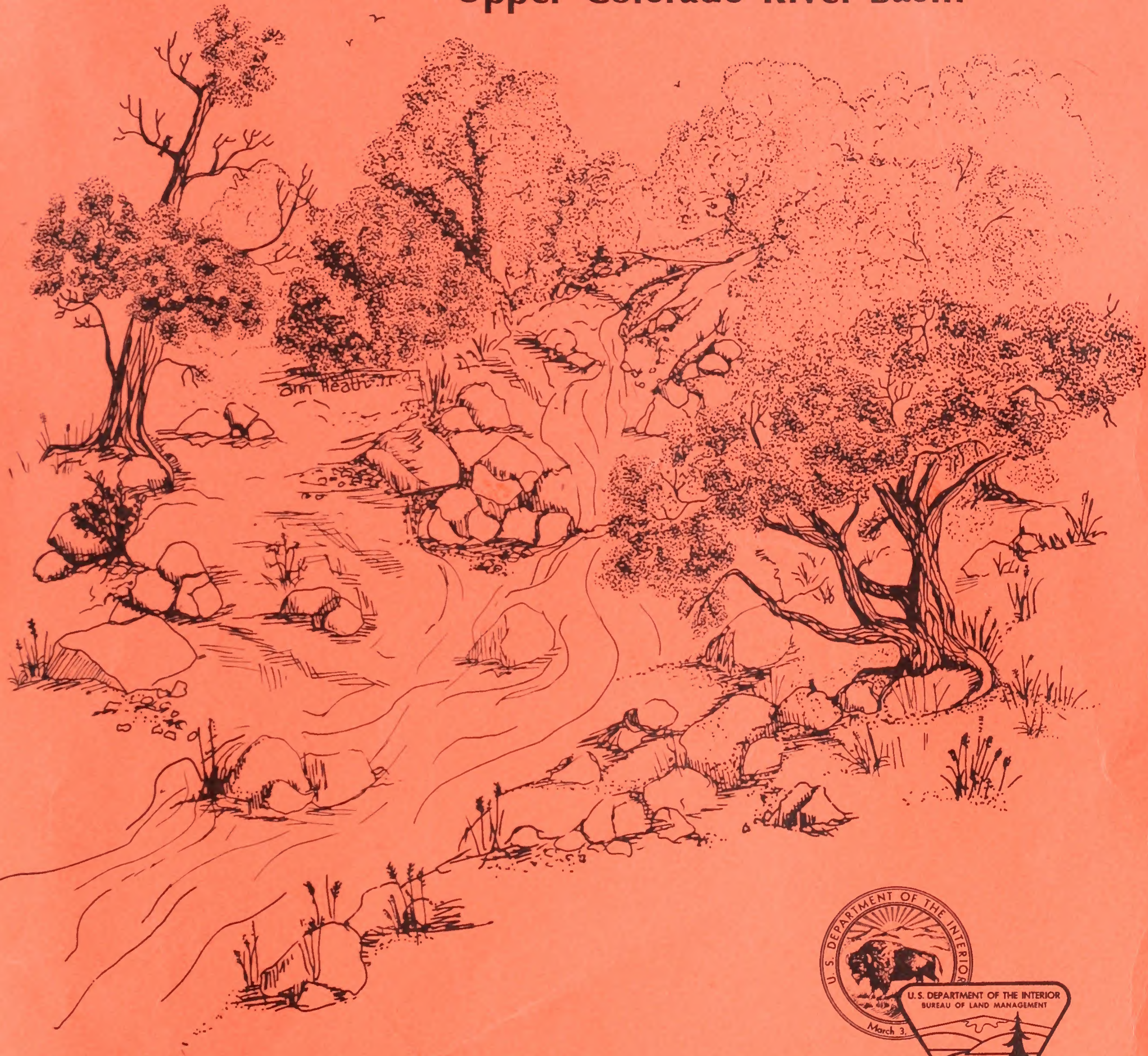
The Effects of Surface Disturbance on the SALINITY of Public Lands in the Upper Colorado River Basin



1977 STATUS REPORT

US DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

The Effects of Surface Disturbance
(Primarily Livestock Use)
on the
Salinity of Public Lands
in the Upper Colorado River Basin

(1977 Status Report)

February, 1978

U.S.D.I., Bureau of Land Management
Denver Service Center, Division of Standards and Technology
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The prospect of increasing salinity in the Colorado River, resulting from greater use of water (agriculture and industry) and soil disturbance (livestock grazing and mineral and energy development), has prompted the Department of The Interior to study possible means of reducing salt yields from diffuse and point sources. The Bureau of Land Management, in this report, discusses the mechanisms involved in salt pickup and transport from diffuse sources on public lands, primarily from overland flow of water. The effects of common man-caused soil disturbance, primarily livestock grazing, on salt yields are discussed. Any practice which compacts or disturbs soil, reduces infiltration, and increases runoff and erosion on saline soils, will increase salt yields. Several common practices, designed primarily to reduce erosion, were analyzed to determine their ability to control salt. The most promising alternative practices were subjected to benefit-cost analysis to determine their economic feasibility. The effects of salinity control practices on regional economies were also studied.

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I. INTRODUCTION

The estimated level of salinity in the Colorado River in 1971 was 865 milligrams per liter (mg/l), as reported at Imperial Dam (53). The Colorado River Board of California predicts that salinity levels may reach 1,340 parts per million (ppm) by the year 2000 (31). The salinity of the Colorado River recently attracted international interest as a result of significant reductions in agricultural production in both the United States and Mexico. Additional treatment costs, incurred by municipal and industrial water users in California, also are attracting public attention.

The average annual salt load of the Colorado River measured at Hoover Dam (based on the 1942-61 period of record adjusted to 1960 conditions) is 10,336,000 tons. Approximately 52 percent or 5,408,000 tons of salt are contributed by natural diffuse sources. The public lands1/ are included in this figure (53). The Upper Basin of the Colorado River produces approximately 8,903,800 tons of salt annually, as measured at Lees Ferry, Arizona (see Table IV-8). The public lands in the Upper Basin states of Colorado, Utah and Wyoming, are estimated to produce approximately 700,000 tons of salt from diffuse overland sources, or 8 percent of the total Upper Basin salt load (see section IV.A.4.e., Summary).

The objective of BLM's salinity study is to provide quantitative and qualitative information on salt pickup and transport mechanisms that occur on public lands. This information is used to analyze the technical and economic feasability of alternative salt control measures. Nearly all of the public lands in the Upper Basin remain in their natural state. The few exceptions are surface mines, spoil piles, drill pads, roads, pipelines, etc. The natural or wildlands have been modified to some degree by domestic livestock grazing and logging. However, when compared to intensive use areas, such as irrigated agriculture and urban centers, the public lands essentially remain natural. Nature also creates changes in the land through wildfire, floods, and protracted droughts.

Salts are yielded from the public lands in several ways. Natural point sources exist, including springs, seeps and natural artesian aquifers. Man has added abandoned oil wells which have tapped saline artesian aquifers. Salts are yielded from other groundwater sources, such as aquifers intersecting perennial streams. These sources are very difficult to identify and quantify. The most significant yield of salts comes from diffuse overland sources, i.e., runoff and erosion from soils and geologic formations containing salts. These sources are easiest to identify and control.

The greatest total quantity of salt comes from rangelands that are relatively well covered with perennial vegetation and receiving greater than 12 inches of average annual precipitation. They comprise 67 percent of all public lands. Salt concentrations are low but total water runoff yield is high. However, this water also dilutes higher concentration water entering the system from more saline areas, as explained in Section IV.A.4.d The other significant source of salt comes from public lands containing saline geologic formations and soils. Some of these lands are at elevations receiving 12 to 16

1/ The term public lands is defined as those lands under the jurisdiction of the Bureau of Land Management (BLM).

inches of annual precipitation. However, those with the highest levels of salt in soils receive less than 12 inches and often 6 to 8 inches of average annual precipitation. The geologic formations and soils are often saline to some degree and vegetative cover is sparse. Any use which disturbs soil, causes accelerated erosion and increased salinity from overland runoff. The quantity of salt yielded is dependent upon the salt content of the geology and soils. The highly saline marine shales are the greatest salt sources. Salt bearing geologic formations and soils are widespread on public lands throughout the Upper Basin (173, 182). Shales produced under freshwater lakes are less of a problem. The major causes of increased salinity on public lands are grazing, off-road vehicles (ORV), and mineral-energy exploration and extraction. These uses should be controlled in order to reduce salinity. The BLM salinity study has concentrated on the effects of grazing and the feasability of its control, because data were readily available and control procedures in common use. Very little data exist on the other uses contributing to the salinity problem. However, their importance is acknowledged.

A. Authority

BLM involvement in developing a salinity control program for the Colorado River Basin has evolved from both legislative action and interagency agreements. These were prompted by the cost of rising salinity and international agreements. In 1972, Public Law 92-500 amended the Federal Water Pollution Control Act to restore and maintain the chemical integrity of the nation's waters. Although the Colorado River salinity problem was not specifically mentioned in the legislation, it is covered generally under consideration of chemical pollution and runoff.

On October 30, 1973, the Assistant Secretary for Land and Water Resources, U.S. Department of the Interior, sent a joint memorandum to BLM and the Bureau of Reclamation (BR) with instructions to "establish a 'working relationship' that will integrate reclamation and public land programs within the Colorado River Basin in such a manner as to expedite the improvement of water quality in the river." The memo further instructed BLM to ". . . assess onland measures to retain diffuse salt sources in place and, if possible, increase the runoff from the public lands through water and land management practices."

Public Law 93-320, The Colorado River Basin Salinity Control Act of 1974, requires interagency coordination to solve the salinity problem of the Colorado River. It directs that the Secretary of the Interior undertake research and develop demonstration projects to identify methods for improvement of the Colorado River's water quality.

The Colorado River Basin Salinity Control Act was prompted by salt damage of crops in California and the Republic of Mexico. The 1944 Treaty allocated 1.5 million acre-feet of water annually to Mexico. However, this treaty made no mention of water quality since salinity was not yet a major concern. By 1961, the situation changed drastically. The already low flow in the Colorado River, caused by a series of dry years, was further reduced by filling the newly-created Lake Powell. At the same time, pumping of highly saline groundwater was begun to lower the water table at the Wellton-Mohawk Irrigation and Drainage District on the Gila River in Arizona. This brine was discharged directly into the Colorado River above the diversion point at

Morelos Dam. The concentration of salts in the water delivered to Mexico increased from 800 to 1500 ppm in only 2 years (45). Negotiations between the United States and Mexico following this period culminated in 1973 with the signing of Minute 242 of the International Boundary and Water Commission. The parties agreed that water delivered to Mexico would ". . . have an annual average salinity of no more than 115 ppm ± 30 ppm . . . . over the annual average salinity of Colorado River waters which arrive at Imperial Dam . . ." (101).

B. BLM Coordination with Other Agencies

The BLM must coordinate its salinity control activities with other agencies and groups working on the salinity program. These include the BR, Soil Conservation Service (SCS), and the Environmental Protection Agency (EPA). The BR is authorized by Public Law 93-320 to construct four projects (units) and complete investigations on 12 others to control salinity from irrigation and major point sources. The SCS is authorized to assist in the control of salinity from private lands, while the EPA is authorized under Public Law 92-500 to monitor and control pollution, including salinity, from point and diffuse sources.

C. Scope of Study

1. Geographic Area

The authorizing documents clearly indicate that the entire Colorado River Basin, including that portion in Mexico, is of concern. However, because of financial and manpower limitations, resource investigations are restricted to a portion of the Upper Basin, i.e., those areas of the Basin located within Colorado, Utah, and Wyoming, as shown in Figure I-1. Economic analyses of corrective actions taken in the Upper Basin include consideration of benefits derived in the Lower Basin.

2. Intensity of Study

The salinity problem of the region (Figure I-1) was first analyzed on a reconnaissance level. Existing reports of other agencies working on the salinity problem as well as other secondary data sources were reviewed. A second level of study involved a detailed analysis of research data concerning mechanisms of salt pickup and transport from upland sites. This included possible means of controlling salinity. Also, economic efficiency and regional economic impacts of alternative control measures were studied.

The economic efficiency analysis is to determine the feasibility of general management practices. Regional economic effects on society are estimated by using existing economic models, including BLM's (27) socio-economic data system (SEDS).

Figure I-1. Location Map of a Portion of the Upper Colorado River Basin

D. Objectives

This report presents information regarding the technical and economic feasibility of continuing BLM involvement in the salinity control program. The specific objectives are as follows:

1. Review existing literature to determine what is known about salinity from diffuse sources.

2. Identify potential diffuse sources of salinity through collection of field data.

3. Analyze information concerning common land treatment and management practices to determine their potential usefulness in reducing salt movement.

4. Analyze the economic effectiveness of selected salinity control measures and regional economic impacts of salinity control in the Upper and Lower Colorado River Basins.

II. BASIN DESCRIPTION

A. Land Ownership

The Upper Colorado River Basin within Colorado, Utah, and Wyoming contains a total of 61,595,000 acres. Public lands (BLM) occupy 44.4 percent of the area, or 27,357,000 acres. State and private lands (17,202,000 acres or 27.9 percent) are often intermingled with public lands. Some lands are intensively used (urban and irrigated agriculture) while a significant portion are undistinguishable from undeveloped public lands and are used for similar purposes (grazing, recreation, etc.). The Forest Service (FS) administers 21.4 percent, or 13,156,000 acres, Indian trust lands occupy 4.6 percent, or 2,812,000 acres, and other federal agencies control another 1.7 percent of the land area, or 1,068,000 acres (205).

B. Uses of Public Lands

The public lands in the Upper Basin are used primarily for grazing, recreation, and mineral-energy exploration and extraction. The intensity of these uses varies among the different regions in the Basin.

Both domestic livestock and wildlife graze on public lands throughout the Basin. Some of the grazing lands administered by BLM are currently being managed under an approved grazing management system. The remainder of the public lands is managed on an interim basis with livestock operators licensed to graze a specified number of animals during a prescribed season each year. Public lands provide significant wildlife habitat, especially during the crucial winter season.

Although the public lands have been used for grazing more extensively than other uses, recreation activities and mineral-energy exploration and extraction are increasing significantly. The nature of recreational activities--such as camping, hunting, and ORV use--often result in their occurrence on areas where soils are easily eroded. Similarly, mineral and energy exploration and extraction activities include seismic paths, access roads, drill pads, pipeline rights-of-way, excavations, and spoil piles, on equally fragile land.

C. Climate

Weather patterns and precipitation in the Upper Basin are associated with two general weather systems--one operating during the winter, the other in the summer. Winter storms result from moist Pacific air transported by frontal systems, moving eastward across the Basin. Orographic lifting is an important cause of precipitation around the larger mountains within the Basin. However, the Upper Basin is on the lee side of the Wasatch and Wyoming Mountain ranges resulting in less precipitation for lower elevation areas. As air descends over these ranges it warms and dries (88). Precipitation increases in the higher elevations of eastern Colorado as air is forced up over the western slope of the Continental Divide and cooled. Winter storms cover relatively broad areas.

The Principal source of summer precipitation is the northerly flow of warm moist air originating in the Gulf of Mexico. High intensity thunderstorms result from thermal heating which creates localized upward movement of air. These storm cells are generally about one mile in diameter and move across the terrain in an erratic pattern. Rainfall amounts and intensities are extremely variable and can be very high.

Precipitation over the Basin ranges from 4 to 40 inches. Weather Bureau data indicate that precipitation on public lands generally ranges from 5 to 17 inches. Temperature also varies greatly throughout the Upper Basin, depending upon elevation and latitude. Winter minimum and summer maximum temperatures can be severe. Daily temperatures, from the daytime high to the nighttime low, can vary as much as 40 degrees Fahrenheit (F). The number of frost-free days (minimum temperature above 32°F) increases as elevation decreases. Winds in the Basin are moderate to high. For example, wind velocity in excess of 50 mph has been recorded at Grand Junction, Colorado in every month of the year (204).

D. Topography

The Upper Colorado River Basin consists of broad plateaus, steep mountains, rolling hills, rough canyon lands, and gently sloping valleys. The numerous plateaus within the Basin reach elevations up to 10,000 feet. The Upper Basin is bordered on the west by the Wasatch Plateau and the Wasatch Range in Utah, and the Wyoming Range of the Overthrust Belt (Bear River Divide) in Wyoming. The eastern and northern borders are formed by the Continental Divide in Colorado and Wyoming. The mountains forming the boundary around the Upper Basin range in elevation from 9,000 to 14,000 feet.

The southwestern portion of the Upper Basin (Utah) is comprised of plateaus and isolated mountain ranges intersected by valleys and steep-walled canyons. Areas of very diverse topography--including isolated buttes, steep escarpments, rock arches, and deep canyons--are widely scattered throughout this region. Some of these areas occur on public lands, but many are located within national parks. Examples are the Arches near Moab, Utah and Canyonlands surrounding the confluence of the Green and Colorado Rivers. The San Rafael Desert, an area of both active and stable sand dunes, is located northeast of Hanksville, Utah.

The San Rafael Swell is a large kidney-shaped dome of stratified rock created by an uplift, situated northwest of the dunes and west of Green River, Utah. The swell is 15 miles wide and 42 miles long, with an average elevation of 7,000 feet. The Price and Grand Valleys of Utah and Colorado cut across the midsection of the Upper Basin from west to east. The Book Cliffs abruptly rise above the northern boundary of the valleys, and the Roan Cliffs rise above the Book Cliffs a short distance to the north. This series of ledges also forms the southern boundary of the Tavaputs Plateau. The Tavaputs Plateau forms a broad U-shaped mass approximately 130 miles long, ranging in elevation from 7,000 to 9,000 feet along its southern or highest level. The plateau dips to the north, decreasing in elevation across its breadth.

The Uinta Mountains north of Vernal, Utah are approximately 145 miles long in a west-east plain, and have an average elevation of approximately 13,000 feet. A long series of south-sloping valleys on the south face of the mountains form a watershed for the Duchesne River, and a similar series of valleys on the north face form a watershed for rivers flowing into Wyoming.

The Wyoming portion of the Upper Basin is a broad, high plain ranging from 6,400 to 7,400 feet in elevation. The interior varies from gently rolling hills to steep bluffs formed from highly erosive sedimentary material.

The eastern portion of the Upper Basin in Colorado is a series of alternating valleys and plateaus from the south to the north, each orientated from the northwest to the southeast. The Uncompahgre, Roan, Grand Mesa, and Tavaputs Plateaus are the major features west of the Continental Divide. The plateaus are separated by the Disappointment, Gypsum, Dry Creek Basin, Paradox, and Grand Valleys. The Piceance and Axial Basins to the north are dissected by lower hills and canyons. The Axial Valley is the result of an extensive uplift which fractured the overlying sedimentary rocks. Erosion has left a low-lying valley of rolling hills in Mancos Shale, surrounded by cliffs and plateaus of the original overburden.

E. Basin Hydrology

1. Hydrologic Setting

The study area of the Upper Colorado River Basin consists of the main stem of the Colorado River and its tributaries above the Utah-Arizona state line. The main stem covers part of east central Utah and west central Colorado. The Green and San Juan Rivers are the two major tributaries. The Green River Basin covers northeastern Utah, northwestern Colorado and southwestern Wyoming, while the San Juan Basin covers southwestern Colorado and southeastern Utah.

The hydrologic setting of the Upper Basin ranges from relatively low-lying arid desert lands, yielding relatively little flow to steep, high mountains, contributing the major streamflow of the Colorado River. Runoff from arid desert areas is generally from high intensity spring and summer thunderstorms. These lands typically yield small amounts of water per year, usually less than 50 acre-feet per square mile.

The mountainous watersheds produce the major perennial streams of the Upper Basin. The flow of these streams can be divided into two parts: (a) base flow and (b) high runoff. The base flow or low flow period is primarily contributed from groundwater and generally occurs from August through March. The discharge during this time is relatively uniform compared to the high flow period.

High runoff generally occurs from April through July and is caused primarily by melting of the mountain snowpack. April and July are often transitional months. April runoff is generally from low elevation snowmelt and may provide a separate discharge peak in the hydrograph. The timing and amount of runoff for a basin varies, depending on elevation, location, and yearly climatic conditions.

Water quality varies depending on stream geology and the influence of man. Natural streamflow and water quality is modified through transmountain diversions, municipal, industrial, agriculture, energy and power generation uses, and storage projects.

2. Water Allocation

The waters of the Colorado River were divided between the Upper and Lower Basins by the Colorado River Compact of 1922 (198). The physical division point was set at Lee Ferry, Arizona. The Compact gave each basin a perpetual right to the "exclusive beneficial use of 7.5 million acre-feet of water per annum." However, it added that "The states of the upper division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 million acre-feet for any period of 10 consecutive years."

The Colorado River waters were further divided by the Mexican Treaty of 1944, providing for delivery of 1.5 million acre-feet annually to Mexico. The Upper and Lower Basin presently provide 10 percent of each's allocation to meet this requirement. The water allocated to the Upper Basin was further divided in the Upper Colorado River Compact (1948); some 50,000 acre-feet were allocated to Arizona for annual consumptive use with the remainder divided between Colorado, Utah, Wyoming, and New Mexico--51.75, 23.0, 14.0, and 11.25 percent, respectively (209).

III. ECONOMIC DAMAGES OF SALINITY

This section discusses the economics of using saline Colorado River water for agricultural, municipal, and industrial purposes. By quantifying the damages of salinity in the Colorado River, and establishing a cost per rise in mg/l of salinity, it is also possible to quantify the damages of salinity originating on public lands in the Upper Basin. These costs are used in Section VII to determine the benefits of salinity control in terms of damages avoided.

To better understand the economic impacts of salinity control it is helpful to note the differences in the incidence of salinity damages in the Upper and Lower Basins (see Figure III-1). Differences in agricultural activities, population, incomes, urbanization, and industrial development all cause differing water-use behavior in the Upper and Lower Basins. The salinity damages in the Lower Basin are considerably worse than those in the Upper Basin. In general, the damage from salts originating in the Upper Basin are borne primarily by the Lower Basin. The expected future expansion of agricultural, industrial, recreational, and municipal water uses will aggravate the problem in the entire Basin. Agricultural damages occur primarily in the Lower Basin agricultural economic region; municipal and industrial damages occur primarily in the Lower Basin municipal and industrial economic region (Figure III-1).

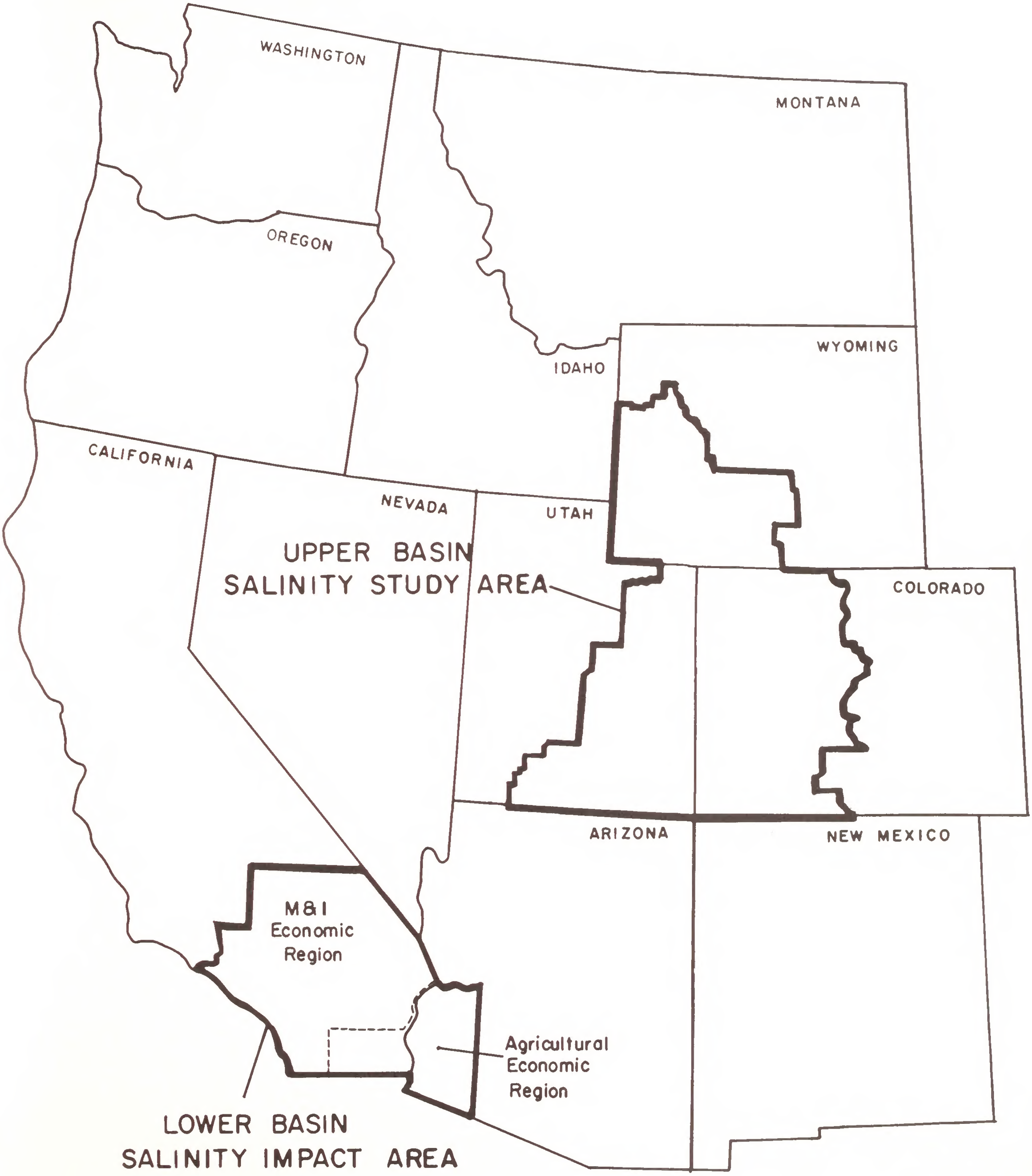
Intermingled in the salinity control problem is the issue of water rights. In essence, beneficial water uses in the Upper Basin often conflict with the economic and social well-being of Lower Basin usage. Unfortunately, no economic or market mechanisms have been adopted to equate the market price of water use with its full social costs. Consequently, there is no direct economic incentive for Upper Basin water users to pay for salinity control practices which are beneficial to the Lower Basin in terms of reduced social costs. Instead, Upper Basin corrective measures are adopted because of legal enforcement of agreements with other regions, states, and Mexico where the harmful effects of salinity are the most apparent. Additional increases in Upper Basin salinity will be accompanied by greater concern and pressure from downstream users.

