term investment in increasing interpersonal awareness which can be designed for a specific office by state Organization Development Specialists or outside vendors. The key is a program designed for specific office needs—not generic "courses" which have little lasting utility.

3. Technical Issues

While this may not on the surface, appear to be an issue involving communications effectiveness, there are indeed very strong indications that this is part of the set of symptoms leading to the conclusion that managers and specialists are not communicating about the right issues or communicating in a common language.

Some specialists attribute their frustration to an apparent lack of technical knowledge by the manager. This myopic view of the real world evades the role issue which states that the specialist is employed to make recommendations based on whatever technical data is available, not to engage the manager in a discussion of technical data as if the manager were a peer professional. Managers on the other hand, far too often spend an inordinate amount of time nit-picking a data base, losing sight of the decision to be made.

Continuing technical training is essential for the specialist and it would also be useful for specialists to periodically brief managers on the basics of technical areas that the manager may not be overly familiar with.

The point to be made is that managers and specialists must display the mature professionalism needed to share information about technical concerns and "differences" in an open up-front manner.

4. Problem Solving and Decisionmaking

This area is one which involves skill building in technique, as well as specialist/manager communication over expectations. The skill building aspect involves the learning of various techniques of problem analysis, problem identification, problem clarification, creative approaches to finding solutions, and selecting and displaying alternatives. In other words, managing a participative thought process which ultimately leads to a decision. Many low-cost alternatives are on the market for formal training in this area. However, I feel strongly that this subject is best introduced and practiced by an internal Organization Development Specialist or outside vendor as a part of a designed teambuilding program. This approach permits a group of individuals who work together continuosuly (area office, district, divisions, etc.) to learn and practice these skills as well as those skills associated with interpersonal competence together as a group.

For course 7000-7, we addressed this subject only briefly in a short segment, and practiced a few new ideas and techniques through the group problem solving and presentation phase the last day of the program. Feedback from the manager audience again was particularly helpful.

5. Personal Values in Resource Management

This is by far the most difficult area to deal with in attempting to enhance communication effectiveness. It is, however, the most significant of all the issues managers and specialists have difficulty in communicating about. As such, it should command our attention at all levels of the Bureau.

Each manager and specialist approaches the decisionmaking process with a set of personal beliefs and a commitment to the "public good." When conflict occurs about competing uses of public lands and the influence of political and pressure group forces, the all too frequent assumption made is that the other party is:

1. Incompetent
2. Unknowledgeable
3. Unconscious
4. Poor decisionmaker
5. Other (negative adjective)
6. All the above

Essentially all that is occurring in the conflict is non-acceptance of an opposing point of view, without any recognition that there are likely to be such conflicts frequently and that each point of view, to the person holding it, is legitimate and real.

The key to overcoming such counterproductive conflict is to share our resource management values openly and continually, so that we recognize them in each other, respect them, accept them, and move to conflict resolution far more quickly and effeciently. By doing so, we can focus on the decision to be made rather than the lack of ability and/or sanity of the other person, simply because he/she disagrees with us.

Skill building in feedback techniques and enhanced interpersonal awareness are the keys to success, and the courage to take the risk of opening yourself up to understanding differences. Some key principles of conflict resolution need to be practiced back-home. For each manager and specialist, one principle is to try and understand what difference do differences make? What happens to us when we are disagreed with? What makes us angry, and why does it make us angry? Why do you notice the things that you notice in other people?

Simply put, the back-home recommendation is to concentrate on conflict managing skills through formal coursework, or better yet, through organizational teambuilding.

For course 7000-7, two short segments, one on values clarification and one on conflict resolution/awareness preceded the group problem-solving phase on the last day of the program. Participants practiced the principle of "non-discounting bias announcements" in their presentations. The manager audience was instructed to share like information and to provide useful feedback, which they willingly did.

Appendix

Pre-training Questionnaire for the Managers of Soil and Water Specialists

Dear Manager,

Part of our training course, Bureau Course 7000-7 "Watershed Rehabilitation," includes a module on improving communication between resource specialists and managers. In designing this module, we would appreciate your input in order to prepare realistic examples. Responses will be kept confidential.

Please answer the following questions and return this questionnaire to me in the enclosed self-addressed envelope by November 16.

Thank you,

Bruce Van Haveren, D-471
Training Program Leader

Please discuss the following:

A) In your situation, what are the primary needs for information from your resource specialist(s); i.e., what do you want to know?

B) In your situation, what factors appear to cause communication barriers with your resource specialist(s)?

C) What would you like resource specialists to better understand about your decision-making process?

D) As a result of this training course, what is one improvement you would like to see in the nature of communication with resource specialists?

Some of the kinds of problems managers of resource specialists could have in the communication process are discussed below. Please indicate the seriousness of these situations in your experience by circling the appropriate numerical rating. If possible, please describe the impact this problem has had on your work. This would greatly aid the examples used in the workshop.

1. Specialists often present information that is too technical to be usefully interpreted by others.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ______________________________

____

2. Specialists seldom discuss the advantages and disadvantages of several alternatives.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ______________________________

____

3. Specialists have a tendency to argue one point of view and seldom present managers with a range of choices.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ______________________________

____

4. Specialists are insensitive to the needs and emotional issues of other members in a discussion.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ____

____

5. Specialists often do not provide visual aids that facilitate understanding the problem or consequences of suggested recommendations.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ____

____

6. Specialists seldom provide me with adequate arguments to use in influencing other power groups.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ____

____

7. Specialists do not understand the nature and complexity of my decision-making role.

serious		often a		seldom a		not a
7	6	5	4	3	2	1
problem		problem		problem		problem

Example: ____

____

Other comments and suggestions are welcome!

Pre-training Questionnaire for Bureau Course 7000-7 Attendees

Dear Participant,

Part of our training course, Bureau Course 7000-7 "Watershed Rehabilitation" includes a module on improving communication between resource specialists and managers. In designing this module, we would like your input so that we can better meet your needs. Responses will be kept confidential.

Please answer the following questions and return this form to me in the enclosed self-addressed envelope by November 16.

Thank you,

Bruce Van Haveren, D-471
Training Program Leader

1. In what ways are you unclear about the kind of information that your manager needs to influence others or reach decisions regarding soil and water issues?

2. What do you think the major communication barriers are in understanding the information you have to present to your manager and other specialists?

3. In what ways are you unclear about your manager's decision-making process?

4. As a result of this workshop, describe two things you would like to be able to do better in the area of communicating with your manager.

Some of the kinds of problems managers of resource specialists could have in the communication process are discussed below. Please indicate the seriousness of these situations in your experience by circling the appropriate numerical rating. If possible, please describe the impact this problem has had on your work. This would greatly aid the examples used in the workshop.

1. Manager is not clear on needs and desires for technical data.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

2. Manager is not clear on format desired for discussion of the advantages and disadvantages of alternatives.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

3. Manager has a tendency to support one predetermined point of view and resists other choices.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

4. Manager is insensitive to the needs and emotional issues of resource specialists in a discussion.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

5. Manager is not clear on desires for visual or other aids that facilitate understanding the problem or consequences of suggested recommendations.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

6. Managers do not provide specialists with adequate information relative to the influence of outside groups on the issue at hand.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

7. Manager doesn't understand the nature and complexity of my specialist role.

serious problem		often a problem		seldom a problem		not a problem
7	6	5	4	3	2	1

Example: ______________________________

____

Your comments and suggestions are welcome!