Research efforts on the economic impacts of salinity have focused primarily on agricultural, industrial, and municipal uses. The physical impacts of salinity are translated into economic impacts either by determining the least cost expenditures necessary to avoid a salinity increase or evaluating the damage caused.

A. Agriculture Damages

Salinity affects irrigated agriculture by decreasing productivity and/or increasing production costs. More specifically, salinity has a tendency to: 1. limit the type of crops that can be grown, or 2. reduce crop yields. Corrective measures depend on the availability of additional water to flush out excess salts from the root zone of irrigated crops. Leaching results in increased water, labor, and fertilizer costs if the same acreage is irrigated and constant yields are expected. If no additional water is available, the irrigator can leach smaller acreages with the same amount of water.

FIGURE III-1. Salinity Study Area in the Upper Colorado River Basin and Economic Impact Area of Reduced Salinity in the Lower Basin (based on County boundries)



Some salinity effects can be mitigated at additional cost by modifying management and production practices. This may involve "...drain installation, ditch lining, land leveling, deep planting, planting bed modification, sprinkler and drip irrigation, and increased irrigation frequency" (114). Although more salt tolerant varieties or crops could be adopted, these would be generally less profitable.

The EPA in 1971 estimated average annual agricultural damage at $45,900 per mg/l per year (52). Kleinman et al (113) in 1977, through a linear program analysis of farmer response to saline irrigation water in the Colorado River Basin reported that agricultural damages for all areas in the Lower Basin averaged $33,168 per mg/l annually (1974 dollars). This 1977 estimate is a substantial reduction from the earlier estimate of $108,400 per mg/l annually (114). Valentine (202) estimated agricultural damages at $129,300 per mg/l per year. Kleinman et al (113) estimated damages of $76,865 per mg/l per year when the salinity range is between 1,300 and 1,400 mg/l. The studies by Kleinman et al (114) and Valentine (202) are based on extrapolation from findings at Imperial Valley, California, where the soils have relatively poor drainage characteristics compared to other soils within the Lower Basin. Although these studies may be somewhat deficient, they are considered the best available. The BLM study uses the average damage estimate developed by Kleinman et al (113).

B. Municipal Damages

Municipal damages from highly saline water are related to increasing capital costs and expenditures for operation and maintenance of water-using household equipment. Capital costs rise when salinity reduces the effective life of such items as water pipes, fixtures, and water-using appliances, (i.e., clothes washers, garbage disposals, water heaters, water softeners, steam irons, swimming pool heaters, pumps and filters, and cooking utensils), as well as lawns and shrubs.

These costs may be partially offset by investment in water softening devices, but operation and maintenance costs expand with increased salinity. For example, more frequent repairs of capital cost items (boilers, pipes, fixtures, etc.) may be expected. Maintenance costs include added soap and detergent use, more frequent swimming pool cleaning, purchase of bottled water, and over-watering of lawns and shrubs.

Valentine (202) estimated annual urban damages to be $124,300 per mg/l per year (1974 dollars) when the salinity of Colorado River water delivered to the Los Angeles basin was projected to increase by 330 mg/l. Anderson and Kleinman (5) estimated average municipal damages at $240,500 (1974 dollars). These damages are adjusted to 1977 dollars in this study. They become benefits when salinity is controlled.

Eubanks and d'Arge (54), in a 1974 study of Water Quality Damage Functions for Los Angeles County, estimated higher economic losses ranging from $620 to $1,000 per household in present value terms for water containing dissolved solids from 200 to 700 ppm. Economic losses were estimated to range from $240 to $325 per household with aggregate damages extrapolated to be between $880 million and $1.4 billion (present value) or an average cost ranging from $70 to $150 million annually. The BR[1] estimated the capitalized savings to be $17 million over a 50-year period. While this study uses the Bureau of Reclamation damage estimates, the estimates by Eubanks and d'Arge (54) and the capitalized savings (BR estimated) are cited to indicate the magnitude of potential damages to municipal users of Colorado River water.

C. Industrial Damages

The mineral content of water affects industry in terms of corrosion and scale formations in boilers and cooling systems. Minerals in boiler water reduce the economic life of the boiler. Industrial water users have the options of obtaining higher quality water at an additional expense, acquiring additional water to maintain the production system, repairing or replacing affected equipment, or treating water before they use it. The EPA estimates the industrial penalty costs to be $1,148 per mg/l per year (52). Similarly, Kleinman et al (114) estimated penalty costs at $1,500 per mg/l per year (1974); adjusted to $1,800 in 1977 dollars.

There are recognized deficiencies in all of the estimates for the agricultural, municipal, and industrial damages. For example, the estimates cite only specific damages in the Lower Basin. Even so, when viewed as indicators of economic damage resulting from salinity, they provide a useful first approximation of salinity as an economic problem.

D. Economic Impacts

The average agricultural, municipal, and industrial damages from salinity in 1977 dollars used in this study are estimated to be $330,800. (For an explanation see Table XII-2-1).

Finally, a better perspective of the economic significance of the salinity problem considered in this study can be gained by realizing that only 8 percent of the Colorado River salt load may be attributed to overland flow from public lands in the Upper Basin. Therefore, the significance of any control measures by BLM may also be limited.

E. Penalties of No Action

If nothing is done about salinity from public lands, present levels of water, sediment, and salt yields will continue to enter streams of the Upper Basin. Table III-1 portrays estimates of these yields from public lands in the three states of Colorado, Utah, and Wyoming. A total of 1 million acre-feet of surface runoff contains 38 million tons of sediment and about 700,000 tons of salt. The damages currently resulting from this salt and sediment would continue, but probably not increase, under a no action alternative.

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[1] Personal communication with Alan Kleinman, September 1977.

Table III-1. Summary of Estimated Total Runoff, Sediment, and Salt Produced from Public Lands in the Three Upper Basin States of Colorado, Utah, and Wyoming.

YIELDS BY STATE	Salinity Class			
	Highly Saline	Moderately Saline	Non-Slightly Saline	TOTAL
COLORADO				
Runoff (ac-ft/yr)	7,600	17,900	287,000	312,500
Sediment (tons/yr)	897,000	986,000	8,099,000	9,982,000
Salt (tons/yr)	34,400	19,400	113,000	166,800
UTAH				
Runoff (ac-ft/yr)	36,900	40,000	445,000	521,900
Sediment (tons/yr)	4,363,000	2,210,000	12,550,000	19,123,000
Salt (tons/yr)	167,000	43,600	176,000	386,600
WYOMING				
Runoff (ac-ft/yr)	7,000	21,300	201,000	229,300
Sediment (tons/yr)	831,000	2,449,000	5,658,000	8,938,000
Salt (tons/yr)	31,900	33,300	79,300	144,500
TOTAL OF 3 STATES				
Runoff (ac-ft/yr)	51,500	79,200	933,000	1,063,700
Sediment (tons/yr)	6,091,000	5,645,000	26,307,000	38,043,000
Salt (tons/yr)	233,300	96,300	368,300	697,900

IV. ENVIRONMENTAL AND LAND USE FACTORS

A. Environment

1. Geology - Relationship to Water Quality[1]

a. Stratigraphy

The ultimate source of nearly all the dissolved ions (salinity) in water entering the Colorado River is the mineral assemblage of the rocks (and soils developed on those rocks) underlying the Colorado River drainage basin. Mineral constituents are taken into solution by both overland runoff and groundwater runoff (the groundwater component of streamflow).[2] Because the usually slower-moving groundwater has longer contact with the rocks, it dissolves larger amounts of mineral constituents and is generally more saline than overland runoff. Consequently, the groundwater component of streamflow contributes significantly to natural salinity of streams in the Upper Colorado River Basin.

Principal properties affecting the natural salinity of water flowing over or through rocks include their mineral composition, texture, and permeability. These properties are related to the rocks' origin, age, and degree of deformation and induration.

Some rocks contain larger amounts of readily soluble minerals than others. For example, certain sedimentary rocks of marine and lacustrine origin commonly contain widespread accumulations of such highly soluble minerals as gypsum and halite. However, most igneous and metamorphic rocks, and sedimentary rocks of terrestrial origin, are composed largely of less soluble minerals such as quartz and various silicate minerals. Consequently, water flowing over or through certain rocks of marine and lacustrine origin (especially the shale, mudstone, and marlstone strata of Mesozoic and Cenozoic age) generally increases in salinity more readily than water flowing over or through most igneous and metamorphic rocks or sandstone strata of terrestrial origin.

Fine-textured rocks afford more surface contact to water that flows over or through them than coarse-textured rocks. Therefore, water flowing over or through fine-textured rocks (such as shale or siltstone) has more opportunity to dissolve mineral constituents before discharging to streams. Such water generally increases in salinity more readily than water flowing over or through coarse-textured rocks (such as conglomerate or coarse-grained sandstone).

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[1] Written by Don Price, Hydrologist, U.S.D.I., Geological Survey, Utah.

[2] The reader is referred to Price and Arnow (157) for more discussion about the relation between surface water and groundwater in the Upper Colorado River Basin.

The permeability (hydraulic conductivity) of a rock is a measure of its ability to transmit water. Rocks with low permeability will, under equal head, transmit water more slowly than rocks that have high permeability. Therefore, water flowing through rocks with low permeability (such as poorly sorted, well-cemented conglomerate) has more time to dissolve mineral constituents before discharging to streams. Such water increases in salinity more readily than water flowing through rocks of high permeability (such as well-sorted uncemented river gravel). Hem (91) describes in some detail the rock sources of most mineral constituents commonly found in natural waters. The reader is referred to that publication for more detailed treatment of the subject.

A large variety of rocks, ranging in age from Precambrian to Holocene, crop out in the Upper Basin. They include various types of igneous and metamorphic rocks, and sedimentary rocks of both continental and marine origin. The igneous and metamorphic rocks--consisting largely of granite, lava, quartzite, schist, and gneiss--are widely exposed in the higher mountains of the region, as are many of the marine sedimentary rocks of Paleozoic age, consisting largely of limestone, dolomite, sandstone, and quartzite. Marine and lacustrine sedimentary rocks of Mesozoic and Cenozoic age--consisting largely of shale, siltstone, mudstone, and marlstone with some sandstone, conglomerate, and limestone--underlie large parts of the Green River, Washakie, Uinta, and Piceance Basins. They also crop out in the Book Cliffs, San Rafael Swell, and along the flanks of the higher mountains and plateaus. Terrestrial sedimentary rocks of Mesozoic age, consisting largely of windblown sandstone, are most widely exposed in the Canyonlands area. Unconsolidated terrestrial deposits of Cenozoic age--consisting mostly of fluvial, glaciofluvial, colluvial, and windblown deposits--have relatively small exposure and are widely scattered throughout the Upper Basin.

Iorns et al (103) grouped the rocks into eight hydrologic units on the basis of their age and general hydrologic properties. Price and Arnow (157) regrouped the hydrologic units of Iorns et al (103) into five geohydrologic units, chiefly on the basis of their water-bearing properties. The geohydrologic units of Price and Arnow (157) are herein regrouped into five other units (Table IV-1 and Figures IV-1a, 1b, and 1c) with respect to their relative effects on the salinity of the water that moves over or through them. Criteria used in the regrouping included dominant lithology, origin, and age of the rocks, and, where known, chemical quality of both groundwater and overland runoff in undisturbed areas underlain by these rocks.

The water moving over or through the five units falls into one or more of the following salinity classes:

Class	Salinity (mg/l)
Nonsaline	0 to 250
Slightly saline	251 to 1,000
Moderately saline	1,001 to 2,000
Highly saline	More than 2,000

Table IV-1. Relative Salinity of Geologic Units in the Upper Colorado River Basin, Colorado, Utah, and Wyoming.

Map Unit (see (Fig. IV-1)	Approximate Area of Outcrop		Dominant Salinity Range (see text)	Predominant Rock Types	Representative Geologic Formation[1/]
	Square Miles	Percent of Map Area			
1	11,400	12	Nonsaline	Plutonic and metamorphic rocks of Precambrian age and igneous rocks of Tertiary and Quaternary age; include granite, lava flows and related igneous rocks, quartzite, gneiss, and shist.	Front Range Granite Group (of former usage), Needle Mountains Group (of former usage), Uinta Mountain Group, Gunnison River series, unnamed igneous rocks.
2	40,400	42	Nonsaline to Slightly Saline	Sedimentary rocks of marine and continental origin; include limestone, dolomite, sandstone, and quartzite of Paleozoic age, sandstone of Mesozoic age; and some siltstone, limestone, shale, and conglomerate of Mesozoic and early Cenozoic age.	Brazer Dolomite, Madison Limestone, Leadville Limestone, Jefferson Limestone, Ouray Limestone, Morgan Formation, Weber Sandstone and quartzite, Oquirrh Formation, Hermosa Formation, Tensleep Sandstone, Phosphoria Formation, Cutler Formation, Park City Formation, Rico Formation, Glen Canyon Group, Summerville Formation, Entrada Sandstone, Curtis Formation, Morrison Formation, Dakota Sandstone, Cedar Mountain Formation; Mesa Verde Group (locally), North Horn Formation, and Flagstaff Limestone.
3	28,600	30	Slightly Saline to Moderately Saline[2/]	Sedimentary rocks of predominantly continental origin; include mostly interbedded sandstone, siltstone, mudstone, and shale with local strata of conglomerate and limestone mostly of Cenozoic age; contain considerable carbonaceous material and evaporite deposits.	Wasatch Formation, Green River Formation, Uinta Formation, Fort Union Formation, Bridger Formation, Duchesne River Formation, Browns Park Formation, Middle Park Formation, and Mesa Verde Group (locally).
4	14,800	15	Moderately[2/] Saline to Highly Saline	Predominantly marine sedimentary rocks of Mesozoic age; include mostly shale with some sandstone, limestone, marlestone, mudstone, and conglomerate.	Moenkopi Formation, Chinle Formation, Mancos Shale, Tropic Shale, Lewis Shale, Baxter Shale, Cody Shale, Steale Shale, Mesa Verde Group (locally), and Straight Cliff Sandstone.
5	1,000	1	Nonsaline[3/] to Highly Saline	Unconsolidated deposits of Quaternary age; include glacial, alluvial, colluvial, and windblown deposits; clay, sand, and gravel along most streams and in glaciated mountain areas; mostly sand and silt in other areas.	Durango Till, Florida Gravel, Cerro Till (of former usage), and many mapped but unnamed, unconsolidated deposits.

[1/] After Iorns et al (103), table 1.

[2/] Generally yield nonsaline to slightly saline water where exposed in high well-wetted areas (see text).

[3/] Glaciofluvial deposits and alluvium along larger main stem streams yield nonsaline water; colluvium and windblown deposits in units 2 to 4 (exposure too small to be shown in Figure IV-1) generally are composed of the same rock material and yield water in the same salinity range as do the respective units on which they lie.

FIGURE IV-1a RELATIVE SALINITY OF ROCKS IN COLORADO

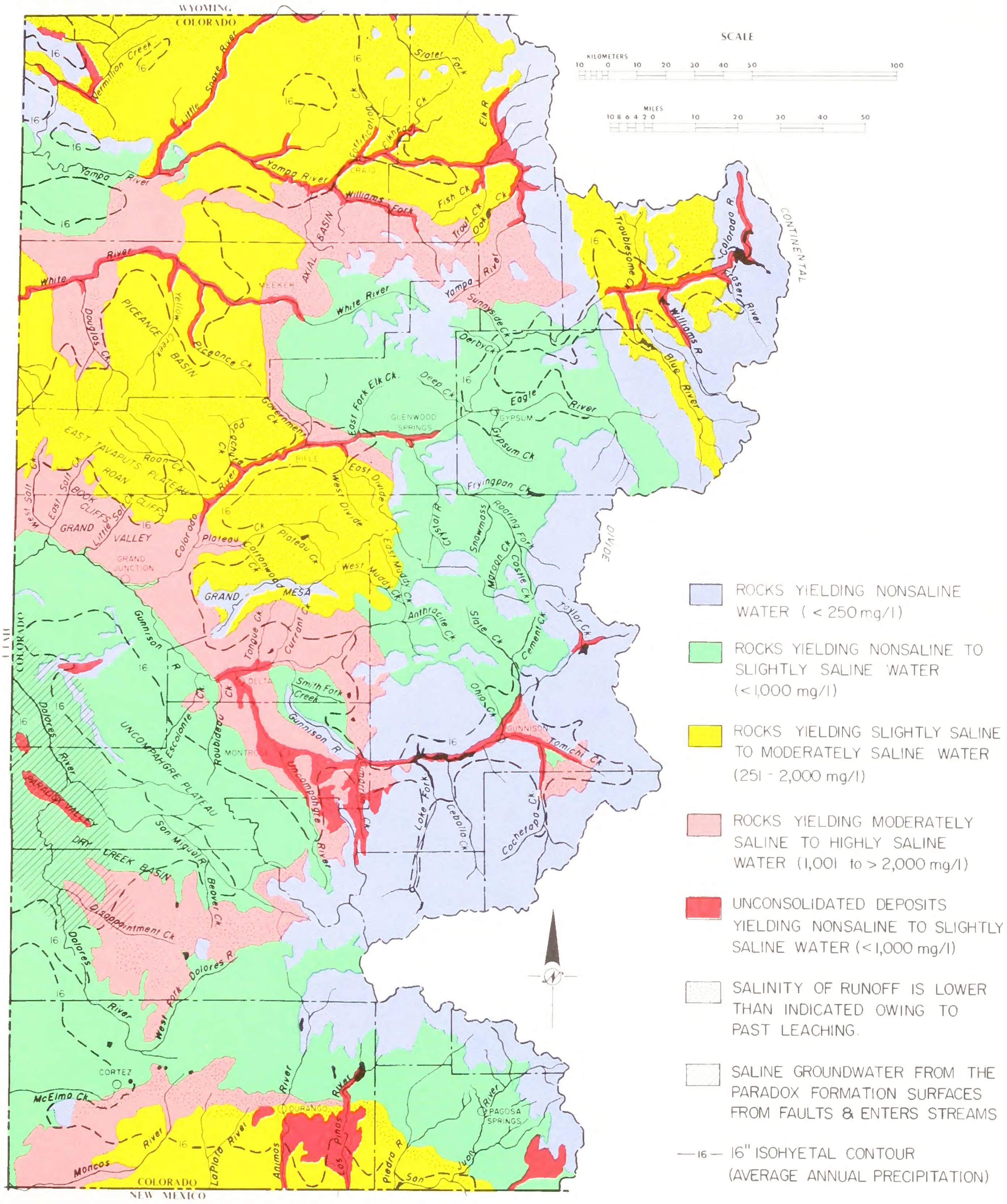


FIGURE IV-1b RELATIVE SALINITY OF ROCKS IN UTAH

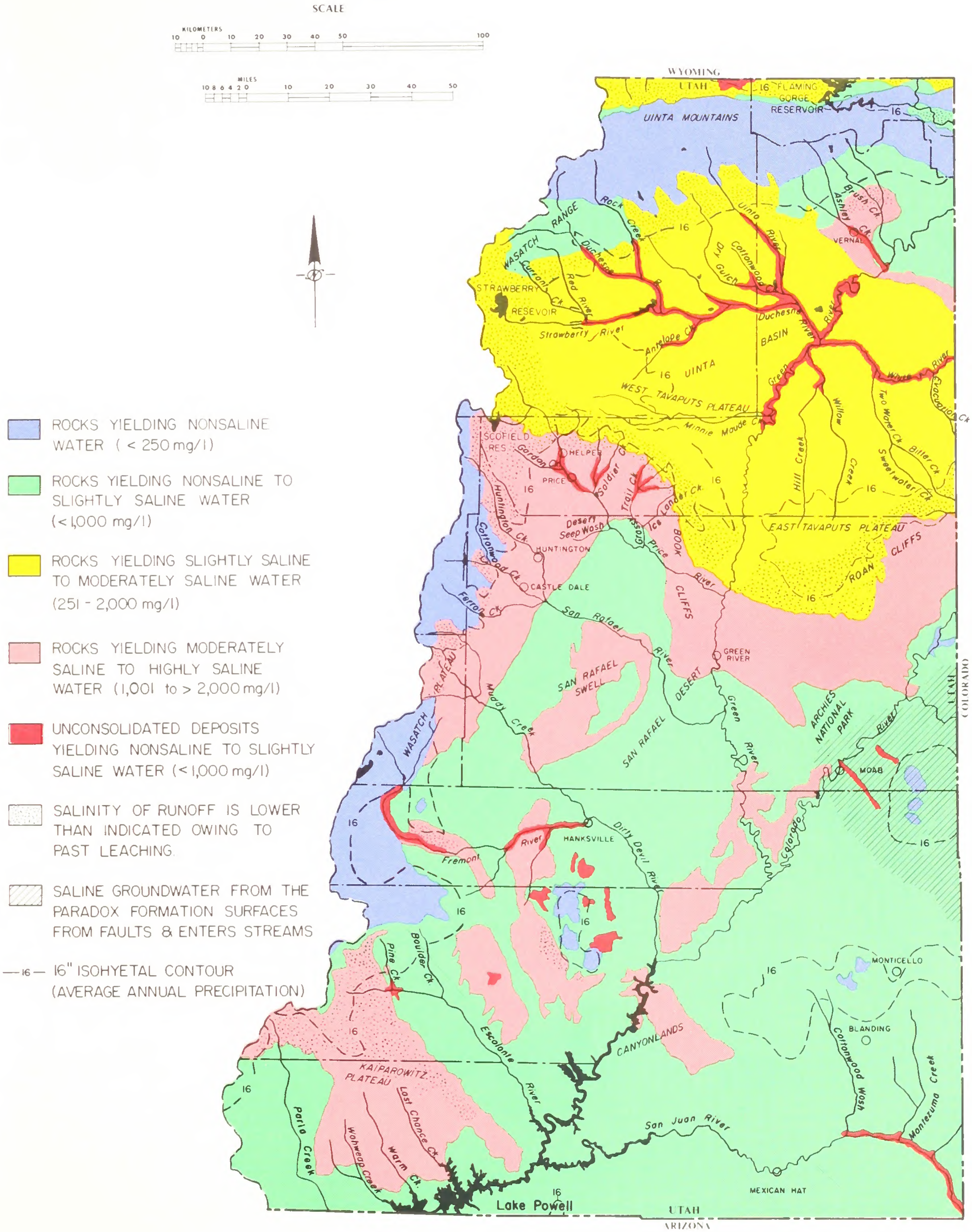
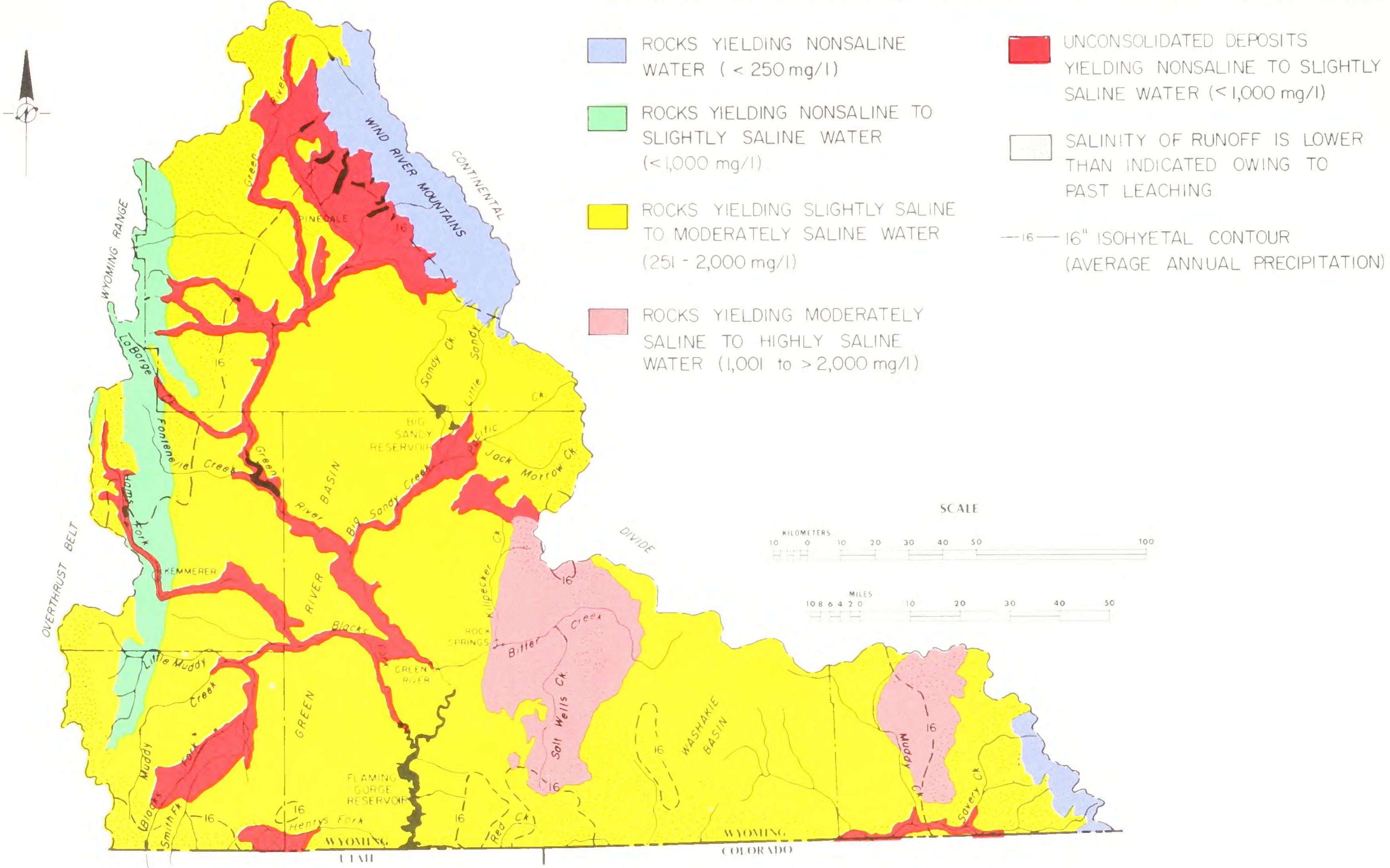


FIGURE IV-Ic. RELATIVE SALINITY OF ROCKS IN WYOMING



These salinity classes are intended to reflect, as nearly as possible, discharge-weighted average concentrations of dissolved solids to be expected in runoff from a given unit. Salinity of peak or flood runoff, however, is lower in most cases. The acreage of lands in each of the salinity classes (Table IV-1) is used in the economic analysis outlined in sections VII and VIII. The process of extrapolating information developed on sample allotments throughout the Upper Basin, using the acreages in Table IV-1, is explained in section VI.

Where parts of units 3 and 4 underlie higher, well-wetted plateaus and mountainous areas (where average annual precipitation exceeds 16 inches), much of the more highly soluble mineral constituents they originally contained have been leached. Therefore, the salinity of runoff generated on those units in the higher altitudes (generally above the 8,000-foot level) will usually be lower than indicated in Table IV-1 and Figure IV-1. Nevertheless, the salinity of the water ultimately flowing from those units into main stem streams will, in most cases, be within the range indicated. For example, runoff in Bitter Creek, originating on the Green River Formation (in unit 3), is nonsaline in the headwaters area, but is highly saline by the time it discharges into the White River. Part of this salinity increase is due to concentration by evapotranspiration along the water course. However, most is due to the groundwater component of the streamflow, which is largely saline. This is indicated by chemical analyses of groundwater samples collected directly from the Green River Formation (158). Similarly, the salinity of runoff in Wahweap Creek, which heads on the Kaiparowits Plateau, increases from less than 1,000 mg/l near the headwaters area to more than 2,000 mg/l where the creek drains into Lake Powell. This increase is due chiefly to saline inflow from water that has been in contact with the Tropic Shale and the Straight Cliffs Sandstone.

Most of the alluvium along main stem streams (unit 5) yields nonsaline water, chiefly because the alluvium is generally highly permeable and because most highly soluble minerals that it may have contained have been leached. However, the alluvium (most of which is not shown in Figure IV-1) along many of the intermittent and ephemeral streams draining units 3 and 4 and parts of unit 2 contains crusts of salt. The salt was deposited by groundwater that evaporated as it seeped from the ground or by water from previous runoff that evaporated. Most of this salt is readily taken into solution by subsequent runoff and is eventually carried into the Colorado River.

Geologic formations that contribute most significantly to the salinity of the Colorado River are shales, such as the Lewis and Mancos Shales of Cretaceous age (in unit 4), and those formations made up largely of shale, siltstone, and mudstone, such as the Green River and Fort Union Formations of Tertiary age (in unit 3). This is especially true in areas where derived soils are being irrigated. This results in highly saline irrigation return flows to the river system. For example, runoff in Spring Canyon Creek, in the Price River Basin of Utah, has been sampled both upstream and downstream from an outcrop of Mancos Shale. Chemical analyses of the sampled water indicate that, although there is no irrigation return flow upstream from either sampling site, there is at least a threefold increase in dissolved-solids concentration of the streamflow where the creek crosses the outcrop of Mancos Shale. Runoff in streams such as Huntington and Muddy Creeks, which drain similar terrain as Spring Canyon Creek and also receive irrigation return flows from soils developed on Mancos Shale, undergo a fivefold to tenfold increase in dissolved-solids concentration.[3] The reader is also referred to Mundorff (142) for a discussion of the effects of the Mancos Shale on salinity of runoff in the Price River Basin.

The Paradox Formation of Pennsylvanian age underlies a large area of western Colorado and eastern Utah (see Figures IV-1a and 1b). The few surface exposures of this formation are grouped with other rocks in unit 2, which consists of rocks that yield nonsaline to slightly saline water. However, the formation, where buried beneath younger rocks, locally contains large accumulations of salt. This salt is dissolved by groundwater, carried in solution, and moves upward chiefly along fault zones to shallower alluvial aquifers. Then it is eventually discharged into streams--chiefly the Dolores River where that stream crosses the Paradox Valley in western Colorado. The B.R. (33) estimates that the annual salt pickup of the Dolores River in that reach is about 200,000 tons.

b. Geologic structure

Nearly all the rocks in the Upper Basin have undergone some structural deformation since their emplacement or deposition. Rocks in the mountainous areas have been complexly folded and faulted; those in the Green River, Washakie, Uinta, and Piceance Basins have been folded into broad synclinal troughs with some associated faulting and secondary folds. Even the relatively flat-lying rocks in the Canyonlands area have been tilted, folded, or faulted to some extent.

Geologic structure has significant influence on both point source and diffuse sources of salinity in the Upper Basin. This is chiefly due to control of certain structures over the movement and discharge of groundwater. For example, faults associated with the formation of salt domes and the collapse of leached-out areas in the Paradox Formation are the principal conduits along which saline groundwater flows to the surface and eventually discharges to streams in and around the Paradox Valley.

Thermal springs, which may be significant point sources of salinity, are also related to geologic structure. Water moves downward deep into the earth along fractures and bedding planes, especially along the west slopes of the Rocky Mountains. The temperature of the water increases with depth, significantly increasing the ability of the water to dissolve mineral constituents. These saline thermal waters return to the surface along faults and discharge large amounts of salt into streams at various points in the Colorado River system (157). The Water Resources Council (206) estimated the annual salt discharge of the major thermal springs in the Basin exceeds 500,000 tons, and that Glenwood Springs alone produces nearly 214,000 tons.

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[3] Written communication with K. M. Waddell, U.S.D.I., Geological Survey, 1977.

Water in the Green River, Washakie, Uinta, and Piceance Basins, is under artesian conditions. Saline groundwater in deeply buried confined aquifers moves upward, usually along fractures in the confining beds, into fresh-water aquifers and eventually into streams. In the Piceance Basin of Colorado, for example, highly saline water from a deep confined aquifer in the Green River Formation moves upward under artesian pressure into shallow aquifers and eventually into Piceance and Yellow Creeks (210). This same condition, doubtless, also exists to some extent in parts of the Green River, Washakie, and Uinta Basins or wherever artesian conditions exist.

2. Soils - Relationship to Water Quality

a. General Classification

The dominant soils occurring in the Upper Colorado River Basin are classified in the Entisol, Aridisol, Mollisol, Alfisol, and Inceptisol orders (90,222,225). General characteristics of these soil orders (including some subgroups and miscellaneous areas) which can affect salt pickup and transport mechanisms are considered. Such characteristics as salt content, horizon development, particle size, humus content, presence of elements which influence soil particle dispersion (sodium) and restrictive layers, are important influences on soil compaction, infiltration, percolation of water, and potential salt and sediment yields. The characteristics discussed are important criteria used to classify and separate each of the soils into distinct orders and subgroups. However, a discussion of these characteristics is not meant to imply each will always exist on any given site.

Entisols are youthful soils with little or no evidence of naturally occurring soil horizons (pedogenic horizons). There are several reasons why horizons have not formed. In many soils the time has been too short. Some soils are on steep slopes where erosion equals or exceeds horizon development, allowing no accumulation of salts or clays. Entisols on alluvial fans and flood plains are the product of frequent deposition of new material. Some soils are accumulations of aeolian material high in erosion resistant minerals such as quartz and occur as sand dunes. Any salts in association with the sand particles would be subject to movement by wind. These coarse-textured soils are classified in the Torripsamments subgroup and are depicted in Figure IV-2 as "sandy" Entisols.

Entisols of the Upper Basin are dominated by an aridic moisture regime occurring in arid and semiarid zones (183). They may contain up to 30 percent clay, and may be saline and/or sodic in some horizons within the soil profile. Soil horizons containing salts may have an E.C. greater than 4,000 μmhos/cm, and a sodium adsorption ratio (SAR) greater than 13. The E.C. can be related to the salt concentration in mg/l as explained in Section IV.A.4.b.1.

Nearly all valley bottoms in the lower elevations of the Upper Basin are classed as Entisols. They are normally saline and almost uniformly have been derived from a parent material containing some degree of calcium (62). Some saline soils of the Aridisol order are found in Utah as inclusions within the Entisols. These are alkali phases of the Torriorthents subgroup, with some Natrargids and Salorthids, and are shown on Figure IV-2b as small areas of Entisols surrounded by "saline" Aridisols. Southwestern Wyoming (Figure IV-2c) contains narrow bands of soils along streams, in the Torrifluvent and Torriorthent subgroups, as depicted by "saline" Entisols. The dominant vegetation on Entisols consists of shadscale and greasewood. Entisols are very fragile soils. Disturbance and compaction of these soils can cause large increases in sediment and salt yields.

Aridisols occur in arid and semiarid zones. Aridisols, as their name implies, do not contain water in sufficient quantities for growth of mesophytic plants during long periods. Soil moisture content is generally

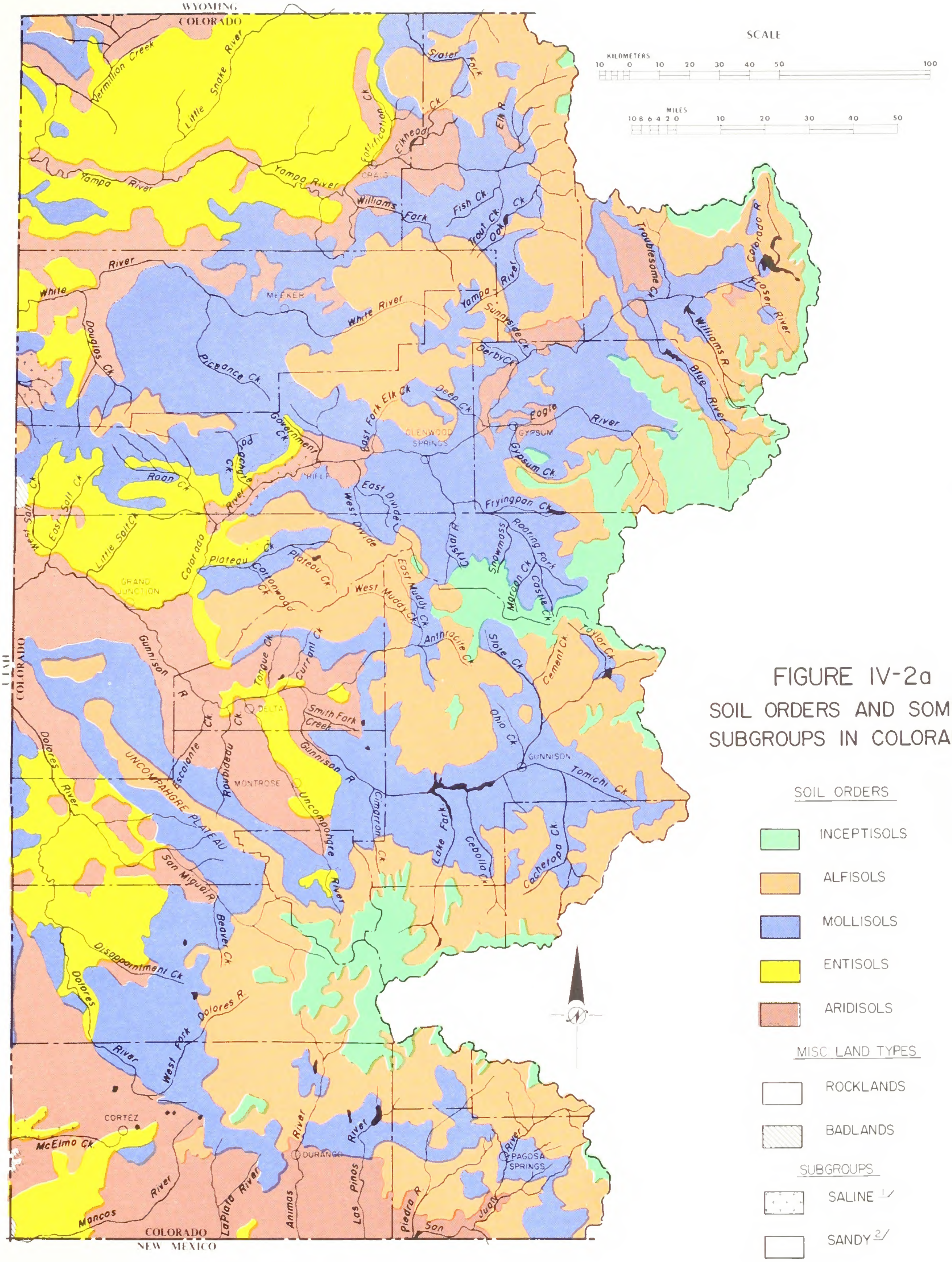


FIGURE IV-2a
SOIL ORDERS AND SOME SUBGROUPS IN COLORADO

1/ Saline includes Natrargids, Salorthids and Torriorthents

2/ Sandy includes Torripsamments

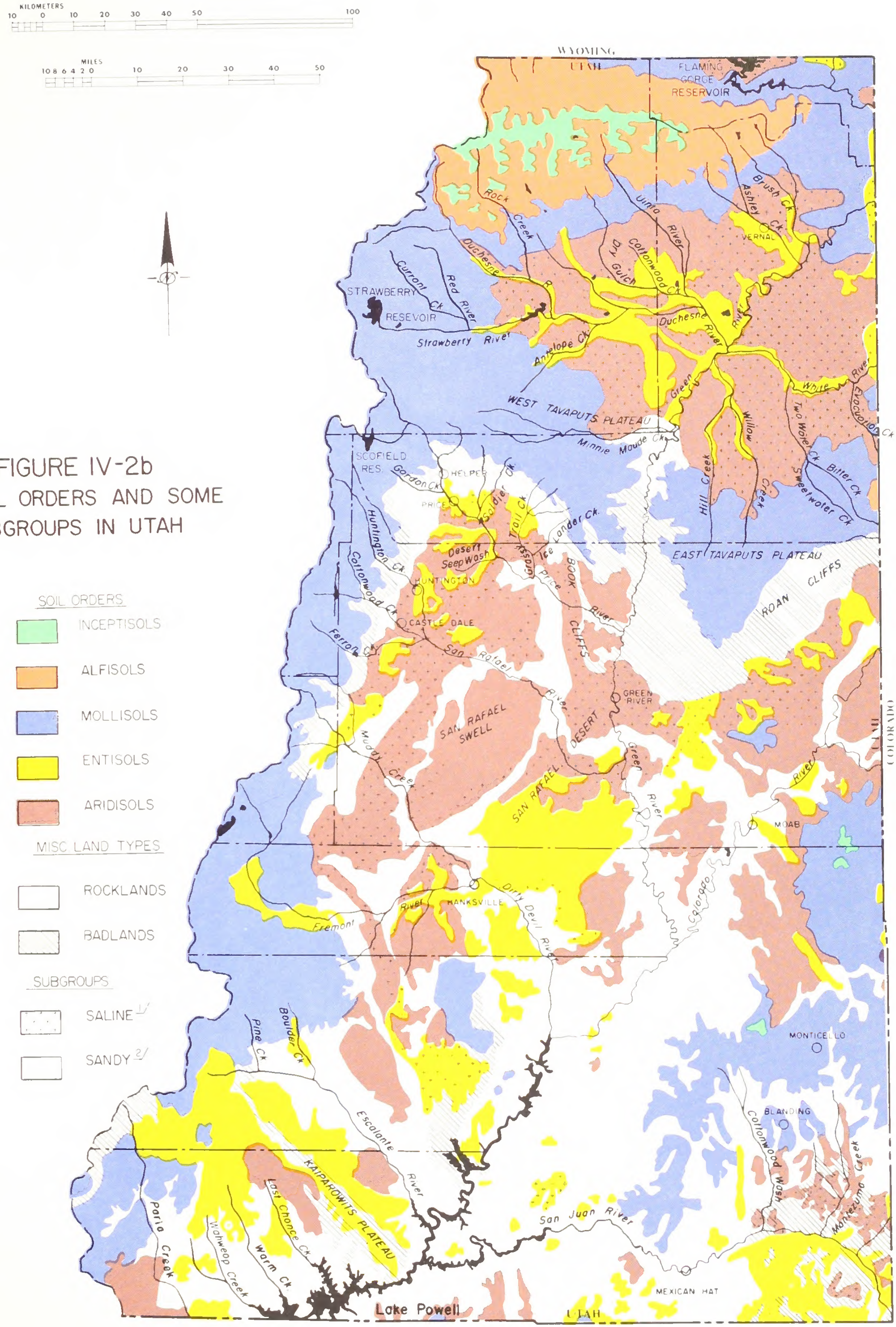
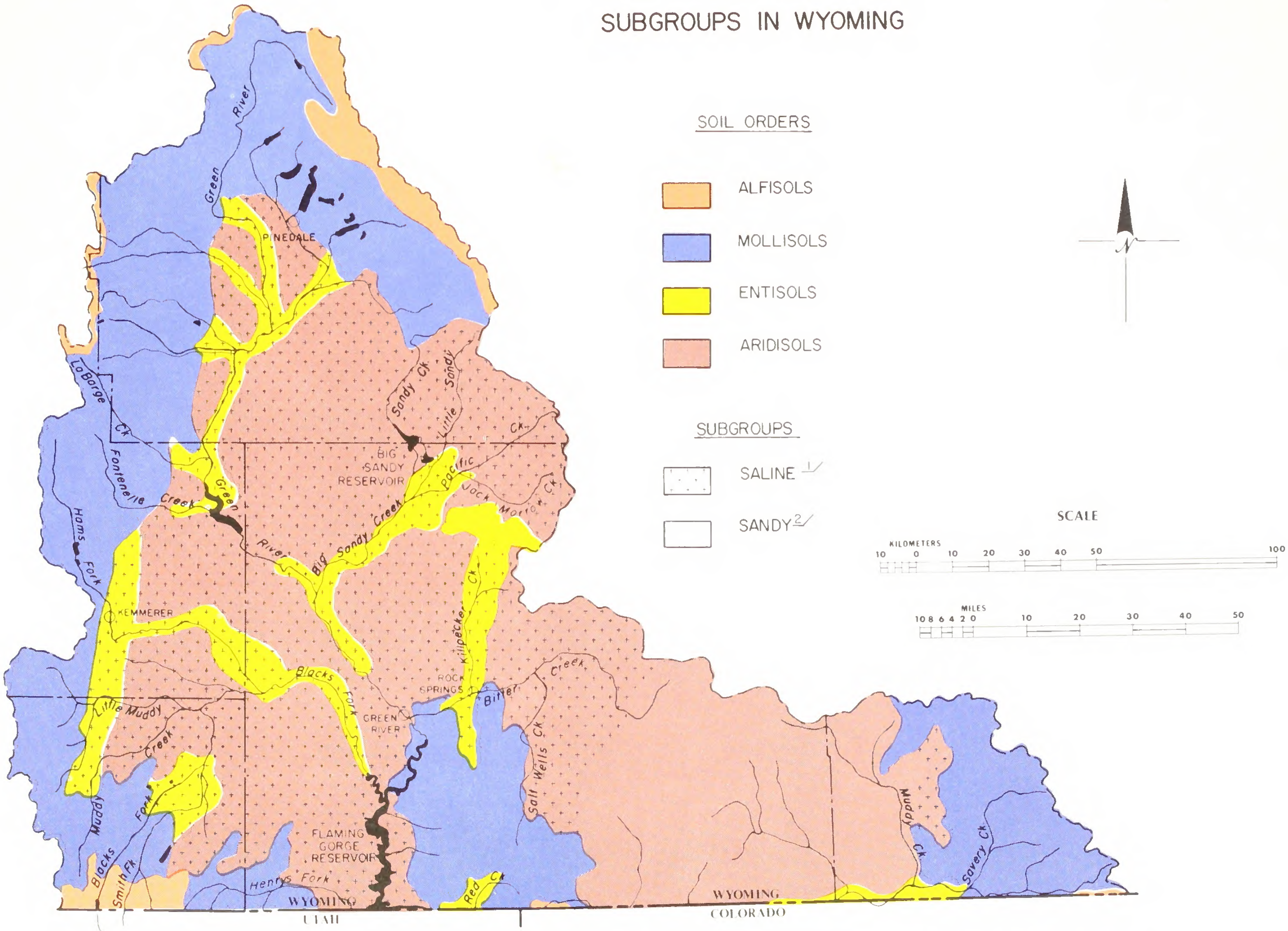


FIGURE IV-2b
SOIL ORDERS AND SOME SUBGROUPS IN UTAH

1/ Saline includes Natrargids, Salorthids and Torriorthents

2/ Sandy includes Torripsamments

FIGURE IV-2c
SOIL ORDERS AND SOME SUBGROUPS IN WYOMING



1/ Saline includes Natrargids, Salorthids and Torriorthents.

2/ Sandy includes Torripsamments.

below the wilting point (greater than 15 atmosphere percentage) when soils are warm enough for plant growth. The aridic moisture regime is a result of several factors including low precipitation and a high rate of runoff. The runoff is a factor of high intensity rainfall, and high clay content or impervious soil crusts which cause water to be absorbed slowly. Also, the soil may be bare of vegetation most of the time. If gravel is present in the soil, the surface may be covered with a gravel layer called erosion pavement (183).

The surface layer of Aridisols is normally light in color and low in organic matter. They have one or more pedogenic horizons which may be the result of translocation and accumulation of salts, carbonates, or silicate clays, or of cementation by carbonates or silica. Aridisols may have restrictive layers, which result in lower infilration rates and limited water-holding capacity. These layers may be argillic horizons (high clay content), clay pans, petrocalcic horizons (cemented calcium carbonate layer commonly called caliche), and duripans (indurated horizons cemented by silica, with secondary amounts of calcium carbonate). Where natric horizons (sodium enriched) exist, they severely restrict plant growth.

Electrical conductivity of Aridisols is dominantly 2,000 μmhos/cm or more in the upper 40 inches of soil; SAR may also be greater than 13. The most saline Aridisols are the Natrargid subgroup with inclusions of Torriorthents, and are shown as "saline" on Figure IV-2b and -2c. About 20 percent of the Aridisols in Utah are easily eroded because of fine-textured surface soils and low percent of vegetative cover. Often, the sparse vegetation is a result of high salt content in soils. Vegetation on the Aridisols consists primarily of shadscale, mat saltbush, Nuttall saltbush, and greasewood at lower elevations, while big sagebrush and juniper-pinyon occur on the cool-moist higher elevation sites. A large area of soils in the Natrargid subgroup is located in southwestern Wyoming, and is shown as "saline" Aridisols on Figure IV-2c. Aridisols are very fragile and become unstable when the surface crust is disturbed or the soil is compacted.

Mollisols occur in the subhumid to semiarid zones, and have sufficient soil moisture to support perennial grasses and shrubs. They have dark-colored surface layers reflecting a high organic matter content. They also have one or more pedogenic horizons that may be the result of translocation and accumulation of salts, carbonates, or silicate clays, or cementation of carbonates or silica. Many Mollisols have argillic, natric, or calcic horizons; a few have a duripan or petrocalcic horizon. Some Mollisols, especially in the semiarid zones, may have E.C.s of 2,000 μmhos/cm or more and/or SARs of greater than 13 in the upper 40 inches of soils.

A small percentage of soils within the Mollisol order possess saline subsoils or substratum. These salt affected soils are associated with saline geologic formations dominated by shales and other soft sediments. These subgroups are not separated from the Mollisols shown on Figure IV-2. Vegetation consists primarily of big sagebrush-grass and juniper-pinyon on the dryer sites, with ponderosa pine, mountain brush, and Douglas fir on the cooler-wetter sites. These soils contribute less salt to the water regime than the Entisols and Aridisols because they are more stable, and salt content of soils is lower due to past leaching.

Alfisols occur at the cool, humid higher elevations (see Figure IV-2). They tend to form a belt between the Mollisols at lower elevations and Inceptisols at even higher elevations (183). These soils have surface layers with moderate to high quantities of basic ions (such as calcium, magnesium, potassium, or sodium) and accumulations of clay particles in the subsoil. They have one or more horizons resulting from the translocation and accumulation of salts, carbonates, iron, or silica. Some soils exhibit packing of soil particles, especially on glaciated land forms. Leaching of basic ions from the soil may occur every year or only infrequently.

Some small areas of Alfisols (not shown on Figure IV-2) are associated with saline geologic formations. The surface layer of these soils are generally nonsaline because of leaching. However, disturbance and exposure of subsoil layers by a loss of plant cover will increase sediment and salt yields. These soils are especially vulnerable to slumping on slopes when protective vegetation is removed. The Alfisols generally support pine, fir, spruce, aspen, and associated grasses and forbs.

Inceptisols are soils of the high elevation humid regions (Figure IV-2). They have altered horizons which have lost basic ions and iron through leaching, but retain some weather resistent minerals. Layers of accumulation of translocated silica, iron, or basic ions are common in the lower soil horizons. Large areas of subalpine and alpine vegetation, and barren rock are common. These soils are very fragile and subject to increased runoff and sedimentation, as a result of soil disturbance or compaction.

Rockland type consists of barren rock (sandstone, etc.) exposed or overlain with a shallow layer of sandy soils. Arches and canyonlands contain formations common to this land type. The volume of runoff and sediment is normally large.

Badland type consists of steep, barren land, ordinarily not stony, dissected frequently by intermittent drainage channels entrenched in soft geologic formations (many are marine shales). The potential for runoff, geologic (natural) erosion, and salt yield is high. Small inclusions of identifiable soils support a sparse vegetative cover.

The BR (34) has grouped the soil areas of the Upper Basin into four salinity classes, as shown in Figures IV-3a, -3b, and -3c. These are nonsaline, slightly saline, moderately saline, and strongly saline (see Table IV-2). The term strongly saline was used by BR (34) and is, therefore, used in the following discussion of their data. However, the term "highly" saline is used by BLM in other sections of this report. The classifications are very general and not useful for detailed interpretations. Their primary value is to indicate where major problems exist. The moderately and strongly saline soils have the greatest potential for salt contribution to the Colorado River. However, the slightly saline and nonsaline soils also contribute large volumes of salt, partly because of their extensive acreage. Surface runoff from these soils contains salts in relatively low concentrations; however, total salt yield is high because of the large volume of water produced.

FIGURE IV-3a. GENERAL SOIL SALINITY CLASSES FOR COLORADO

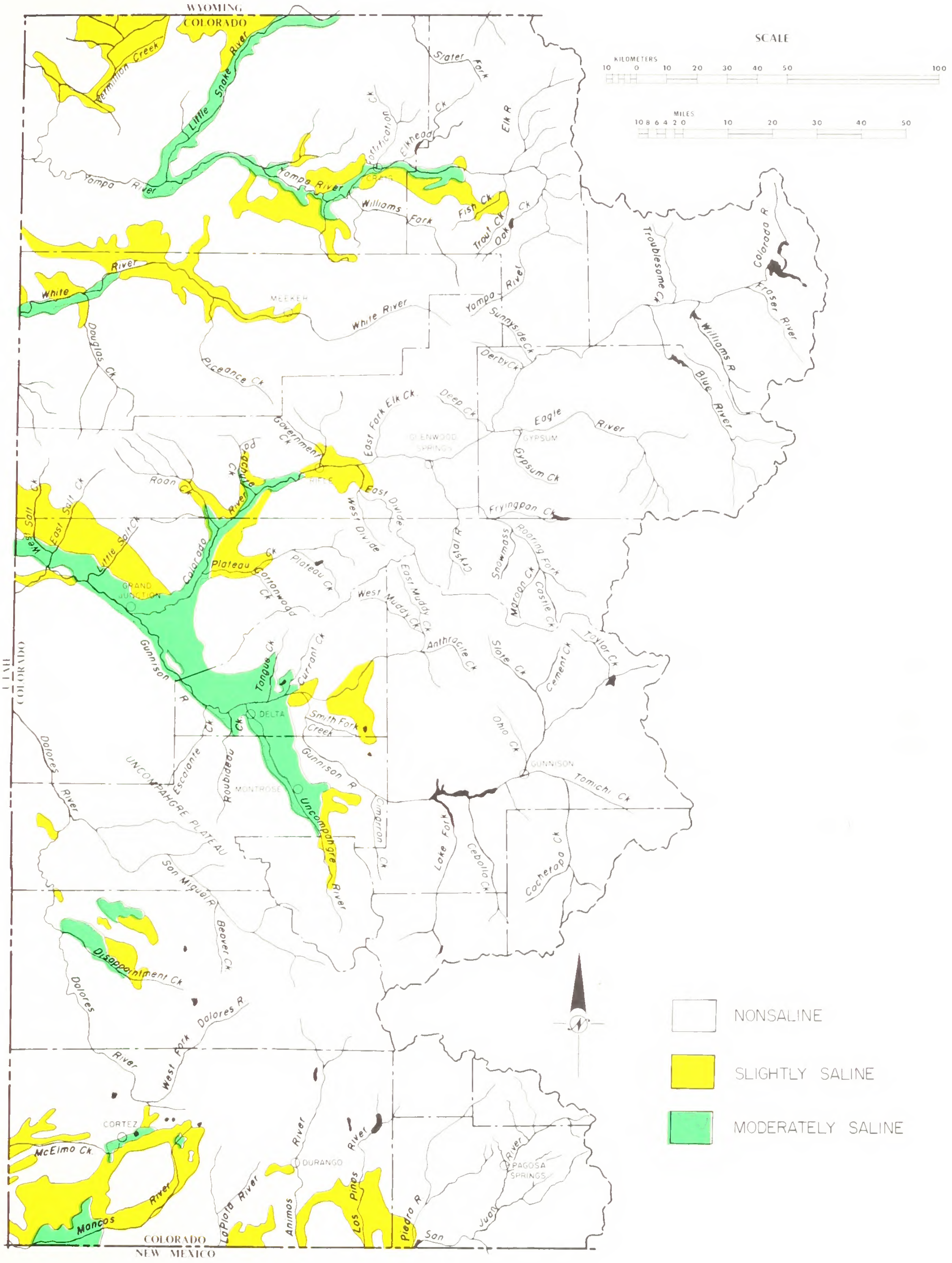


FIGURE IV-3b. GENERAL SOIL SALINITY CLASSES FOR UTAH

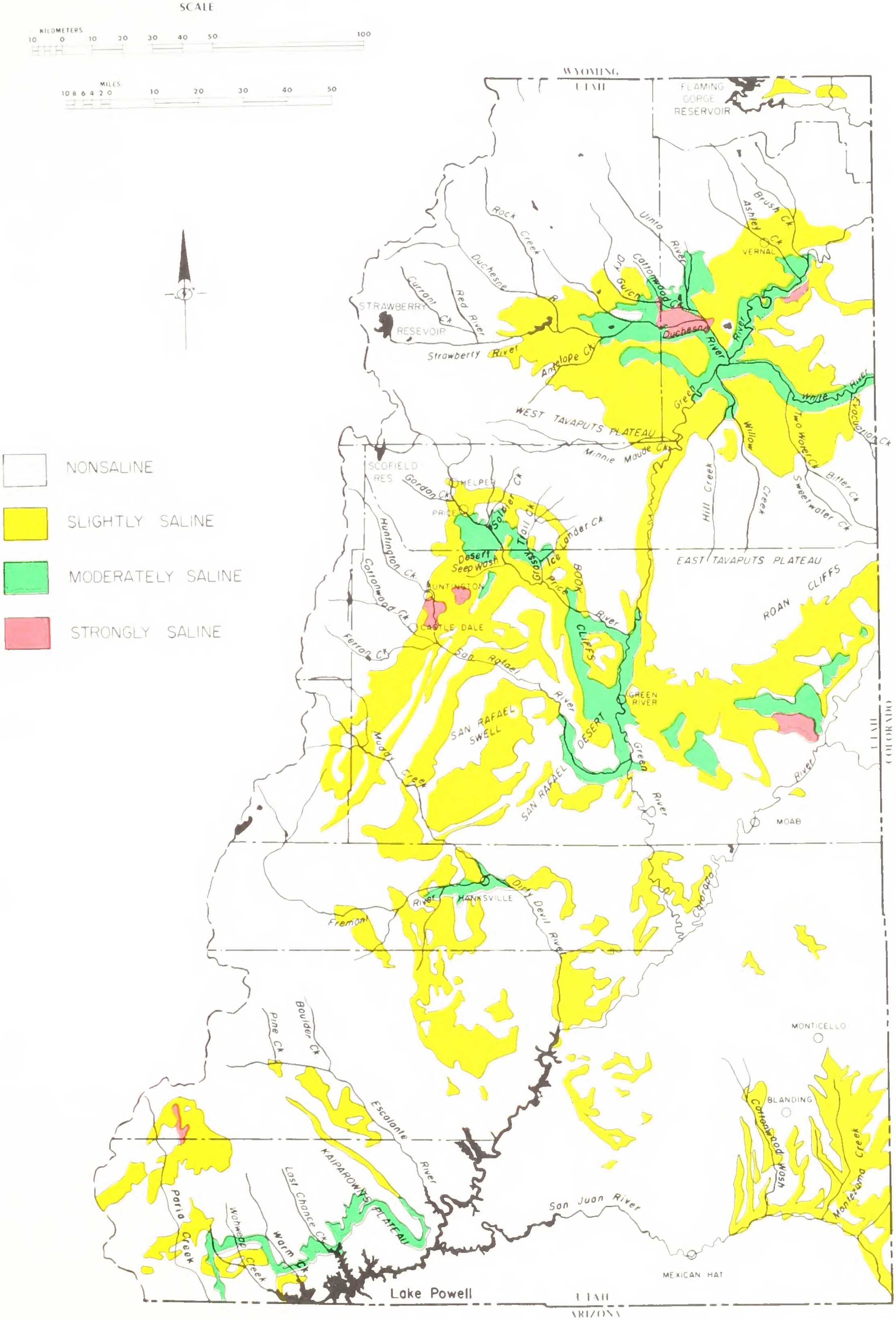
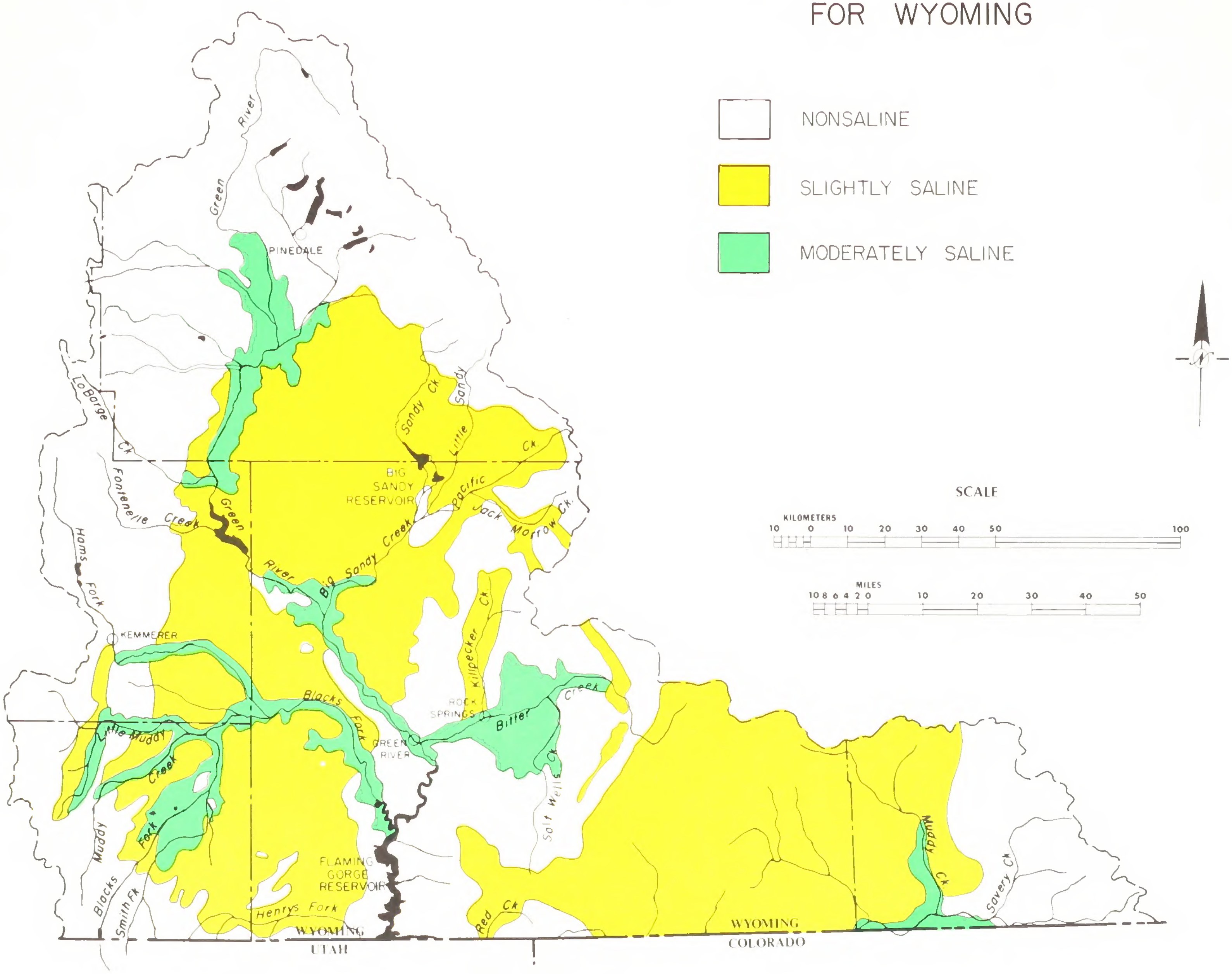


FIGURE IV-3c. GENERAL SOIL SALINITY CLASSES FOR WYOMING



The agronomic salinity classification system in current use (Table IV-2) was developed for irrigated agriculture. The high upper limit of 4,000 μmhos/cm for the nonsaline category reflects the thesis that, below this point, salts can be successfully leached from the crop root zone through irrigation, without using special water control practices (including soil drainage systems and greater applications of water). A soil salinity classification system should include nonsaline and slightly saline categories much lower in salts than those presently used, if it is to be more responsive to salinity of surface runoff from rangelands under natural climatic and land use conditions.

Table IV-2. Common Agronomic Soil Salinity Classification System (34).

	Electrical Conductivity at 25° C. of Saturation Extract in micromhos/cm	
Salinity Class	Upper Soil Layer	Lower Soil Layer
Nonsaline	< 4,000	< 4,000
Slightly Saline	< 4,000 above 8 inches	4,000-16,000 below 8 inches
Moderately Saline	4,000-16,000 above 20 inches	> 16,000 below 20 inches
Strongly Saline (Highly)	> 16,000	> 16,000

The strongly saline soils are situated on poorly-drained bottom lands with a shallow water table. Evapotranspiration results in a water loss and salt accumulation in the upper soil layer and on the soil surface. Heavy concentrations of salts also occur when seepage from canals or farmlands causes large volumes of water to pass through undisturbed soils. The leached salts accumulate where the water comes to or very near the surface and evaporates (see Figure IV-4). The Upper Basin contains 103,000 acres of strongly saline soils, all of which are located in Utah, as shown in Figure IV-3b.

The strongly saline soils are primarily concentrated in four areas: (1) 58,000 acres in the Uinta Basin; (2) 18,000 acres in Emery County near Huntington and Cleveland, Utah; (3) 24,000 acres in the lower portion of Sagers Wash near Cisco, Utah; and (4) 3,000 acres in the Upper Paria River Basin near Tropic, Utah. The public lands account for approximately one-quarter of the total or 28,000 acres, with most of this being concentrated along Sagers Wash.

Moderately saline soils are much more extensive in the Upper Colorado River drainage. A total of 2,204,000 acres are classified as moderately saline, wih approximately half of this acreage located on public lands. These lands are the most prominent contributors of diffuse sources of salts to the Colorado River. Approximately 37 percent, or 812,000 acres of the moderately saline lands are found in Utah, as shown in Figure IV-3b. The largest concentrations of these lands occur in the Uinta and Price Basins and significant amounts are on irrigated farmlands.

Figure IV-4. Salts Accumulating Below a Canal as the Result of Water Seepage.

Most of the moderately saline soils within Colorado (743,000 acres) are associated with major streams (see Figure IV-3a). The largest areas of moderately saline soils occur in the Grand and Uncompahgre Valleys, with a significant amount on irrigated farmlands. Much of the moderately saline lands associated with the Mancos Formation in Utah and Colorado receive less than 10 inches of average annual precipitation.

The Upper Basin in Wyoming contains 649,000 acres of moderately saline soils. These soils exist in large areas primarily concentrated along the major rivers and tributaries (see Figure IV-3c).

Some 10,568,000 acres of slightly saline soils cover 18 percent of the Upper Basin. Typically, soils receiving more than 16 inches per year of average annual precipitation are nonsaline to slightly saline. This amount of precipitation is adequate to leach salts from the soil and/or prevent salt buildup in the profile. Nonsaline soils total 46,299,000 acres or 78 percent of the Upper Basin. Most of the national forest lands are classified as nonsaline because of the low concentrations of salts in the parent geology or past leaching of salts from soils by high precipitation.

b. Soil Properties in Relation to Salinity

Inherent physical and chemical soil properties have important influences on salt movement. These properties are discussed in the following subsections.

(1) Physical Soil Properties

West and Ibrahim (216) mapped the soils of Sagers Wash, near Cisco, Utah. It was found that soils located at different positions on the landscape had developed distinct characteristics including location and amount of salt. Soils developed on gravel pediments were coarse-textured with well developed profiles, and nonsaline in the surface 2.5 feet, but saline at greater depths; soils on the eroded slopes of the pediments were loamy and nonsaline in the surface 15 inches, but saline at greater depths; soils developed on the exposed Mancos Formation were fine-textured and nonsaline in the first 12 inches, but saline at greater depths; and soils in the alluvial deposits of the valley were fine-textured and saline throughout the profile. Each soil supported a distinctly different vegetative community. These data give an indication of the complexities involved in studying factors affecting salinity, even within a small geographic area. Salinity can be influenced by the amount of salt in the parent material from which soils are derived, soil texture, soil permeability, and processes of erosion. In turn, these factors and the amount of salts in soils, influence the kinds and quantity of plants that occupy a site.

Allis and Kuhlman (4) found that soil texture had a very important influence on runoff. Medium-textured soils yielded 0.92 inches of runoff, while fine-textured soils yielded 3.16 inches, a more than threefold increase. On bluegrass ranges in the Black Hills, bulk density and total pore space varied as a function of the silt to clay ratio. Increases in bulk density and decreases in pore space were greater on fine-textured soils than on medium-textured soils where grazing intensities were considered similar.

Compaction by livestock was measured at greater depths and recovery time was longest on soils with the highest clay content (145). (A detailed discussion of the effects of livestock on soil compaction is given in Section IV.B.1.). Lull (122) suggests that particle size is important in soil compaction. However, it is stated that soils with the greatest range of particle sizes (medium-textured) will compact to the greatest extent. It is suggested that this is caused by fine particles filling the voids between the coarse particles.

Soil texture influences bulk density and total pore space which, in turn, affect infiltration, runoff, and erosion. Lull (122) defines soil compaction as an increase in soil density through a decrease in pore space. It is stated that "the more porous the soil initially, the greater the compaction depth." Soils with good structure can be compacted to a high degree. Aggregates of soil particles are highly porous, have low bulk densities, and allow the highest intake of water. Forces which normally compact soil particles cause greater damage to soil aggregates. Under pressure the aggregates collapse, filling the interaggregate pore spaces (large pore space), and permeability is reduced.

Thorud and Frissell (192) found it would require at least 6 years to reverse, by natural means, the increases in bulk density due to mechanical compaction of sandy loam forest soils. It was reported that freezing and thawing can reduce bulk density if compaction does not continue. Thorud and Frissell (193) reported that additional natural processes, such as wetting and drying and water movement through soils, were helpful in reducing bulk density over long periods of time. Heidmann and Thorud (89) found that depth of freezing increased with increasing bulk density.

Rauzi et al (161) found that soil structure was the most important soil factor influencing water intake (infiltration) in simulated rainfall studies on Plains rangelands. The data showed that water intake on soils with poor and fair to good structure was 46 and 69 percent respectively, as compared to the rate measured on soils with excellent structure. All ranges had approximately equal plant cover. Soils having poor structure required 60 percent more vegetal cover than soils with good structure to maintain a similar rate of water intake.

Structure is defined as the aggregation of soil particles. This aggregation is influenced by soil texture (size of soil particles), the amount of organic matter, animal activity, climate, and chemical properties. The relative volume of pore space and size of pores (macro vs. micro) is a factor in determining soil structure. Thus, bulk density is one indicator of structure. However, vertical cleavage patterns are also important and would not necessarily be identified by bulk density measurements. Rauzi et al (161) state that structure of the subsoil (lower horizons) influence downward water movement after the surface layer has been saturated. Specifically, prismatic or subangular blocky structures, with vertical cleavage patterns are conducive to downward water movement, while coarse blocky or angular blocky structures, with a higher percentage of horizontal cleavage patterns, retard the downward movement of water.

Organic matter reduces compaction of soils. More force is required to compact soils high in organic matter. Plant material acts as a cushion, keeping soil particles from coming together and closing pore spaces. Also, a greater amount of water is needed to influence compaction. This is because organic matter absorbs water which would otherwise reduce friction between soil particles.

Soil moisture has the effect of lubricating soil particles, thus enhancing compaction and reducing pore space. Dry soil particles tend to rearrange themselves (be displaced) rather than adhere to one another to reduce pore volume. Soils, however, do not have to be saturated to obtain maximum density. Lull (122) suggests that a moisture content somewhere midway between field capacity and wilting point is sufficient. He infers that soils at field capacity tend to move laterally away from the compacting force, thereby reducing the adverse effects of compaction. Effects of compaction may persist longer in dry climates if frost heaving is not a significant factor, and if soils are medium-textured and low in organic matter.

Rainfall causes compaction when raindrops strike bare soil, dislodging soil particles which are then washed into pore spaces. As rainfall continues, fine soil particles are evenly distributed over the soil in a thin layer. Upon drying, these fine particles form a crust which further reduces infiltraton during subsequent storms. A ground cover of vegetation and litter can effectively neutralize the force of raindrops. Soil litter and basal area of live plants are effective in reducing overland flow, allowing more time for water to infiltrate.

Soils derived from marine shale formations are often high in salt and montmorillonitic clay, and are subject to a high degree of swelling when wet. When the soil surface becomes wet during rainfall, it quickly swells, closing pore spaces and effectively sealing the surface against infiltration. Continued rainfall builds up on the surface until gravity causes runoff. These soils may also be high in sodium. Sodium influences physical properties of soils by helping to seal the soil surface through dispersion of particles. This dispersion causes fine particles to fill pore spaces in a manner similar to falling raindrops. When pore spaces are filled, transfer of oxygen between the atmosphere and soil is impeded and soil aeration is retarded. The results of this process can be seen in barren alkali slicks or pan spots on flat areas or depressions.

(2) Chemical Soil Properties

Whitmore (218) found that Mancos Shale-derived soils are high in calcium, magnesium, sodium, and potassium cations; sodium is the most common monovalent ion. White (217) also found that gypsum ($CaCO_4$) was the most common component of salt. The solubility of gypsum was increased 1.7 times by the addition of sodium chloride and magnesium chloride. Both salts are common components of evaporites found in gullies and stream channels. It was also found that two other common salts in evaporites, sodium sulfate and calcium chloride, acted to depress the solubility of gypsum. This made it difficult to predict the resultant salinity of runoff from upland sites which ultimately flows down gullies and dissolves evaporites on its way to perennial streams. However, the large quantities of gypsum and the presence of evaporites along flow patterns form a significant reservoir of potential salt (218).

Whitmore (218) and Jurinak et al (109) found that the larger the soil particle size, the slower the salt was released. However, the total amount of salt finally released by each soil fraction was the same. It was found, under controlled laboratory conditions, that an estimated 80 percent of the total salt was taken into solution within 2 minutes. This represented the dissolution of evaporites and salts on or near the surface of soil particles. A second reaction, accounting for the final 20 percent of the salt, required 7 to 9 days. This represented a weathering of particles and a breakdown of larger mineral fragments.

Laronne (117) found that E.C. measurements of surface runoff were not a reliable indicator of the total salt yield of an area. It was concluded that sediment is an important contributor to salt yields from geologic formations containing large amounts of salt, such as the Mancos and Mesa Verde. Ponce (154) found there is a linear correlation between concentration of suspended solids and total dissolved solids (salts) concentration, but that the correlation is site specific. Many investigators have reported that salts have been leached from the surface of arid and semiarid soils (62, 117, 154, 211, 218). Ponce (154) found that E.C. of runoff varies directly with rainfall intensity only when the increased intensity results in erosion of the soil surface. Erosion is the result of a "digging" action of raindrops exposing soils deeper in the soil profile where salt concentrations are greater.

Runoff from Mancos Shale-derived soils generally becomes saturated with gypsum at about 2,500 µmhos/cm (218). Laronne (117) indicated that where E.C. is greater than 2,000 µmhos/cm in sediment-water mixtures, gypsum approaches saturation. In water samples collected during a runoff event in West Salt Wash, Colorado, all samples were found to be saturated or supersaturated with calcite and gypsum. Results of research reported by Laronne (117) suggest that sediment laden water from streams such as the Price River, often in equilibrium with respect to gypsum, may contribute increased quantities of salts to more diluted rivers such as the Green and Colorado. It was found that the addition of distilled water to sediment laden water samples taken from the Price River increased salt yields as much as 500 percent. Laronne (117) found that Mancos-derived soils on hill slopes contained 5 percent salt, while those in the alluvial sites contained 3 percent salt.

Soils derived from Mancos Shale--sampled in an alluvial valley at Boco Mountain near Wolcott, Colorado, by McWhorter (134)--have salinity profiles, as shown in Figure IV-5 for observation well number 3. These soils would be rated as slightly saline based on the agronomic classification systems used by BR (34). The data in Figure IV-5 suggests there is little or no water percolation through the root zone. Water infiltrating the soil would leach salts in surface layers, gradually moving them to the depth of maximum water penetration. Salts have accumulated at the 3-4 foot level, possibly, as a result of several factors. The average annual precipitation of 13.5 inches may not be sufficient to leach salts further. Season of precipitation could be important, since 67 percent falls between April and October, when storm intensities and percent of runoff are high.

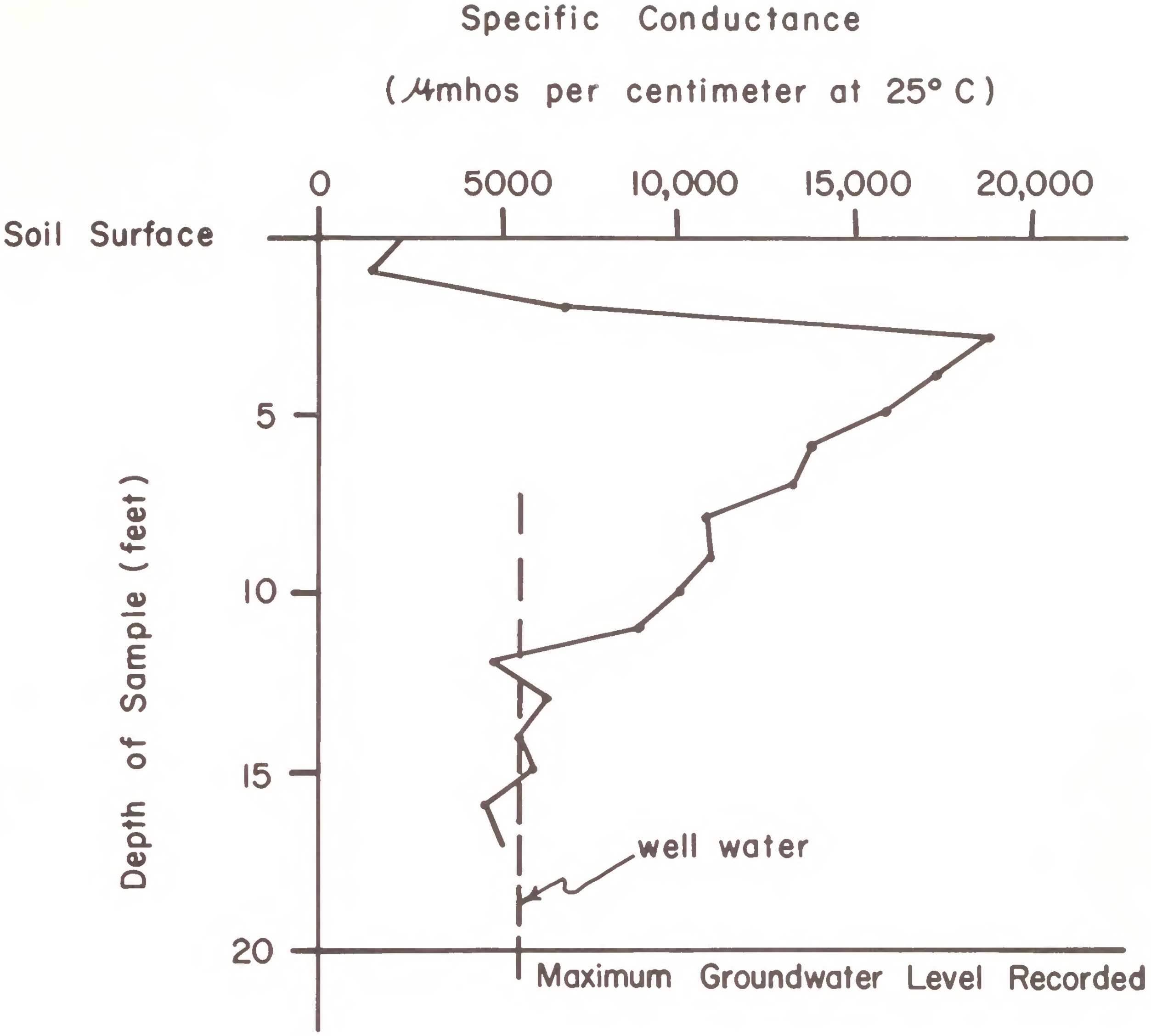


Figure IV-5. Typical Soil Chemistry Profile of Weathered Mancos Shale at Boco Mountain Interflow Study Site Near Walcott, Colorado.

Much of the winter snowfall resulted in runoff, during a study conducted in the latter half of the 1960s. This was due to soils being frozen at the time of snowmelt (179). The fine-textured soils may also be a factor in reducing water percolation. The most important factor may be the removal of water from the soil profile by transpiration through plants, leaving salts formerly in solution to accumulate. The salt profile illustrated in Figure IV-5 is probably representative of many arid and semiarid rangeland soils with salt accumulations.

The groundwater encountered at the 20-foot depth is not believed to be an important factor in soil salinity. The location and movement of groundwater appears to be along the soil-bedrock interface. The recharge area is believed to be at the base of steep hills along the upland edge of the valley, where soils of the valley are shallow to unweathered shale. The groundwater table discharges into a deeply incised channel draining the valley. During the summer of 1977, flow rate was 1 to 2 gallons per minute with an average specific conductance of 5,000 μmhos/cm.

Laronne (117) and Whitmore (218) found in laboratory experiments that the total amount of salt yielded from soils is related to the sediment-water ratio and contact time. The effects of mechanical turbulence (mixing) on the erosion of soil particles and resulting salt yields were related to volume of sediment in water. Particles, especially coarser ones, tended to settle and become stagnant in the mixing process (less tumbling action) as the volume of sediment in water was increased. Erosive forces on particles were greater and salt yields higher when particles remained in suspension. The breakdown of finer particles and soil aggregates was faster than that observed in coarser materials and initial dissolution of salts was faster.

Salts tend to increase with depth of soils (62, 117, 154, 211, 218). Gates et al (62) found that chemical soil characteristics vary greatly within the salt desert shrub region studied. In general, sodium, calcium, magnesium, chloride, and sulfate all increase significantly with depth on all sites, up to the depths measured (60 inches). The accumulation of sodium at lower depths, result from its high solubility and ease of replacement on the soil exchange complex. This accumulation may also be an indication that soil moisture is not sufficient to leach salts, especially soluble sodium, below the root zone. Downward or lateral movement of water or a seasonal water table (winter) would cause a loss of sodium rather than a buildup. No buildup at shallow soil layers was measured. Higher concentrations at these layers would suggest upward movement through capillary action to the plant roots.

c. Processes of Erosion

An understanding of the processes of erosion is important to the successful control of salinity from overland diffuse sources. Two types of erosion occur on the surface of the earth, i.e., geologic erosion and accelerated erosion. Geologic erosion occurs at rates which are controlled by the natural environment. Accelerated erosion occurs at a rate greater than natural erosion as a result of man's activities. The activities of man, animals, and machines, usually increase runoff and soil loss by compacting the soil and reducing plant cover. The increasing use of land by man may well create new problems faster than existing ones can be solved (165).

Erosion, for purposes of this discussion is conveniently categorized by location, i.e., upland erosion occurring on the general land surface, and erosion within channels. Arid and semiarid soils are especially vulnerable to upland erosion because of sparse vegetation, steep slopes, and occurrence of violent thunderstorms. Erosion is further enhanced where fine-textured soils occur in combination with these environmental factors. Laronne (117) found that areas underlain by Mancos Shale and associated shallow alluvial deposits are the major source of sediment and salt in runoff from natural lands in the Grand Valley area of Colorado. The presence of gullies was also considered a significant factor.

Meeuwig and Packer (139) state that excessive rain-splash detachment of surface soil particles is the first stage of rangeland deterioration. Raindrop energy breaks down the soil structure, compacts the surface (reduces infiltration), and allows detached particles to be carried away in the runoff. This type of erosion is best controlled by maintenance of sufficient plant cover. The most important aspect of vegetation (live plants and litter) is its ability to absorb the impact energy of raindrops, the main cause of soil detachment. Vegetation also impedes overland flow by reducing velocities. This, in turn, reduces the sediment carrying capacity of the runoff.

The erosion energy and sediment-carrying capacity of runoff is directly proportional to the velocity squared. As runoff increases, the velocity increases and, therefore, the potential to dislodge, pick up, and transport soil particles increases. Leopold et al (118) found that upland sheet erosion was the most significant source of sediment in a semiarid area of New Mexico over a 6-year study. Sheet erosion was greatest from steep slopes. However, it was also reported that deposition occurred on flat slopes just below and that small rills were aggrading. This deposition was considered to be only temporary.

Gully formation is an important feature of sediment loss and increased salinity from rangelands. Leopold et al (118) state that a large body of literature over the past century indicates a history of sequences of alluviation and erosion in semiarid valleys. It was suggested also, that periods of degradation are coincident with increasing aridity and periods of aggradation with increasing precipitation. Schumm and Hadley (172) also cite studies indicating that overgrazing by large numbers of livestock may have been an initiating factor. Climatic change was the chief factor, however, primarily the incidence of high intensity rainfall. Hastings and Turner (82) also mention a number of authors who discuss the importance of climate.

Schumm and Hadley (172) state that gully-cutting first begins at a point where the gradient of the valley floor steepens. The reverse is true in the creation of discontinuous gullies (a healing process). Sediment is deposited in alluvial fans, creating discontinuous gullies where the gradient of the gully bed is smaller than the ungullied alluvium. Heede (86) indicates that a break in the slope gradient (or change) is also important in the initiation of discontinuous gullies. Leopold and Miller (120) give several hydraulic factors which relate to the forces involved in gully formation. The velocity of water increases with discharge. Discharge increases as the size of drainage basin increases. Also, stream length is a function of drainage basin size.

Studies by Schumm and Hadley (172) strongly suggest an inverse relationship between slope gradient at which cutting begins and rate of discharge, and that discharge is also related to the size of the watershed. In large valleys covering from 0.6 to 19 square miles, gullies formed on slopes ranging from 1.5 to 2.5 percent. In small valleys covering from 0.05 to 0.5 square miles, slopes increased from 2.5 to 5.4 percent before gullies were initiated.

Schumm (171) found the width-depth ratio of channels increased in proportion to the particle size of material in channel banks and bottoms. In general, channels in fine-textured soils would tend to be narrow, while those in coarse-textured soils would be more wide than deep. Leopold and Maddock (119) state that shear forces tend to be greater on channel banks in deep channels with narrow widths. Leopold and Miller (120) found that bank erosion in steep-walled, narrow gullies cut in fine-textured alluvium, occur after water recedes following a runoff event. Wetting of the fine soil particles coupled with the force of gravity acting on the vertical soil wall, cause large columns of soil to fall away. Investigations made by BLM personnel reveal many such examples (see Figure IV-6). This process provides an important source of sediment for future runoff events.

Leopold and Miller (120) found that very little of the water entering gullies resulted from overpour of the vertical banks. This was not an important source of erosion. Collapse of gully walls was increased by soil piping. The major portion of the water reaching gully channels came from piping tunnels, tributary gullies, and rills. Leopold et al (118) recorded mass soil creep of side slopes in channels where vertical walls were not a factor. New gullies form when horizontal pipes enlarge, weakening the soil overburden causing it to collapse into the pipe.

Fletcher and Carrol (56) found that two conditions must be present before piping can occur. First, water must penetrate the subsoil faster than it can be absorbed. Second, there must be an outlet for lateral flow of the excess water, such as a gully. It was observed that this lateral movement to an outlet could cover a distance as great as three-quarters of a mile. Soil piping occurs in soils subject to shrink and swell and dispersion of particles. These processes break down soil structure. Soils most subject to piping are high in montmorillonite, causing them to swell when wet and form open cracks when dry. These cracks may extend for several feet through the soil profile (see Figure IV-7). Brown (19) suggests that piping begins when runoff enters these cracks and concentrates in sufficient volume to wash away soil particles and leach excess salts, such as calcium, from the soil. Sodium remains to act as a dispersing agent on soil aggregates. Once the particles are dispersed, they are easily washed away in subsurface flow to nearby gullies.

Heede (84) also emphasizes the importance of sodium in the soil as a prerequisite of piping. Soils high in clay content (47.8 percent), but with a low exchangeable sodium percentage (1.0), were stable. However, soils not only high in clay content (45.8 percent), but also with a high exchangeable sodium percentage (12.0), were unstable and produced pipes. It was also noted that soils high in sodium had less vegetative cover. Wetting of the soil was as important to the piping process as dispersion of soil particles. Piping did not occur following high intensity thunderstorms. Soils became sufficiently wet during the winter and spring from snowmelt to cause pipes to develop.

Figure IV-6. Channel Bank Erosion in Gully During Receding Flow, After the Bank Soil has been Wetted.

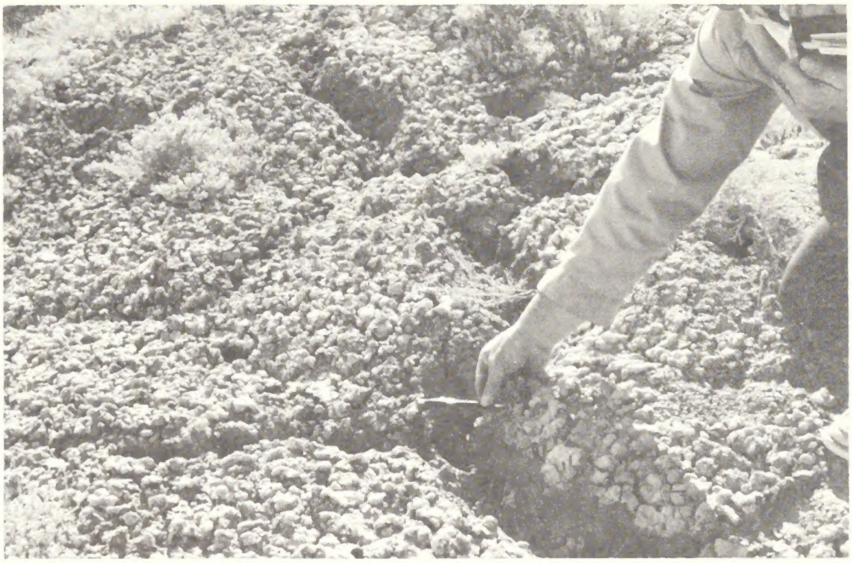


Figure IV-7. Crack Formed in Montmorillonitic Clay (Mancos Shale-Derived) Soil When Very Dry.

Schumm and Hadley (172) found that gullies are extended by upstream migration of headcuts. Leopold and Miller (120) report that plunge pools are an important aspect of headcutting. Headcuts are characterized by a vertical upstream soil wall. Water pouring over this vertical wall forms a pool at its base. Turbulence of the water in the plunge pool is increased, causing the swirling water to undercut the bank and subsequent collapse into the channel.

Ephemeral channels are characterized by a uniform increase of width and depth with an increase in stream order (size) and size of drainage basin. Width of ephemeral channels increases in the downstream reaches, the depth-width ratio decreases, and gradient of the channel bed decreases. Leopold and Miller (120) report that gully width increases downstream as a function of the square root of the velocity. Gully banks erode and widen in order to accommodate the increased velocity of water.

Leopold and Maddock (119) suggest that changes in channel roughness downstream are more conservative than other hydraulic factors. However, channels tend to be smoother downstream. Leopold and Miller (120) relate that "channel roughness is not determined entirely by particle size." However, particle size did tend to decrease downstream. The decrease in slope downstream is coincident with a decrease in particle size and both are an expression of channel roughness. Channel bed stability is a function of bed material size with larger particles more resistant to erosion. In some cases, the surface of the channel floor becomes armor-plated with larger material (gravel and cobbles) protecting finer underlying material from detachment.

Sediment concentration increases downstream as a function of water percolating into the channel bed and pickup of additional sediment in the channel (119). Heede (85) suggests that sediment loads are more closely related to the duration of the flow than its magnitude. Sediment is kept in suspension by increased velocity. The distance that sediment can be transported downstream is a function of velocity. Leopold and Miller (120) suggest that ephemeral channels tend to maintain a quasi-equilibrium between erosive forces and deposition. When one force is altered, the other forces adjust to conform to the change.

Heede (86) suggests that vegetation characteristics of a watershed may more strongly influence channel erosion processes than soils. This is based on studies made by several researchers on watersheds where the vegetation was altered by mechanical means or wildfire. The influence of vegetation is probably greater in regions where soils have been developed under significant ground cover. In more arid regions, the importance of soil characteristics takes on a greater importance because of the historically sparse vegetative cover.

Schumm and Hadley (172) state the presence of stable discontinuous gullies on oversteepened alluvial fill in semiarid valleys is a strong indication that the natural process of alluviation is occurring. The key factor in development of discontinuous gullies is a deficiency of water and a decrease in velocity, causing deposition of sediment. Once deposition occurs, aggradation migrates upstream. Such a process can result from increased vegetative cover and soil characteristics which increase infiltration on upland sites, a reduction in storm intensity, and absorption of water in the gullies themselves.

Heede (86) warns that a true equilibrium or "steady state" may not be possible in ephemeral channels. The increase of vegetation (invasion) in channels may be only a temporary stage brought on by a dry cycle. An increase in runoff may scour the channel. The process of gully development is not necessarily an orderly one, progressing from one stage to another. The processes of erosion may accelerate for a time and then be replaced by periods of inactivity or even aggradation. The result of an individual runoff event might even alter channel morphology, leaving a gully more or less stable for a time. A subsequent flow could reverse the condition.

3. Vegetation - Relationship to Water Quality

a. General

The Upper Colorado River Basin falls within the Great Basin and Cordilleran Forest Provinces, according to Gleason and Cronquist (76). The most important climatic factors affecting vegetation are temperature and precipitation. The amount and kinds of salts in the soil also have a definite influence upon the species growing on a site as well as the number of plants which can be supported per given area.

At higher elevations, length of growing season, or the number of consecutive days having temperatures above a critical point, determine vegetation boundaries. At lower elevations, plant boundaries are more affected by the ability of a plant to withstand desiccation. Degree of slope, amount of sunlight reaching a site (exposure), and soil characteristics (depth, particle size, water holding capacity) can extend the boundaries of a plant community above or below its normal range of altitude (76).

Salt in very high concentrations--such as found in playas, around saline seeps, and compacted clay soils in small depressions (pan spots)--can reduce plant density. Where salt content of the soil is low to moderate, the percent of ground covered by vegetation is determined by effective soil moisture and grazing pressure.

Goodin (77) states that "moisture is probably the most important formative factor in determination of vegetative type (community), particularly in arid and semiarid regions, but the chemical constituents of the soil determine to a very great extent the vegetational parameters." It also describes "vegetation patterns" over a given saline area as a "complex mosaic" resulting from interactions between salts and precipitation. Branson et al (16) point out that ". . . soil-moisture relationships (stress) are the primary cause of different plant communities." Gates et al (62) found that basal density of Nuttall saltbush increased 0.5 percent with each 1 percent increase in water-holding capacity of the soil.

In a study by Branson et al (17), the authors were unable to determine specific plant-site relationships which might help to explain areal distribution of species. It was concluded that plants probably respond to the total effects of the environment, rather than single factors. The ability of a plant to withstand certain maximal values of variables such as internal plant stress, soil salinity, and amount of water available for plant growth must be of major importance in site adaptation.

Caution must be exercised when using plants as a precise indicator of the level of salinity. Branson et al (16) state that "In general, the greater the salt tolerance of a specie, the wider the range of salinity of the soils on which it grows." Greasewood, Nuttall saltbush, four-wing saltbush, and shadscale are all very widely distributed salt-tolerant and drought-resistant plants. Gates et al (62) found that sagebrush and winterfat were not generally found growing on soils with high sodium content, while greasewood, shadscale, and Nuttall saltbush were found on soils containing the highest sodium content. All five species were found in pure stands on soils having as much as 4.6 milliequivalents of exchangeable sodium per 100 grams of soil (meq/100 gm). However, only shadscale, Nuttall saltbush, and greasewood were found on soils having sodium contents in excess of 5.5 meq/100 gm. Greasewood grew on soils having 6.1 to 7.2 meq/100 gm at soil depths of from 6 to 60 inches. The broad range of sodium values which greasewood will tolerate suggested that, although it does not require high concentration, greasewood is physiologically adapted to soils containing very high amounts. The maximum tolerance to sodium appears to affect distribution of plants within the salt deserts.

Gates et al (62) also found that, on a relatively flat plain, abrupt changes in soil chemistry did not result in similar changes in plant communities. Vegetation communities studied were very pure, each composed almost exclusively of the dominant plant. The authors postulated that perhaps ecotypic variation, caused by interbreeding and natural selection, had created species adapted to sites which are morphologically indistinguishable from similar looking species unable to withstand harsh site conditions. Mitchell et al (141) found on the same study area that physical factors of soil did not relate significantly to distinctly separate plant communities. Ibrahim (100) found that where soil characteristics were influenced by differences in geology and land form, edaphic factors were of primary importance in determining the distribution of plant communities.

Mitchell et al (141) could find no obvious evidence that plants in the salt desert had influenced soil changes. Malekuti (129) found that salt-tolerant plants increase the sodium concentration of surface soils. Salts from lower soil horizons are taken up by roots and deposited on leaf surfaces during transpiration. Rain then washes salts from leaves onto the soil. Also, leaf fall and subsequent decomposition adds salts to the soil surface. It was stated, however, that these processes are a minor contributor to the total salt problem. However, Sharma and Tongway (174) found that pH of the upper 3 inches of soil increased under the litter of several species of Atriplex.

The control of wildfire during this century has brought about changes in plant communities. Fire favors grass species while the absence of periodic fires allows the establishment of shrub and tree species. Questions exist today concerning the plant form most effective in controlling erosion, i.e., reducing impact of raindrops, slowing movement of overland flow of water, or reducing concentration time of floodwater. Early literature, based more on observation than quantitative research, suggests that grass plants offer better protection for the soil against erosion than shrubs. However, recent research indicates that consistent, significant differences between juniper, pinyon, sagebrush, and grass cannot be documented (6, 13, 65, 69, 176, 221).

Rauzi et al (161) report that infiltration was highly correlated with total plant cover and total weight of herbage, during simulated rainfall tests on Plains rangelands. These vegetation factors were found to be more important than soil texture or structure on sandy and silty soils and of equal importance with soil properties on clayey and shallow (silt loam and clay) soils. However, in all cases, the influence of soil texture and structure on infiltration was also significant. Vegetation was of least importance on saline-alkali soils, probably because of the low percent ground cover and herbage production.

b. Effect of Vegetation Communities on Water Quality

Existing vegetation communities on all lands within the Upper Basin states of Colorado, Utah, and Wyoming were mapped at a scale of 1:250,000 using data from the LANDSAT-2 satellite. This information was reduced to the scale shown in Figures IV-8a, 8b, and 8c, and some of the detail eliminated. Figures IV-8aa, 8bb, and 8cc contain all information on plant communities and are produced at a much larger scale. These figures are located in the map pocket found at the back of the report. In the following narrative, communities important to the salinity problem are evaluated as to the relative volume of water they produce with their associated salt content, level of geologic erosion, and susceptibility to increased sediment loss as a result of condition of vegetative cover relative to that existing in the pristine state. Table IV-3 lists the most important plant species found in each of the natural vegetation communities (9, 10, 63, 81, 143).

(1) Barren

The barren community consists of steep mountain slopes above timberline, escarpments, and cliffs having a very sparse plant cover. This community is relatively stable and produces large quantities of very high quality water from runoff. This water dilutes salt concentrations at lower elevations of the Colorado River system.

(2) Alpine and Subalpine Meadow

(a) Alpine

The alpine and subalpine meadow community occurs over a wide range of elevations from 5,500 feet to above timberline, i.e., from 5,500 to 12,000 feet in Colorado and Utah and from 5,500 to 9,000 feet plus in Wyoming (143). Alpine meadows are fragile and the natural balance is easily upset by activities which reduce the protective vegetative cover. However, alpine meadows characteristically produce large amounts of very high quality water. This water dilutes salt concentrations at lower elevations of the Colorado River system.

(b) Subalpine

Subalpine meadows occur below timberline, where deep alluvial soils receive concentrated amounts of runoff collected from surrounding uplands or subirrigation from streams.

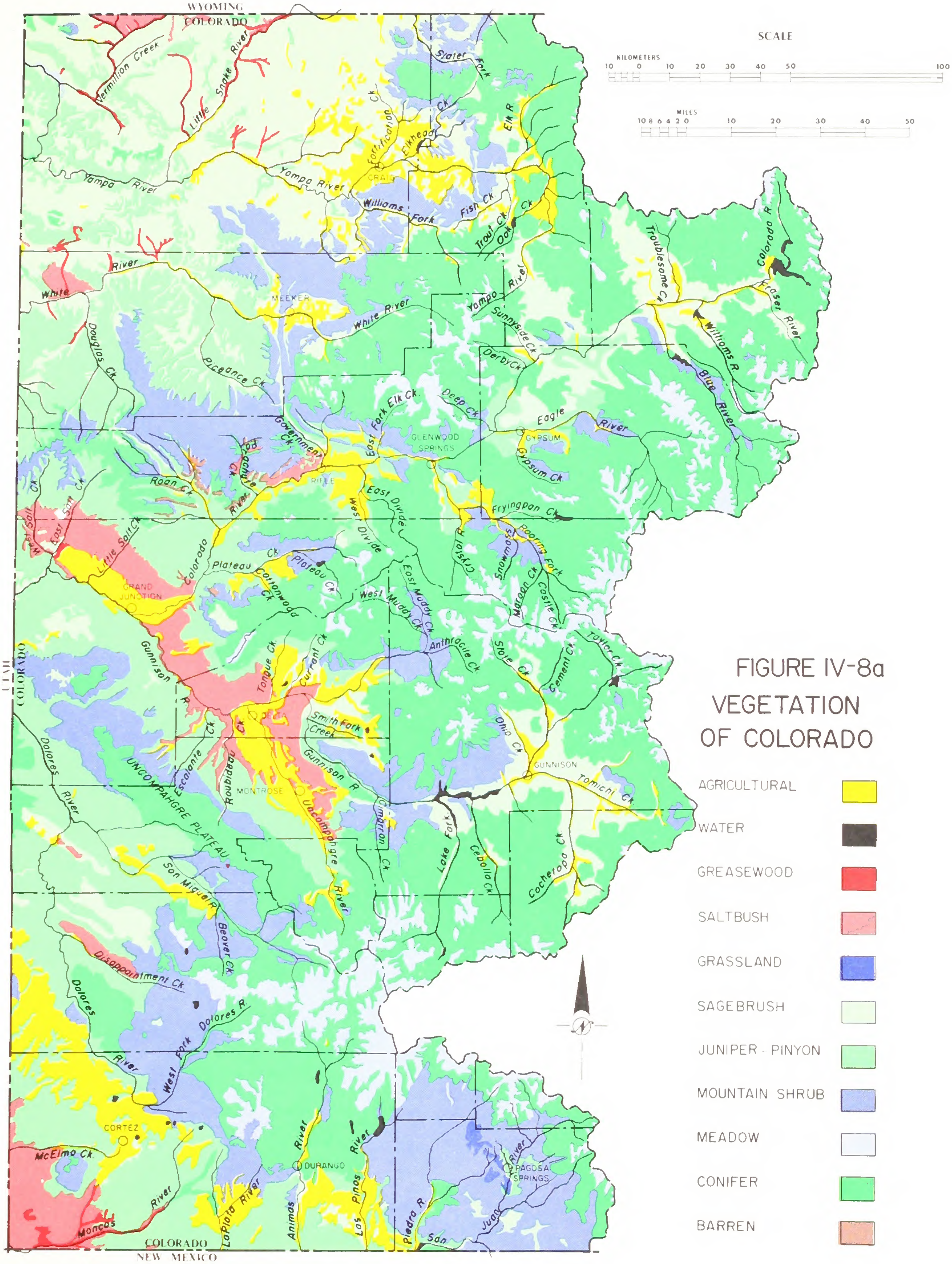


FIGURE IV-8a
VEGETATION OF COLORADO

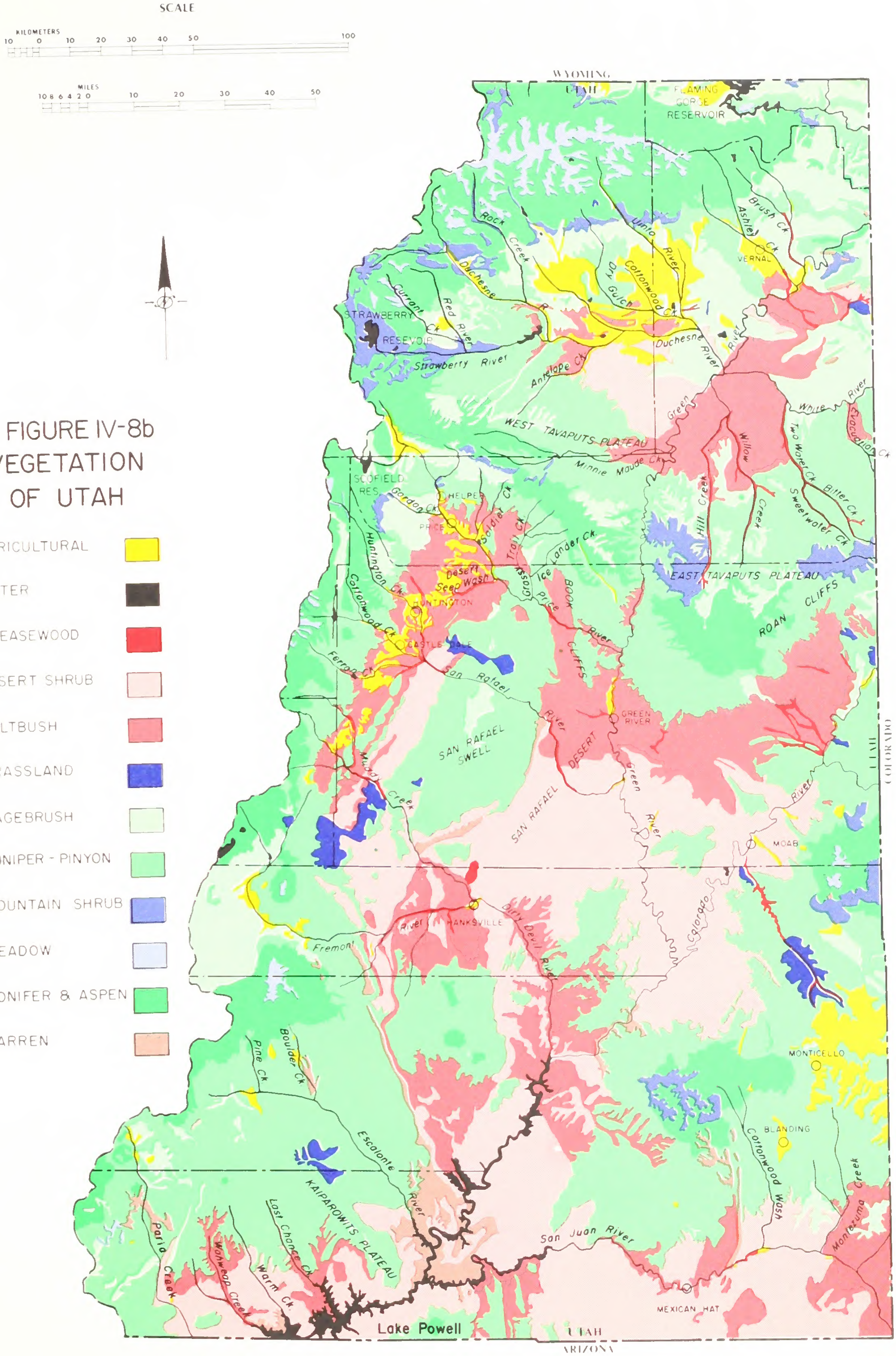


FIGURE IV-8b
VEGETATION
OF UTAH

FIGURE IV-8c

VEGETATION OF WYOMING

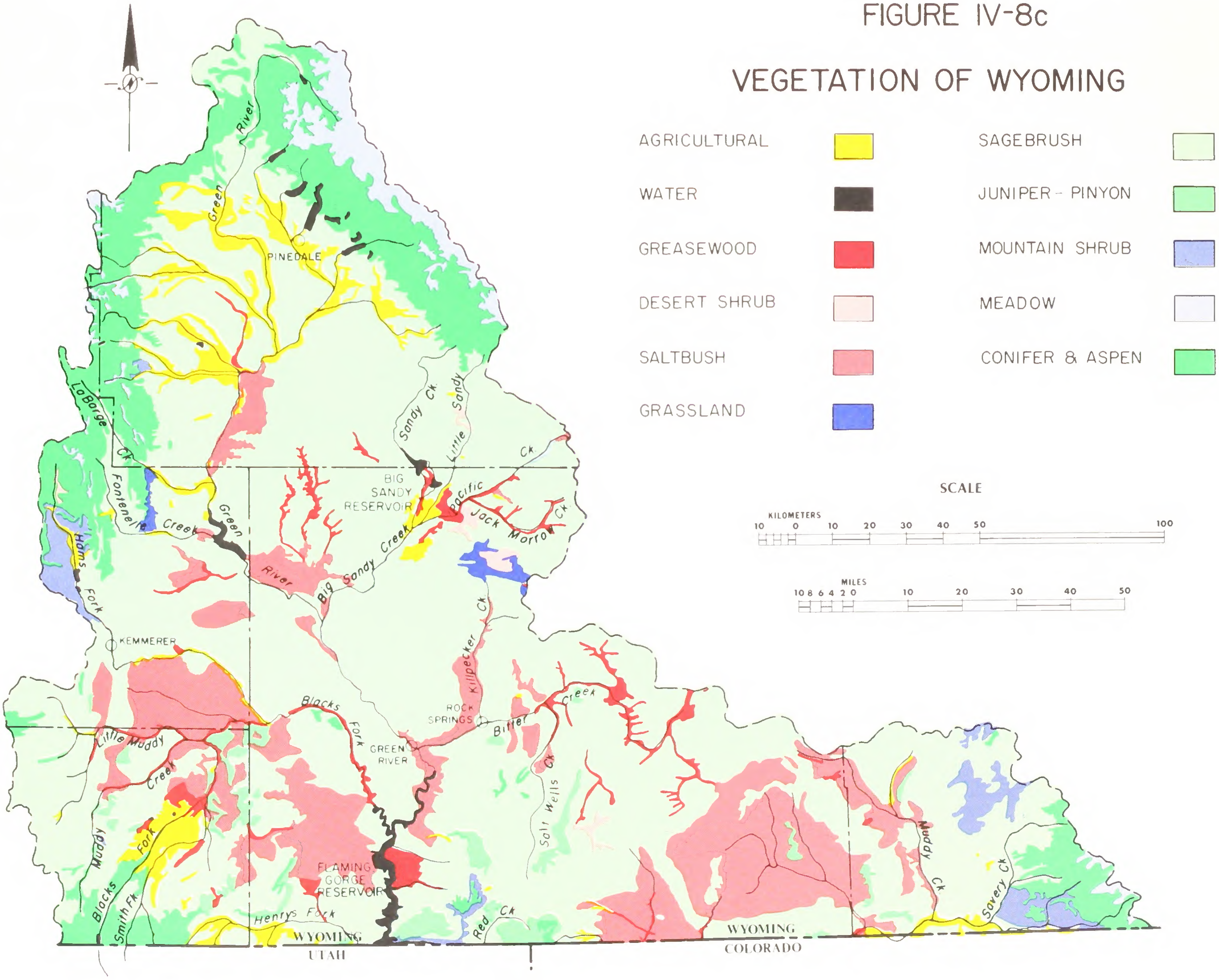


Table IV-3. Plant Species by Existing Vegetation Community.

			Conifer							Grassland			
Major Plant Species	Barren	Alpine and Subalpine Meadow	Western Spruce-Fir-Douglas Fir Forest	Pine-Douglas Fir Forest	Ponderosa Pine Forest	Mountain Shrub	Juniper-Pinyon Woodland	Sagebrush	Desert Shrub	Foothills Prairie, Galleta-Three-Awn, Grama-Galleta	Saltbush	Greasewood	Riparian
sedge - *Carex* spp.		X	X	X	X	X		X					
rush - *Juncus* spp.		X											
willows - *Salix* spp.		X											X
Douglas fir - *Pseudotsuga menziesii*			X	X									
lodgepole pine - *Pinus contorta*			X	X									
Colorado blue spruce - *Picea pungens*			X	X									
Engelmann spruce - *Picea engelmannii*			X	X									
white fir - *Abies concolor*			X	X									
subalpine fir - *Abies lasiocarpa*			X	X									
quaking aspen - *Populus tremuloides*			X	X	X								
mountain brome - *Bromus carinatus*		X	X	X	X	X							
prairie junegrass - *Koeleria cristata*		X	X	X	X	X	X	X		X			
ponderosa pine - *Pinus ponderosa*				X	X								
Idaho fescue - *Festuca idahoensis*		X		X	X	X	X	X		X			
serviceberry - *Amelanchier utahensis*					X	X	X						
mountain mahogany - *Cercocarpus montanus*						X	X						
snowbrush - *Ceanothus velutinus*					X	X							
Gambel oak - *Quercus gambellii*						X							
mtn. snowberry - *Symphoricarpos oreophilus*					X	X							
bitterbrush - *Purshia tridentata*					X	X	X						

Table IV-3. (Continued)

			Conifer							Grassland			
Major Plant Species	Barren	Alpine and Subalpine Meadow	Western Spruce-Fir-Douglas Fir Forest	Pine-Douglas Fir Forest	Ponderosa Pine Forest	Mountain Shrub	Juniper-Pinyon Woodland	Sagebrush	Desert Shrub	Foothills Prairie, Galleta-Three-Awn, Grama-Galleta	Saltbush	Greasewood	Riparian
greenleaf manzanita - *Arctostaphylos patula*					X	X	X						
big sagebrush - *Artemisia tridentata*					X	X	X	X					
hairy goldaster - *Chrysopsis villosa*					X	X	X	X					
Colorado rubberweed - *Hymenoxys richardsoni*					X	X	X	X					
bluebunch wheatgrass - *Agropyron spicatum*					X	X	X	X		X			
needle-and-thread - *Stipa comata*					X	X	X	X		X			
blue grama - *Bouteloua gracilis*					X	X	X	X	X	X		X	
scarlet globemallow - *Sphaeralcea coccinea*					X	X	X	X	X	X			
rubber rabbitbrush - *Chrysothamnus nauseosus*					X	X	X	X	X				
Utah juniper - *Juniperus osteosperma*							X						
pinyon pine - *Pinus edulis*							X						
snakeweed - *Xanthrocephalum sarothrae*						X	X	X	X	X			
gumweed - *Grindelia squarrosa*					X	X	X	X	X	X		X	
fourwing saltbush - *Atriplex canescens*							X				X	X	
galleta grass - *Hilaria jamesii*							X	X	X	X	X	X	
Indian ricegrass - *Oryzopsis hymenoides*							X	X		X	X		
sand dropseed - *Sporobolus cryptandrus*							X		X	X			
Kentucky bluegrass - *Poa pratensis*					X	X	X			X			

Table IV-3. (Continued)

			Conifer							Grassland			
Major Plant Species	Barren	Alpine and Subalpine Meadow	Western Spruce-Fir-Douglas Fir Forest	Pine-Douglas Fir Forest	Ponderosa Pine Forest	Mountain Shrub	Juniper-Pinyon Woodland	Sagebrush	Desert Shrub	Foothills Prairie, Galleta-Three-Awn, Grama-Galleta	Saltbush	Greasewood	Riparian
muttongrass - *P. fendleriana*		X				X	X	X		X			
Sandberg bluegrass - *P. secunda*					X	X	X	X		X			
western wheatgrass - *Agropyron smithii*					X	X	X	X					
blackbrush - *Coleogyne ramosissima*									X				
shadscale - *Atriplex confertifolia*											X	X	
Nuttall saltbush - *A. nuttallii*											X		
mat saltbush - *A. corrugata*											X		
winterfat - *Ceratoides lanata*											X		
spiny hopsage - *Grayia spinosa*									X		X	X	
budsage - *Artemisia spinescens*											X	X	
Mormon tea - *Ephedra viridis*							X		X		X		
Fremont barberry - *Berberis fremontii*							X		X				
horsebrush - *Tetradymia spinosa*							X		X				
yucca - *Yucca* spp.							X		X				
greasewood - *Sarcobatus vermiculatus*												X	
tamarix - *Tamarix chinensis*													X
narrowleaf cottonwood - *Populus angustifolia*													X
saltgrass - *Distichlis stricta*												X	
boxelder - *Acer negundo*													X
red birch - *Betula fontinalis*													X

Subalpine meadows are more stable because the longer growing season allows more opportunity for plants to recover from defoliation. However, a significant decrease in plant cover will result in accelerated erosion. They produce high-quality water where soils are nonsaline or where precipitation is great enough to leach salts from surface soils. This water dilutes higher concentration water from saline areas.

(3) Conifer

(a) Western Spruce-Fir-Douglas Fir Forest

The high altitude coniferous forests are combined for purposes of the BLM salinity study. These communities are quite similar in relation to the quality of water produced. The spruce-fir-Douglas fir forests are found within a range of elevations from 7,000 to 11,500 feet (58, 81, 156). The pure Douglas fir forest occurs at elevations from 6,000 to 8,500 feet. Aspen occurs throughout the coniferous forests, at all elevations, in pure stands as a result of fire, and as scattered trees. Water quality from high mountain country is generally good; total dissolved solids are low and capable of diluting higher concentration water from saline areas. Volume of water is high and discharge is fairly constant throughout the base flow period (fall-winter).

(b) Pine-Douglas Fir Forest

The pine-Douglas fir forest occurs over a wide range of sites at elevations from 6,000 to 9,000 feet in the Upper Basin. It is a transition zone between the higher elevation western spruce-fir-Douglas fir forest and more pure Douglas fir forest, and the lower elevation ponderosa pine forest. For a description of plants found in this community (see Table IV-3). Water yield and quality from the higher elevations of the pine-Douglas fir forest would be similar to the spruce-fir forest, while those from the lower elevations would be similar to the yields from the ponderosa pine forest.

(c) Ponderosa Pine Forest

The ponderosa pine forest ranges in elevation from 5,500 to 9,000 feet in the Upper Basin. Volume of water from the pine forest is lower than from the high elevation spruce-fir forests and may cease as surface-flow during the hot summer because of lower precipitation, higher temperatures, and increased evapotranspiration. Water quality is fair, depending upon salinity of geologic formations and condition of vegetative cover.

(4) Mountain Shrub

Mountain shrublands are located as a transition zone between woodlands and conifer forests (see Figure IV-8) at elevations of from 6,000 to 8,000 feet. Volume and quality of water yielded from shrublands is comparable to water yield from the ponderosa pine forest.

(5) Juniper-Pinyon Woodland

The juniper-pinyon woodland community is located in the foothills and plateaus below the ponderosa pine region at elevations ranging between 5,000 to 7,500 feet. Base flow water produced by the juniper-pinyon woodland region is minimal and comes from springs and seeps. Runoff is primarily from spring snowmelt and localized summer thundershowers.

The juniper-pinyon, sagebrush, desert shrub, and grassland communities do not contribute to groundwater recharge from the general soil surface because of the high evapotranspiration (67). Much of the water received as rain or snow is intercepted by crown canopies of juniper and pinyon trees and shrubs. It is then evaporated into the atmosphere, with excess water falling to the ground where it is absorbed by the layer of litter beneath the trees. In the case of juniper trees, intercepted water may run down the tree trunk and be absorbed by the thick stringy bark before it can reach the ground. Skau (178) found that during 1 year about 17.2 percent of the average annual precipitation falling on a Utah juniper stand in northcentral Arizona was intercepted by tree canopies. A storm in excess of 0.25 inches (within a relatively short period of time) is required to produce any overland flow.

Water from higher elevation forests moves through the juniper-pinyon woodland on its way to larger streams. Because of high temperatures and lower precipitation in the woodland region, some of this water is consumed. The remaining water contains salts at a higher concentration but not always at an increased load. Sediment production from woodlands is moderate to high during summer thundershowers, depending upon storm intensity and condition of vegetative cover.

(6) Sagebrush

The big sagebrush community is found at the same elevations as the juniper-pinyon community, between 5,000 and 7,500 feet. The hydrology of the sagebrush-grass community is similar to the juniper-pinyon woodland.

(7) Grassland

The foothills prairie grassland community is a small area in southwestern Wyoming (see Table IV-3) within an elevation range of 6,000 to 7,000 feet. The galleta-three-awn and grama-galleta grassland communities (see Table IV-3) are found at elevations between 4,000 and 6,000 feet in Colorado and Utah. These grassland areas are hydrologically similar to the juniper-pinyon and sagebrush regions.

(8) Desert Shrub

The desert shrub community is a complex mixture of plant species growing on the most arid sites (see Figure IV-8 and Table IV-3). Soils associated with the community are nonsaline to moderately saline. The blackbrush type is a major component of desert shrub vegetation and is confined to the state of Utah, mostly along the San Juan River and Lake Powell, at elevations ranging between 4,000 and 5,000 feet. The natural dense crown cover of blackbrush, erosion pavement, and cryptogams offer protection against erosion. Water is yielded from the blackbrush region on an intermittent basis following thunderstorms. Sediment yield is low-to-moderate under stable soil conditions. Amount of salt would be low-to-moderate depending upon surface geology, but no high salt levels are known to exist. The blackbrush type and other vegetation types within the desert shrub community are in the arid and semiarid climatic zones. Therefore, any use which destroys vegetative cover can have a long-lasting effect on runoff and erosion.

(9) Saltbush

The saltbush community is found within an elevation range of 4,000 to 6,000 feet. Saltbush grows characteristically on low to moderately saline soils derived from salt-bearing geological formations such as marine shales. Water yielded from the saltbush community comes as high-peak runoff, following high-intensity thundershowers (greater than 0.25 inches) of short duration. Water from gentle, long-duration storms (characteristic of winter frontal systems) generally remains on site and is later lost to the atmosphere through evapotranspiration. Runoff generally does not exceed 0.5 inches per unit area per year.

Sediment yield is low-to-moderate under normal conditions where vegetative ground cover is 15 to 25 percent. The vegetation offers protection from erosive forces of raindrops and overland flow of water. Sediment yield is high on soils derived from Mancos or other marine shales, and where vegetative cover is very sparse. Electrical conductivity of water coming from the saltbush community ranges from 300 µmhos/cm to 2,400 µmhos/cm depending upon the salinity of the soil and the amount and sources of sediment carried in the water.

(10) Greasewood

The greasewood community occurs in a narrow band along water courses throughout the Upper Basin within a wide range of elevations from 3,600 to 6,500 feet (see Figure IV-8). Quantity of water yielded from the greasewood community specifically is very low because of the restricted acreage of greasewood sites. However, a large volume of water passes through the greasewood community, as it collects from larger surrounding plant communities. Most of the rivers in the Upper Basin pass through the greasewood community at some point along their courses. Sediment load from the greasewood community can be very high depending upon the amount and velocity of water flowing through the community, percent of vegetative cover, steepness of channel sides, and channel depth and slope. Salt levels of water flowing through the greasewood community are generally high.

4. Hydrology

a. Water Quality

Water yield from the Colorado River varies because of location, soils, vegetation, climatic conditions, and geologic formations. The high mountain winter snowpack, summer rainfall, and groundwater discharge combine to maintain continuous streamflows from higher elevations. The intermediate elevations contribute flow during periods of high intensity rainfall and short periods of snowmelt, while the lower, more arid sites contribute runoff only during infrequent high intensity rainfall. Average stream discharges and chemical quality data are shown in Tables IV-4 through IV-9 for major gaging stations in the Upper Basin.

Tables IV-4, -5, and -6 present water quality data since 1965. Conditions prior to 1958 (construction of many storage reservoirs) are contained in Tables IV-7, -8, and -9. In spite of differences in hydrologic conditions, there appears to have been a reduction in discharge and an increase in total dissolved solids concentration.

b. Water Quality

(1) Basin Assessment

The chemical quality of the Colorado River is a function of: (a) precipitation-runoff events; (b) geologic origin of soils; (c) subsurface geology; (d) amount of irrigation; (e) municipal and industrial uses; (f) transmountain diversions; (g) transpiration of phreatophytes; and (h) other minor uses. Chemical quality is reported as either total dissolved solids (TDS) concentration in milligrams per liter (mg/l) or parts per million (ppm) and are used interchangeably for concentrations below 7,000 mg/l. The chemical constituents that contribute to the salinity of water are measured in determining TDS. The terms salinity and TDS are also used interchangeably in this report.

An indicator of salinity in water is the specific conductance of the water as measured by an electrical conductivity (E.C.) meter in micromhos per centimeter (µmhos/cm). The relationship between specific conductance and total dissolved solids is a function of the chemical makeup of the water and is frequently represented with a linear relationship as shown:

$$S = AK$$

where:

S = total dissolved solids in mg/l
A = conversion factor
K = specific conductance in µmhos/cm at 25° Centigrade

Table IV-4. Average Annual Salt and Water Yields at Selected Gaging Stations in Colorado Since 1966[1]

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Yampa River near Maybell, CO	283,000	1,144,000	182	1966-75
Little Snake River near Lily, CO	128,700	455,100	208	1967-75
Colorado River near Hot Sulphur Springs, CO	19,500	180,300	80	1966-75
near Dotsero, CO	431,300	1,511,000	210	"
below Glenwood Springs, CO	581,500[2]	2,528,000[3]	256	"
near Cameo, CO	1,510,000	2,732,000	406	"
at CO-UT State Line	3,595,000	4,267,000	619	"
Eagle River below Gypsum, CO	151,200	395,200	281	"
Roaring Fork at Glenwood Spgs., CO	308,100	860,700	263	"
Plateau Creek near Cameo, CO	59,800	130,500	337	"
Gunnison River near Grand Junction, CO	1,364,600	1,653,000	607	"
Piceance Creek below Ryan Gulch, CO	21,800	16,400	978	1971-75
at White River, CO	38,200	19,000	1,479	"
Animas River at Howardsville, CO	10,100	70,600	105	"
near Cedar Hill, NM	187,800	681,800	202	"
Mineral Creek above Silverton, CO	2,100	15,800	99	"

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[1] Salt load and water yield computed by the Geological Survey Central Region under contract for BLM. (Figures have been rounded.)

[2] Salinity measured above Glenwood Springs, CO.

[3] Discharge of Colorado River measured below confluence with Roaring Fork River at Glenwood Springs. The annual discharge associated with salt load is 1,667,000 acre-feet.

Table IV-5. Average Annual Salt and Water Yields at Selected Gaging Stations in Utah Since 1966[1].

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Colorado River - CO-UT State Line	3,595,000	4,267,000	619	1966-75
Near Cisco	3,816,000	4,569,000 302,000	614	"
Dolores River Near Cisco	489,800	573,700 271,700	628	"
Green River near Greendale	1,135,000	1,616,000	516	"
Near Jensen, UT	1,572,000	3,332,000	347	"
At Green River, UT	2,834,000	4,392,000	474	"
Duchesne River near Duchesne	63,200	274,900	169	"
Near Myton	167,800	300,700	410	"
Near Randlett	418,000	462,600	665	"
Strawberry River near Duchesne	53,700	104,500	378	"
Uinta River near Neola	5,500	144,800	28	"
White River near Watson	275,100	486,300	416	"
Price River near Woodside	263,800	84,400	2,298	"
San Rafael River Near Green River	201,100	73,100	2,023	"
San Juan at Bluff	1,032,000	1,542,000	492	"

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[1] Salt load and water yield computed by the Geological Survey Central Region, under contract for BLM. (Figures have been rounded.)

Table IV-6. Average Annual Salt and Water Yields at Selected Gaging Stations in Wyoming Since 1966[1].

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Green River at Warren Bridge, WY	82,900	395,200	154	1966-75
near LaBarge, WY	315,300	1,271,000	183	"
below Fontenelle, WY	378,900	1,254,000	222	"
near Green River, WY	585,200	1,353,000	318	"
New Fork River near Big Piney, WY	67,200	581,400	85	"
Big Sandy River below Eden, WY	88,200	45,700	1,418	"
Blacks Fork River near Lyman, WY	125,300	131,600	700	"
near Little America, WY	211,900	277,200	562	"
Henrys Fork River near Linwood, UT	63,300	75,600	616	"

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[1] Salt load and water yield computed by the Geological Survey Central Region under contract for BLM. (Figures have been rounded.)

Table IV-7. Average Annual Salt and Water Yields at Selected Gaging Stations in Colorado Prior to 1958[1].

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Yampa River near Maybell, CO	1,004,000	2,147,000	344	1951-57
Little Snake River near Lily, CO	108,000	374,200	212	1951-57
Colorado River at Hot Sulphur Springs, CO	26,000	297,100	64	1947-57
near Glenwood Springs, CO	605,600	1,742,000	256	1942-57
near Cameo, CO	1,555,000	2,925,000	391	1934-57
at Grand Junction, CO	2,112,000	2,653,000	585	1932-41
Eagle River below Gypsum, CO	190,500	430,400	325	1948-57
Gunnison River near Grand Junction, CO	1,508,000	1,731,000	641	1953-57
Dolores River at Gateway, CO	478,400	658,100	535	1948-52
near Cisco, UT	428,200	549,500	573	1952-57

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[1] Summarized from data contained in Professional Paper 442 (102). (Figures have been rounded.)

Table IV-8. Average Annual Salt and Water Yields at Selected Gaging Stations in Utah Prior to 1958[1].

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Dolores River near Cisco, UT	428,200	549,500	573	1952-57
Colorado River near Cisco, UT	4,363,000	5,255,000	610	1929-57
at Hite, UT	7,117,000	9,216,000	563	1951-57
at Lees Ferry, UT	8,904,000	12,208,000	536	1929-56
Green River near Greendale, UT	930,200	1,938,000	351	1957
at Jensen, UT	1,627,000	3,748,000	319	1948-57
near Ouray, UT	2,900,000	5,572,000	383	1951, 52, 57
at Green River, UT	2,495,000	4,147,000	442	1929-57
Duchesne River near Duchesne, UT	73,300	252,700	214	1942
near Myton, UT	229,400	402,500	419	1942
near Randlett, UT	417,700	420,600	730	1951, 57
Strawberry River near Duchesne, UT	60,000	107,100	413	1942
White River near Watson, UT	323,000	501,400	474	1951-57
Willow Creek near Ouray, UT	25,000	18,500	994	1951-54
Price River at Woodside, UT	267,000	83,600	2,348	1952-57
San Rafael River near Green River, UT	215,000	102,600	1,540	1948-57
Dirty Devil near Hite, UT	238,700	85,500	2,052	1949-53
Escalante River near Escalante, UT	35,300	66,900	388	1952-53
San Juan River near Bluff, UT	1,001,000	1,737,000	423	1930-57

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[1] Summarized from data contained in Professional Paper 442 (102). (Figures have been rounded.)

Table IV-9. Average Annual Salt and Water Yields at Selected Gaging Stations in Wyoming Prior to 1958[1].

Name of Station	Salt Load (tons)	Discharge (ac-ft)	Concentration (mg/l)	Period of Record
Green River near Green River, WY	516,100	1,295,000	293	1952-57
Blacks Fork near Marston, WY	114,600	155,200	543	1954-57
near Green River, WY	228,600	318,200	528	1952-53
Henrys Fork near Linwood, UT	45,200	46,800	709	1952-56

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[1] Summarized from data contained in Professional Paper 442 (102). (Figures have been rounded.)

Hem (91) indicates that conversion factor "A" will vary with a change in the kinds of ions present in the dissolved solids. It may also change with the concentration of ions. The range of values is usually between of 0.55 and 0.75, but may range from 0.50 to 0.95. The factor "A" has been assumed to be equal to 0.65 for use in this report unless stated otherwise, since sufficient data are not available to establish the actual relationship. Tables IV-4 through IV-9 contain a summary of Upper Basin long-term water quality data and a general salinity picture. It should be noted that, since concentrations represent an average annual value which is flow weighted, they reflect periods of higher runoff. Under low flow conditions, the salinity concentration can be several times greater than the average. For example, the Little Snake River at Lilly, Colorado, has an average concentration of 208 mg/l and a discharge of 628 cubic feet per second (cfs), while on a single day a concentration of 1,600 mg/l was measured with a discharge of 17 cfs.

Water from high mountain watersheds contains low concentrations of salts, mainly calcium bicarbonate. As water moves through the river system, the major constituents change from calcium bicarbonate to calcium sulfate, sodium sulfate, and sodium chloride. This shift can be caused by such factors as: (a) a change in the salinity of the alluvial material that water contacts; (b) the chemical makeup of soils and geologic formations contributing surface runoff and groundwater; and (c) the relative cation-anion exchange activity between salt producing ions. Sodium and chloride are the most active ions and tend to replace, or exchange with, other elements in solution as well as have a high solubility level.

The regional water quality assessment consists of data from Geological Survey (GS) gaging stations, data collected by BR in their salinity control program, 208 regional planning agencies (authorized through Section 208 of Public Law 92-500), BLM, and other miscellaneous data. Tables IV-4, -5, and -6 contain a summary of the GS gages. Annual flow weighted salt loads were computed for each water quality station from 1966 through 1975 to reflect salinity conditions during the operation of major reservoirs. Data also were summarized from Iorns et al (102) and are shown in Tables IV-7, -8, and -9 for Colorado, Utah, and Wyoming, respectively. Unfortunately, these data cover various periods of record and climatic conditions and cannot be compared directly to the more recent 10-year period. Approximate locations of BLM water quality collection sites are shown in Figures IV-9a, -9b, and -9c. These data were used to develop Figures IV-10a, -10b, and -10c showing annual water and salt yields with associated concentrations.

Figure IV-10a shows approximate average annual water concentration of the Colorado River in Colorado. The headwaters near the Continental Divide have average annual concentrations less than 100 mg/l. Muddy Creek Basin near Kremmling, Colorado is the first area with significant salt concentrations. Concentrations are affected by runoff from saline geologic formations, irrigation consumption, and return flow. Other small tributary streams along the Colorado River between Derby and Deep Creeks also have high salinity concentrations because of saline geologic formations and some irrigation use. The BLM has measured E.C.s ranging from 290 to 2,330 μmhos/cm, while discharge ranged from 100 to 0.5 cfs.

FIGURE IV-9a. LOCATION OF WATER QUALITY DATA COLLECTION STATIONS IN COLORADO

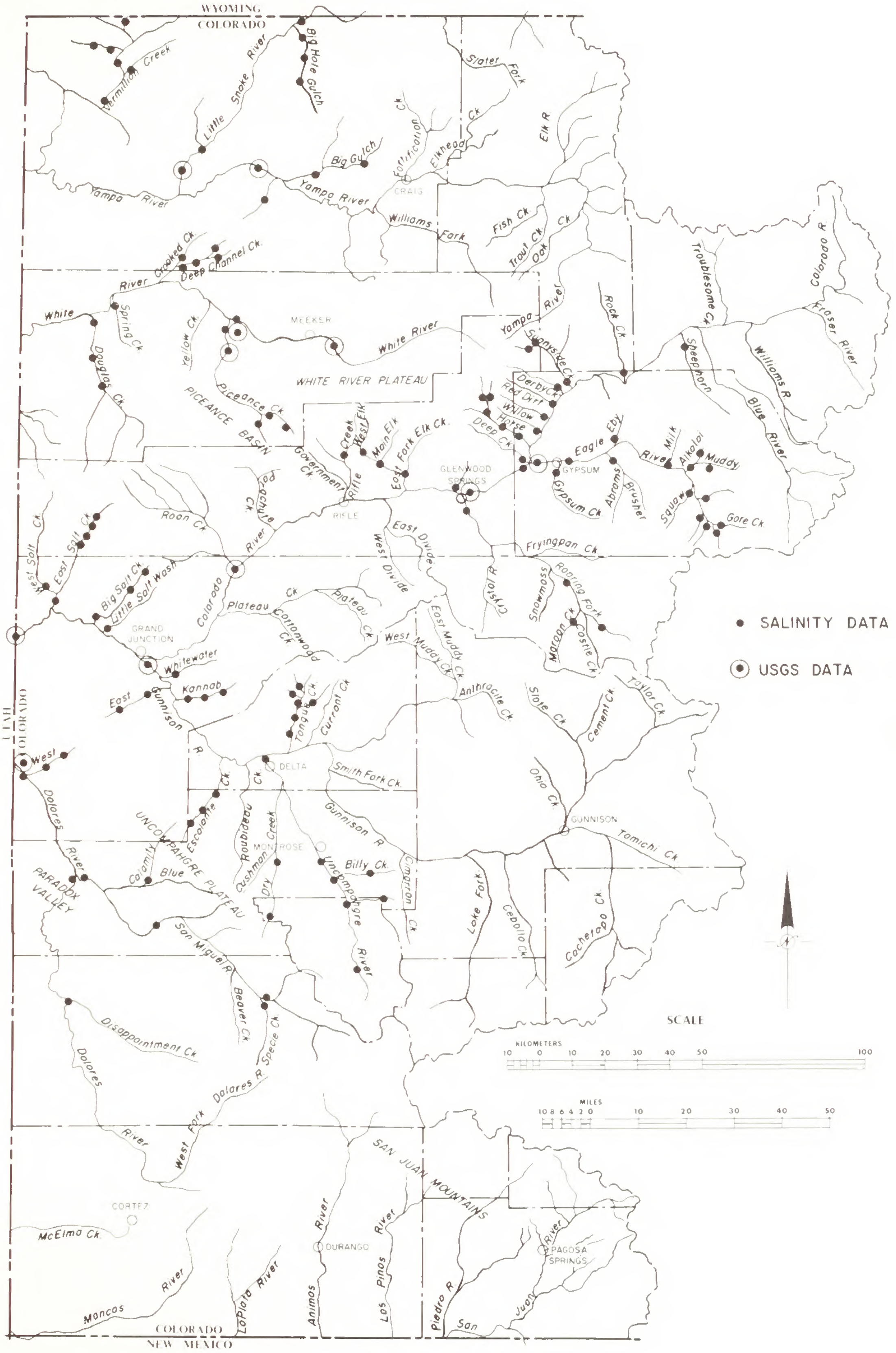


FIGURE IV-9b. LOCATION OF WATER QUALITY DATA COLLECTION STATIONS IN UTAH

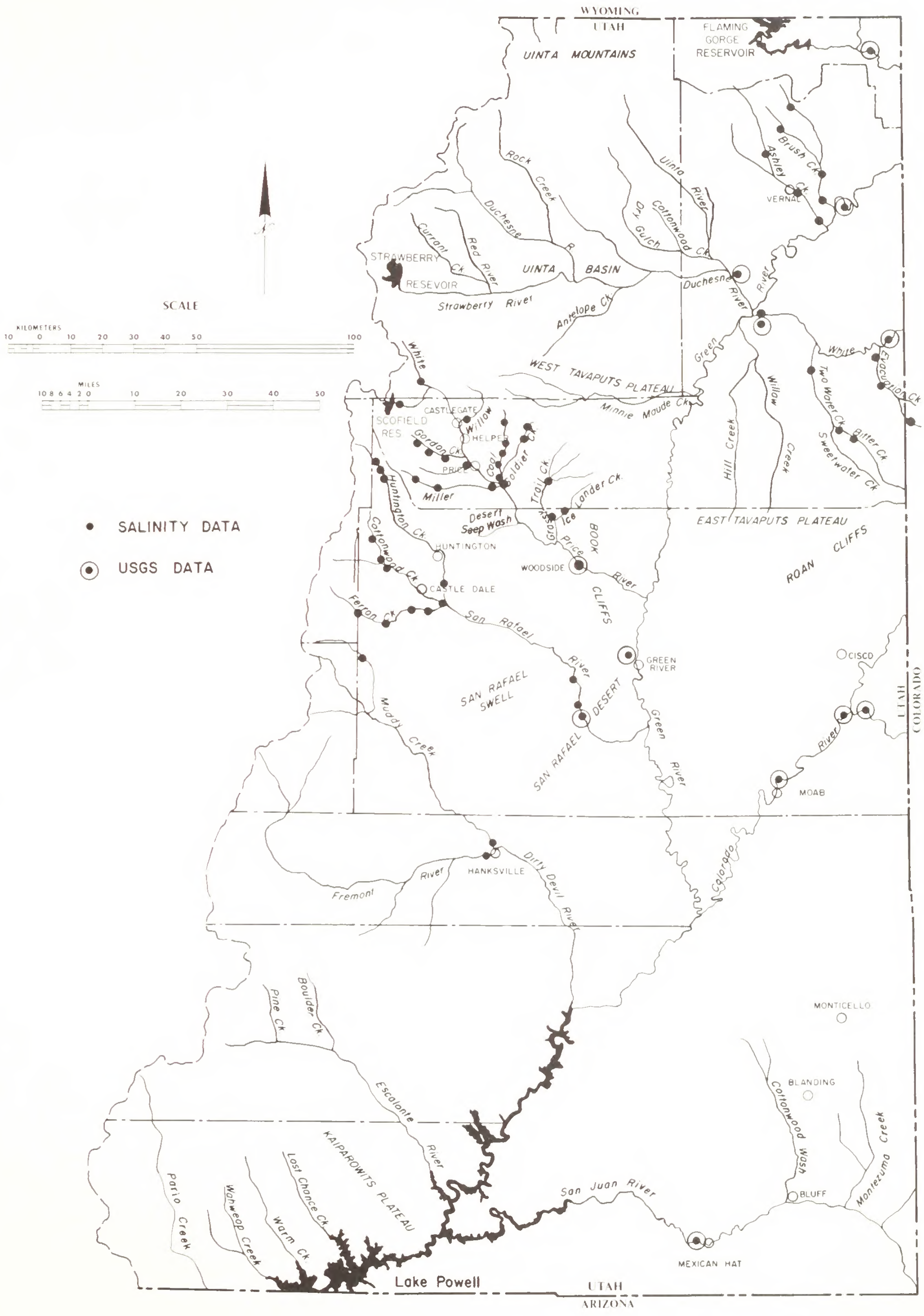


FIGURE IV-9c.

LOCATION OF WATER QUALITY DATA COLLECTION STATIONS IN WYOMING

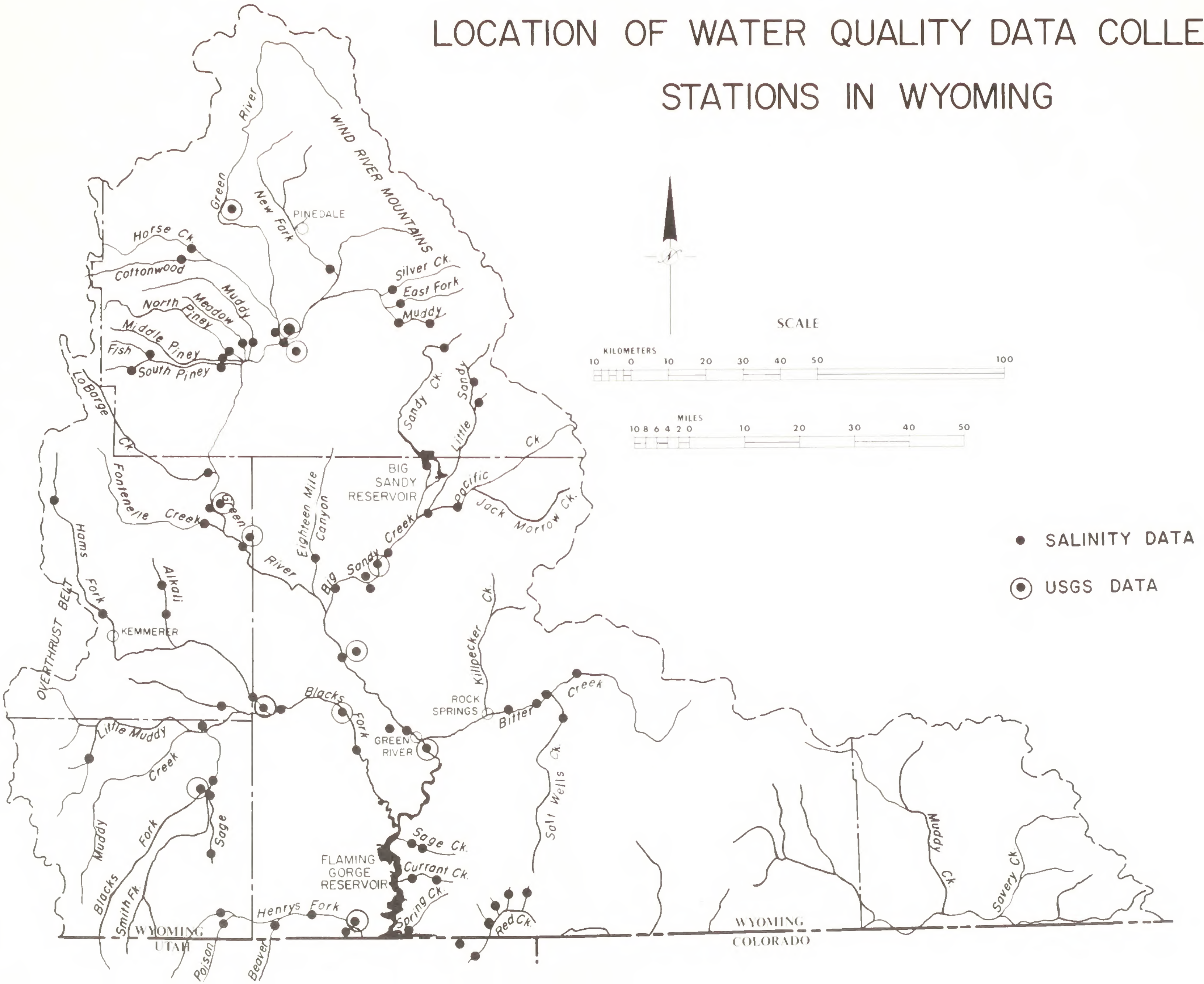


FIGURE IV-10a.
TOTAL DISSOLVED SOLIDS CONCENTRATION WITH AVERAGE ANNUAL WATER & SALT YIELD FOR COLORADO

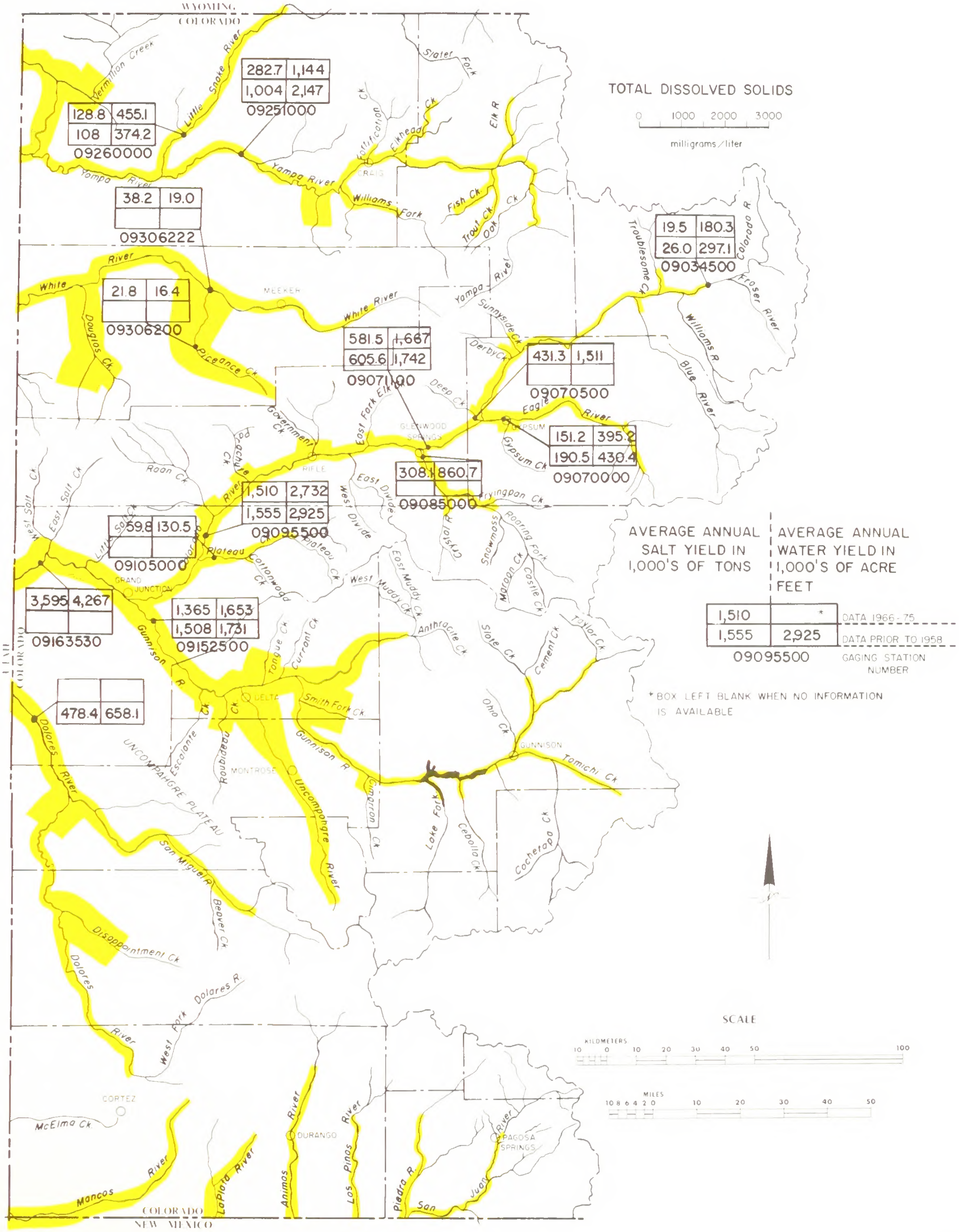


FIGURE IV-10b. TOTAL DISSOLVED SOLIDS CONCENTRATION WITH AVERAGE ANNUAL WATER & SALT YIELD FOR UTAH

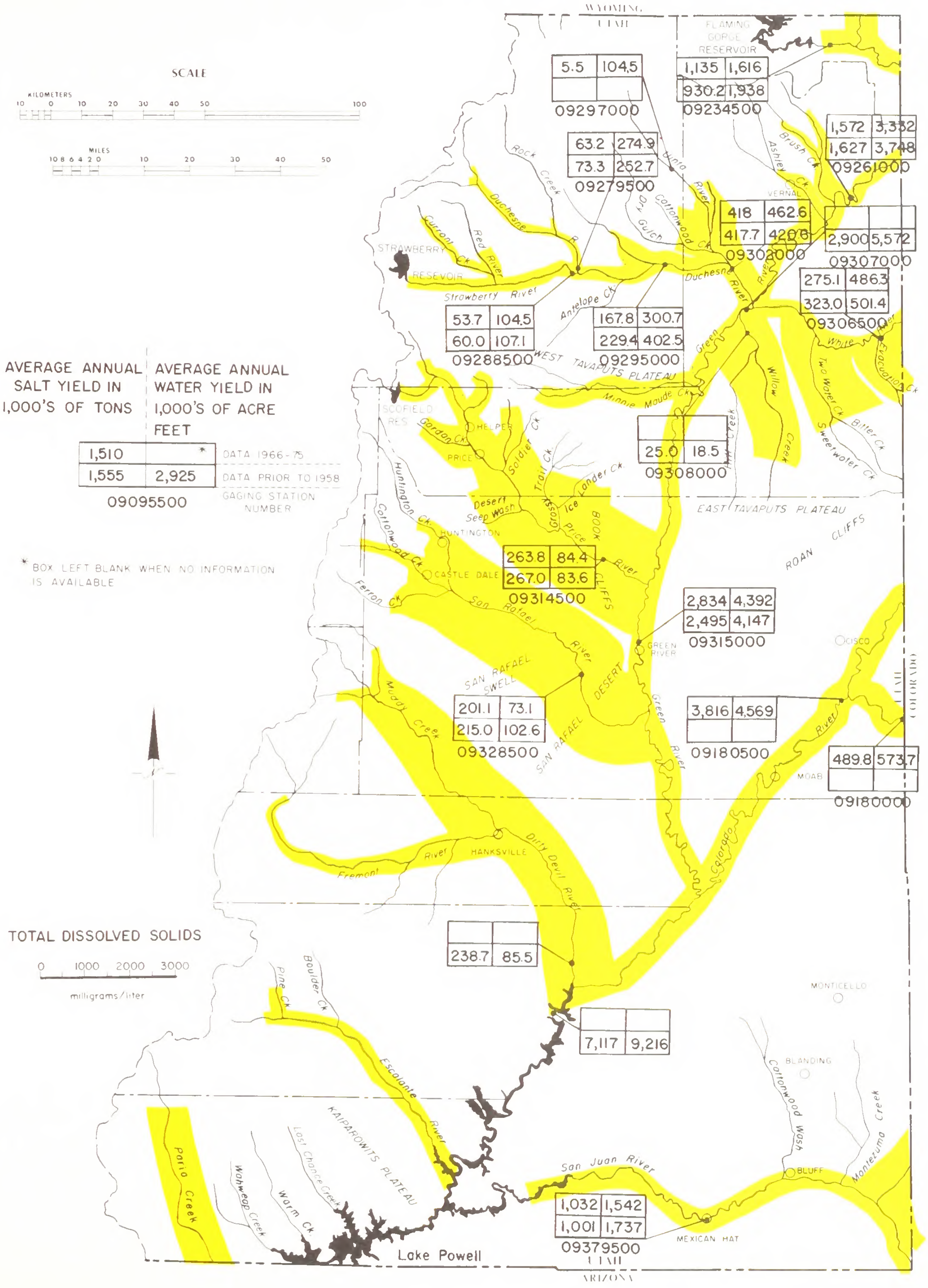
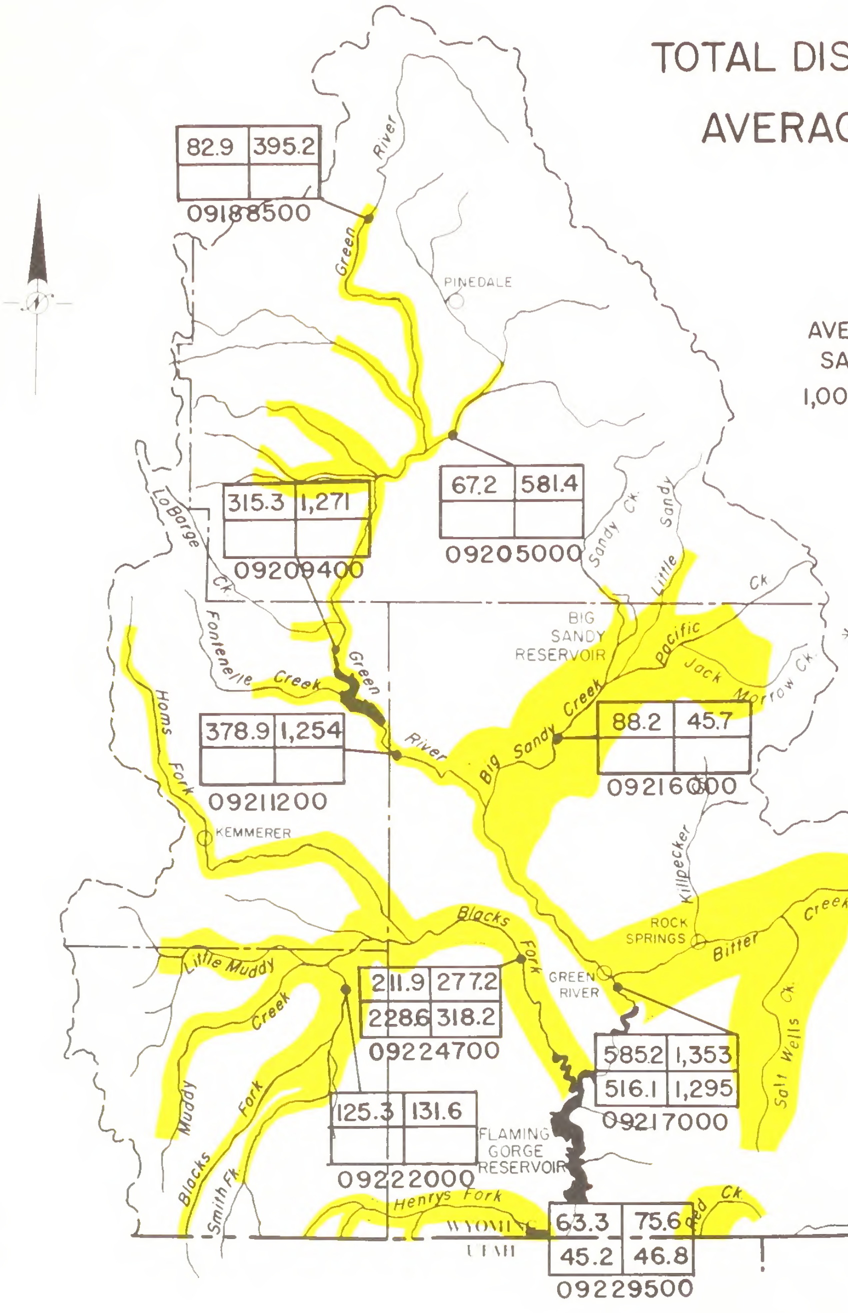


FIGURE IV-10c

TOTAL DISSOLVED SOLIDS CONCENTRATION WITH AVERAGE ANNUAL WATER & SALT YIELD FOR WYOMING



TOTAL DISSOLVED SOLIDS

0 1000 2000 3000

milligrams/liter

AVERAGE ANNUAL SALT YIELD IN 1,000'S OF TONS	AVERAGE ANNUAL WATER YIELD IN 1,000'S OF ACRE FEET	
1,510	*	DATA 1966-75
1,555	2,925	DATA PRIOR TO 1958
09095500		GAGING STATION NUMBER

* box left blank when no information is available

SCALE

KILOMETERS
10 0 10 20 30 40 50 100

MILES
10 8 6 4 2 0 10 20 30 40 50

The same saline geologic formations outcrop in the Eagle River Basin from Minturn, Colorado to the mouth of the river. The major salt pickup is from irrigation return flow. However, salinity measurements in Alkali, Milk, Gypsum, and Eby Creeks had specific conductances ranging from 480 to 1,360 µmhos/cm with discharges from 15 to 0.5 cfs, which add to the salt load. The salt concentration of the Eagle River increased from about 100 to nearly 300 mg/l at its mouth.

Most tributaries of the Colorado River between the confluences of the Eagle and Roaring Fork Rivers originate on the White River Plateau. They have average annual dissolved solids of about 200 mg/l. In addition to the surface runoff, saline seeps and springs (Glenwood-Dotsero) contribute significant amounts of sodium chloride along with lesser amounts of other salts to change the general chemical composition to a calcium sodium bicarbonate chloride. The salt composition of the Colorado River remains relatively constant until its confluence with the Gunnison River.

The headwaters of the Roaring Fork and Frying Pan Rivers yield water with concentrations of 100 mg/l or less. The tributaries from the south generally have higher annual concentrations and may reach 200 mg/l. This difference is primarily due to more saline geologic formations, less resistant to weathering. The Roaring Fork and some of its tributaries are adjacent to significant areas of irrigated agriculture which consume water and add to the salt load through leaching of the subsoils.

The Colorado River flows westward over more saline geologic formations from Glenwood Springs to near Cameo, Colorado. The major tributaries are Elk, Rifle, Parachute, Roan, and East and West Divide Creeks. The small amount of chemical quality data available (102, 194, 196) indicates the major salt contribution is from irrigated agriculture.

As the Colorado River enters the Grand Valley near Grand Junction, Colorado it flows through an area comprised of Mancos Shale bedrock overlain by alluvial deposits of Mancos-derived soils. The salinity of surface runoff from the Mancos-derived soils has been measured at Badger Wash. Concentrations are typically less than 2,000 mg/l. Salinity and flow increase in the washes that drain the area as a result of irrigation return flow. During most of the year, the washes are dry upstream from irrigated lands. Runoff from rangelands and irrigation tail water reduce salt concentrations in the washes created by subsurface drainage from irrigation.

The Gunnison River is the major tributary of the Colorado River in Colorado. Salt concentrations in the Gunnison River are generally less than 100 mg/l, until it flows into the Gunnison Valley near Gunnison, Colorado. Here, agriculture consumes the water causing a gradual increase in the concentration. Salt pickup from Cimarron Creek and North Fork, along with natural runoff and water consumption by irrigation, increases the concentration of the river to about 400 mg/l at Delta, Colorado, where it meets the Uncompahgre River.

The Uncompahgre River contains salt in concentrations of about 200 mg/l at its headwaters. However, there is a significant salt buildup from both natural and man-caused sources, until the average annual concentration at its mouth approaches 1,200 mg/l. Runoff from the Uncompahgre Plateau entering the Gunnison River is generally of better quality than the river itself. The average concentration ranges from about 300 to 500 mg/l. Runoff from Grand Mesa to the east is highly utilized for irrigation of Mancos-derived soils and enters the river at concentrations greater than 1,000 mg/l, except during short periods of spring runoff. During much of the growing season, all natural flows are diverted for agriculture and only irrigation return flows enter the Gunnison River.

The impact of the Gunnison River and irrigation in Grand Valley on salinity of the Colorado River is great. Sulfates become the major anion, along with lesser concentrations of the calcium and sodium cations. The water character of the Colorado River below the Gunnison River remains essentially the same until it reaches the Dolores River.

The Dolores River enters the Colorado River near Cisco, Utah. It has an average annual salinity concentration similar to the Colorado River at this point, however, chemical composition is different. The Dolores River contains less than 200 mg/l of salt at its headwaters in the San Juan Mountains. Its major salt pickup is in the Paradox Valley where it receives brine inflow from the Paradox Formation, as shown by the sharp increase in concentration in Figure IV-10a. Another source of salt is the runoff from Mancos-derived soils in Disapointment Valley. However, the average annual runoff and salt load is low when compared to the total tons of salt carried by the river as it leaves its headwaters. The major tributary of the Dolores River is the San Miguel River. It reduces the concentration of salts in the Dolores River by contributing a relatively large volume of good quality water. The total salt load (tons of salt carried by the Dolores River) is increased slightly by the salt carried in the San Miguel waters.

The Dolores River contains a low concentration of calcium bicarbonate at its headwaters, but takes a much greater concentration of sodium chloride into solution as it passes through the Paradox Valley. The San Miguel River also contains a moderate amount of calcium sulfate. The chemical composition of the Dolores River below its confluence with the San Miguel consists of a sodium calcium chloride sulfate. The Dolores River causes an increase in sodium and chloride content of the Colorado River. Sodium and calcium concentrations are at approximately the same level and chlorine is nearly equal to bicarbonate concentrations. Sulfate is the most prevalent anion. The concentration of salts in the Colorado River increases as it approaches the confluence with the Green River, although the relative chemical composition of the ions does not change significantly.

The Green River is the next major tributary of the Colorado River. It originates in the Wind River Mountains of southwestern Wyoming. Its average annual dissolved solid concentrations are shown in Figure IV-10c, while a summary of average annual discharge and salt loads are contained in Tables IV-6 and -9. The water originating in the Wind River Range has concentrations of less than 100 mg/l while waters originating in the Overthrust Belt area to the west typically have concentrations of about 200 mg/l. These concentrations are modified as water is consumed by irrigation. The alluvial irrigated lands above Fontenelle Reservoir generally yield less than 1 ton per acre of salt through leaching (53).

The Big Sandy River is the first major contributor of salt to the Green River. It originates in the southern tip of the Wind River Mountains and flows southwesterly across a large, relatively flat, semiarid plain, where significant quantities of water are removed for irrigation. This loss of water raises the concentration of salts in the river. The Big Sandy is further affected by saline seeps which are fed by natural groundwater and irrigation return flow that discharge along banks and in the channel bottom. These seeps have a concentration of approximately 6,000 µmhos/cm and produce a total discharge of about 20 cfs. Pacific Creek and its tributary, Jack Morrow Creek, should be investigated to determine if feasible means of reducing their salt yield can be found.

Bitter Creek enters the Green River near Green River, Wyoming. It originates in the high plains area where runoff per unit area is extremely low. For example, discharge at Rock Springs is typically less than 5 cfs, except during isolated thunderstorms. The dissolved solids concentration is typically between 1,000 and 2,000 mg/l, except during high flow when it is less.

The Blacks Fork River enters the Green River at the upper end of Flaming Gorge Reservoir. It originates on the east slope of the Overthrust Belt and on the north slope of the Uinta Mountains. Water from the Uinta Mountains typically contains dissolved solids of less than 100 mg/l while those from the Overthrust Belt contain nearly 200 mg/l (Hams Fork and Muddy Creek). The Blacks Fork flows north where it is used for irrigation, causing average annual salt concentrations to increase to 700 mg/l. Concentrations may exceed 2,000 mg/l during low flow periods. The Hams Fork flows into the Blacks Fork at Granger, Wyoming and improves its water quality. The chemical quality of water in streams entering Flaming Gorge from the east ranges from less than 500 to greater than 5,000 mg/l, depending on the time of year and geologic formations present in the watersheds. Big and Little Firehole Basin and Sage Creek should be investigated to determine if salt yields from erosion can be reduced.

The Henrys Fork enters Flaming Gorge Reservoir near Manila, Utah with an annual salt load of 63,000 tons and a concentration of 620 mg/l. The head of the river is in the Uinta Mountains; it is used for irrigation on lands similar to those found in the Blacks Fork. Large amounts of salts are picked up from the saline soils and carried to the Flaming Gorge reach of the Green River. Streams in Wyoming contain primarily calcium bicarbonate at their headwaters and degrade to sodium calcium sulfate in the downstream reaches.

Streams that enter the Green River from the west, in Utah, all have low concentrations of dissolved solids, except for Ashley Creek near Jensen, Utah. Streams that enter from the east, in Utah and Colorado, between Flaming Gorge Reservoir and the Yampa River, carry higher concentrations, although their discharges are still relatively small. Vermillion and Red Creek Basins should be investigated for possible salinity control.

The Yampa River, a major tributary to the Green River, originates in the northern Colorado Rockies where salt concentrations are typically less than 100 mg/l. Concentrations have exceeded 1,000 mg/l at Maybell, Colorado during low flow periods. The water quality and discharge of the Little Snake River are similar to that of the Yampa and, therefore, do not have a significant impact. Milk Creek flows north into the Yampa below the Williams Fork and has significantly higher dissolved solids as shown in Figure IV-10a. However, its discharge is small, reducing the impact on the Yampa River. The Yampa River improves the quality of the Green River, as shown in the data from the gaging station near Jensen, Utah in Table IV-5 and in Figure IV-10b.

As the Green River enters the agricultural areas of the Ashley Valley, it picks up significant salt loads from Brush Creek and Ashley Creek. Both streams have good quality water near their origin and are degraded from lowland runoff and irrigation return flows, as shown in Figure IV-10b.

The Duchesne River drains the Uinta Basin and discharges into the Green River below Ashley Creek and upstream of the White River. Tributaries which originate in the Uinta Mountains are of high quality with salt concentrations less than 100 mg/l. This high quality water is degraded, primarily by irrigation, as shown in Figure IV-10b, for the Lake Fork and Uinta Rivers. Only small amounts of runoff originate in areas to the south; salt concentrations are approximately 300 mg/l. The Duchesne River carries approximately 400,000 tons of salt to the Green River annually.

The White River originates on the White River Plateau between the Yampa and Colorado Rivers. The headwaters generally have salt concentrations near 100 mg/l, primarily calcium bicarbonate. The first major salt increase results from artesian flows through abandoned exploration wells in the Meeker Dome oil field. Attempts to plug these wells have been unsuccessful. The Piceance Creek is the next significant contributor of salt. It yields about 38,000 tons of salt from natural and man-caused pollution. Salt seeps are visible along the creek in the lower one-third of the Piceance Basin. Natural salt concentrations range from about 300 to 1,000 mg/l. Nearly all of the tributaries downstream from Piceance Creek yield runoff with salt concentrations greater than 500 mg/l.

Evacuation and Two Water Creeks, in Utah have the highest salinity concentration of any tributary to the White River. Fortunately, their discharge is small and, therefore, the total tons of salt yielded is low. The concentration of salt in the White and Green Rivers is similar at their confluence, with the composition of salts being a calcium sodium bicarbonate sulfate.

The Price River contributes large quantities of salt to the Green River. It originates in the eastern edge of the Wasatch Plateau where the water typically has salt concentrations of 200 mg/l. The flow is highly regulated and used for irrigation in the valley below Price, Utah on soils derived primarily from the saline Mancos or Mesa Verde Formations. The total streamflow is normally diverted for irrigation, except during periods of high runoff when canal capacity is exceeded. The water quality of Desert Seep Wash is typical of irrigation return flow to the Price River. Ephemeral streams like Soldier and Coal Creeks have a concentration of about 500 mg/l at the base of the Book Cliffs. The quality of their water deteriorates to about 1,500 mg/l within a distance of 5 to 8 miles as the result of lowland surface runoff, small groundwater seeps, irrigation return flow, and consumption of water by riparian vegetation. The Price River has a salt load of about 260,000 tons a year as shown in Table IV-5. The water is primarily sodium calcium sulfate.

Water quality of the San Rafael River is very similar to that of the Price. Water for irrigation of the Mancos-derived soils requires the diversion of all normal discharge during the irrigation season. This use has a major impact on chemical quality. The San Rafael yields approximately 200,000 tons of salt and is the last of the major tributaries to the Green River above its confluence with the Colorado River.

The Colorado River then flows into Lake Powell in southeastern Utah. The Dirty Devil River discharges water with high salt concentrations directly into the reservoir. It is formed by the confluence of Muddy Creek and the Fremont River. Muddy Creek is influenced by irrigation of Mancos Shale-derived soils and natural runoff from the saline geology. It has salt concentrations greater than 1,000 mg/l. The Fremont River has low salt concentrations ($<$ 150 mg/l) at its headwaters and gradually deteriorates to about 700 mg/l at its mouth. Water quality of the Dirty Devil River below this point changes very little along its course to Lake Powell. The Escalante River also discharges directly into Lake Powell. Its low salt concentration tends to improve the quality of the Colorado River.

The last major tributary to Lake Powell is the San Juan River which drains southeastern Utah, southwestern Colorado, and northwestern New Mexico. Since this study involves only Colorado, Utah, and Wyoming, salt yields are not identified for New Mexico areas. The headwaters of the San Juan generally have less than 100 mg/l dissolved salts. The La Plata and Mancos Rivers, as well as McElmo Creek, have high salt concentrations and degrade the San Juan waters. Water of the San Juan reduces salt concentrations in the Colorado River because of its lower dissolved solids concentration and relatively large discharge.

The water of the San Juan River, at its upper reaches, contains primarily calcium bicarbonate. At its confluence with the Colorado River, salt concentrations change to calcium sodium sulfate. The La Plata River is high in calcium magnesium sulfate while McElmo Creek is magnesium calcium sulfate.

Finally, the Paria River discharges about 20,000 acre-feet of water annually near Lees Ferry, Arizona. It has a concentration of about 1,000 mg/l. Flows originating in the Mancos Shale headwaters contain greater salt concentrations than those originating in the sandstone formation close to the Colorado River.

The previous discussion relates primarily to diffuse or nonpoint sources of salt. Known and unknown point sources are not discussed in detail since this section intended to display the general water quality condition in the Upper Basin.

(2) Perennial Streams

The perennial streams originating at higher elevations on private and national forest lands, contribute most of the Upper Basin runoff. As described earlier, although they contain low salt concentrations, the high volume of runoff contributes a significant part of the natural salt load. Perennial streams are characterized by high runoff from April through July when snowmelt makes a major contribution to discharge. During the remainder of the year the flow is contributed by groundwater, forming a relatively constant discharge called base flow. Base flow has little annual variation except during periods of extreme drought.

Because of the perennial discharge, streams are utilized for agriculture and other consumptive uses, including municipal and industrial, energy production, and transmountain diversions. Nearly all arable lands along streams are in private ownership and used to grow irrigated crops. Storage projects have been developed to impound excess spring runoff for later use during low flow periods.

The Eagle River is typical of streams that do not pass through large areas of irrigated saline soils. Table IV-10 characterizes the water yield and salt loading for the Eagle River below Gypsum, Colorado for the spring runoff, base flow, and irrigation return flow periods from 1966 through 1975. Spring runoff was assumed to occur from April through July, with base flow occurring the rest of the year. Irrigation return flow occurs from July through October. The average monthly discharge, salt load, and concentration are shown in Figure IV-11 and are quite typical of higher elevation streams.

Table IV-10. Average Annual Water and Salt Yields for the Eagle River Below Gypsum, Colorado for Selected Runoff Periods.

		Spring Runoff[1]		Base Flow[2]		Irrigation Return Flow[3]		Annual Total	
	Year	Discharge (ac-ft)	Salt Load (tons)	Discharge (ac-ft)	Salt Load (tons)	Discharge (ac-ft)	Salt Load (tons)	Discharge (ac-ft)	Salt Load (tons)
	1966	175,260	61,200	109,840	81,990	63,060	44,840	285,100	143,190
	1967	220,040	59,550	95,890	85,960	94,760	62,170	315,930	145,510
	1968	245,850	61,740	123,080	90,690	115,690	61,060	368,930	152,430
	1969	256,000	69,080	105,480	84,830	106,040	57,020	361,480	153,910
	1970	348,680	76,160	128,260	93,030	135,930	60,960	476,940	169,190
	1971	322,050	66,600	134,020	86,270	119,980	57,950	456,070	152,870
	1972	250,490	53,060	113,720	87,860	84,640	44,600	364,210	140,920
	1973	333,830	64,760	120,550	80,620	140,860	53,780	454,380	145,380
	1974	329,380	67,970	111,650	91,700	92,220	53,400	441,030	159,670
	1975	316,020	57,640	111,760	90,830	166,690	56,350	427,780	148,470
Average		279,760	63,780	115,430	87,380	111,990	55,210	395,190	151,160
Percent of Annual		71	42	29	58	28	37	100	100
Average Concentration During Period			168		557		362		281
Average Monthly Discharge per Period		69,940		14,428		27,998		32,933	
Average Monthly Salt Load per Period			13,945		10,992		13,802		12,597

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[1] Spring runoff period used is April, May, June, and July.

[2] Base flow period is remainder of the year.

[3] Irrigation return flow period is July, August, September, and October.

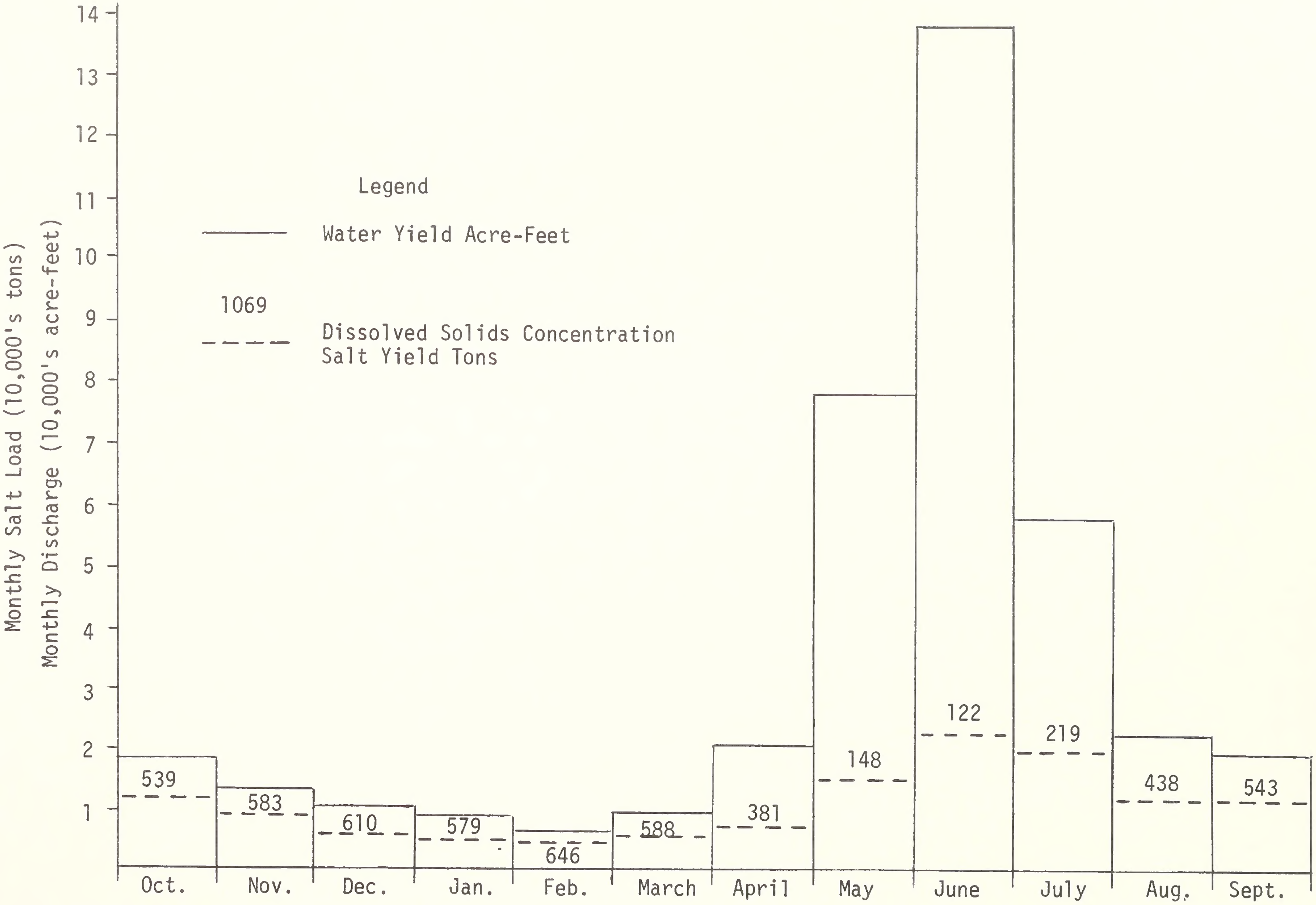


Figure IV-11. Average monthly discharge and salt load for Eagle River below Gypsum, Colorado for 1966-1975.

The runoff period contributes 71 percent of the annual discharge for the Eagle River and 42 percent of the salt load with an average monthly discharge of 69,940 acre-feet and salt load of 13,945 tons. The average salinity concentration was 168 mg/l. The base flow period contributed 29 percent of the discharge, 58 percent of the salt load, and had an average concentration of 557 mg/l. The irrigation return flow period contributed 28 percent of discharge and 37 percent of the annual salt load as shown in Table IV-10.

The Price River is typical of a completely opposite circumstance. The river flows through irrigated, strongly saline soils and nearly all water is diverted for agriculture. Data in Table IV-11 and Figure IV-12 illustrate water quality of the Price River, measured at Woodsite, Utah well below the irrigated lands.

(3) Ephemeral Streams

Runoff and salt yields from public lands in the Upper Basin generally come from ephemeral streams. Representative runoff and water quality data are expensive and difficult to obtain since most of the runoff occurs during short periods of high-intensity rainstorms. Runoff generally lasts for only a few hours and seldom for more than a day. Basin shape, slope, soils, vegetation, and land use also contribute to the variability in runoff volume and peak discharge between watersheds. Different salinity levels of soils and geologic formations also add variability between basins.

Data collected by BLM were used to quantify runoff concentrations and total salt loads. Most data collected represents only one point on the hydrograph. However, one nearly complete runoff event near Woodside, Utah was monitored for discharge and salinity. The location is Marsh Flat Wash, 4.5 miles northwest of Woodside on U.S. Highway 6 and 50. A discharge and salt yield summary is contained in Table IV-12, and the hydrograph and salt concentration are shown in Figure IV-13. The watershed contains approximately 9,000 acres. The upper portion is comprised of ledges of the Book Cliffs, with juniper-pinyon woodland in the canyons. The midsection of the watershed consists of gravel pediments with sparse vegetation and the lower area is Mancos-derived soils with a sparse cover of shadscale and Nuttall saltbush. The runoff event salt load is approximately 1.5 to 2.2 tons, depending on the correlation factor used to estimate TDS from E.C. The salinity concentration of the leading edge (beginning) of the hydrograph is not typical of expected conditions. Generally, the leading edge will have a higher salt concentration and decay to a nearly constant lower value. This is probably due to the period of low intensity rainfall that occurred prior to runoff. This would leach surface salts deeper into the soil profile out of contact with the runoff. The salinity increased during high flow when erosion would be at a maximum. The high concentration at the end is probably from water stored in gully banks draining back into the channel and carrying higher concentrations of salt from deeper in the soil profile. Other data collected indicate salt concentrations of runoff are usually between 750 and 2,000 mg/l from Mancos Shale watersheds.

Table IV-11. Average Annual Water and Salt Yields for the Price River at Woodside, Utah for Selected Runoff Periods.

Year	Spring Runoff1/ Discharge (ac-ft)	Spring Runoff1/ Salt Load (tons)	Base Flow2/ Discharge (ac-ft)	Base Flow2/ Salt Load (tons)	Irrigation Return Flow3/ Discharge (ac-ft)	Irrigation Return Flow3/ Salt Load (tons)	Annual Total Discharge (ac-ft)	Annual Total Salt Load (tons)
1966	22,530	76,900	44,090	185,200	16,250	75,700	66,620	262,200
1967	44,320	110,400	32,230	138,670	24,830	86,800	76,550	248,900
1968	61,670	109,400	39,450	166,500	34,710	122,900	101,120	275,800
1969	100,950	151,100	61,460	218,530	37,400	137,000	162,410	369,500
1970	30,070	113,200	33,690	153,500	21,710	83,400	63,760	266,800
1971	23,920	69,600	28,690	112,450	18,270	67,900	52,610	182,050
1972	14,820	54,580	30,730	115,710	30,380	84,000	45,550	170,290
1973	84,240	156,700	54,760	182,080	23,760	84,800	139,000	338,780
1974	14,860	51,100	24,260	99,130	11,550	44,630	39,120	150,230
1975	61,970	114,400	35,570	131,320	31,790	91,500	97,540	245,720
Average	45,940	100,730	38,490	150,300	25,065	87,860	84,430	251,030
Percent of Annual	54	40	46	60	30	35	100	100
Average Concentration During Period		1,612		2,871		2,577		2,186
Average Monthly Discharge per Period	11,490		4,811		6,270		7,040	
Average Monthly Salt Load per Period		25,180		18,790		21,970		20,920

1/ Spring runoff period used is April, May, June, and July.

2/ Base flow period is remainder of the year.

3/ Irrigation return flow period is July, August, September, and October.

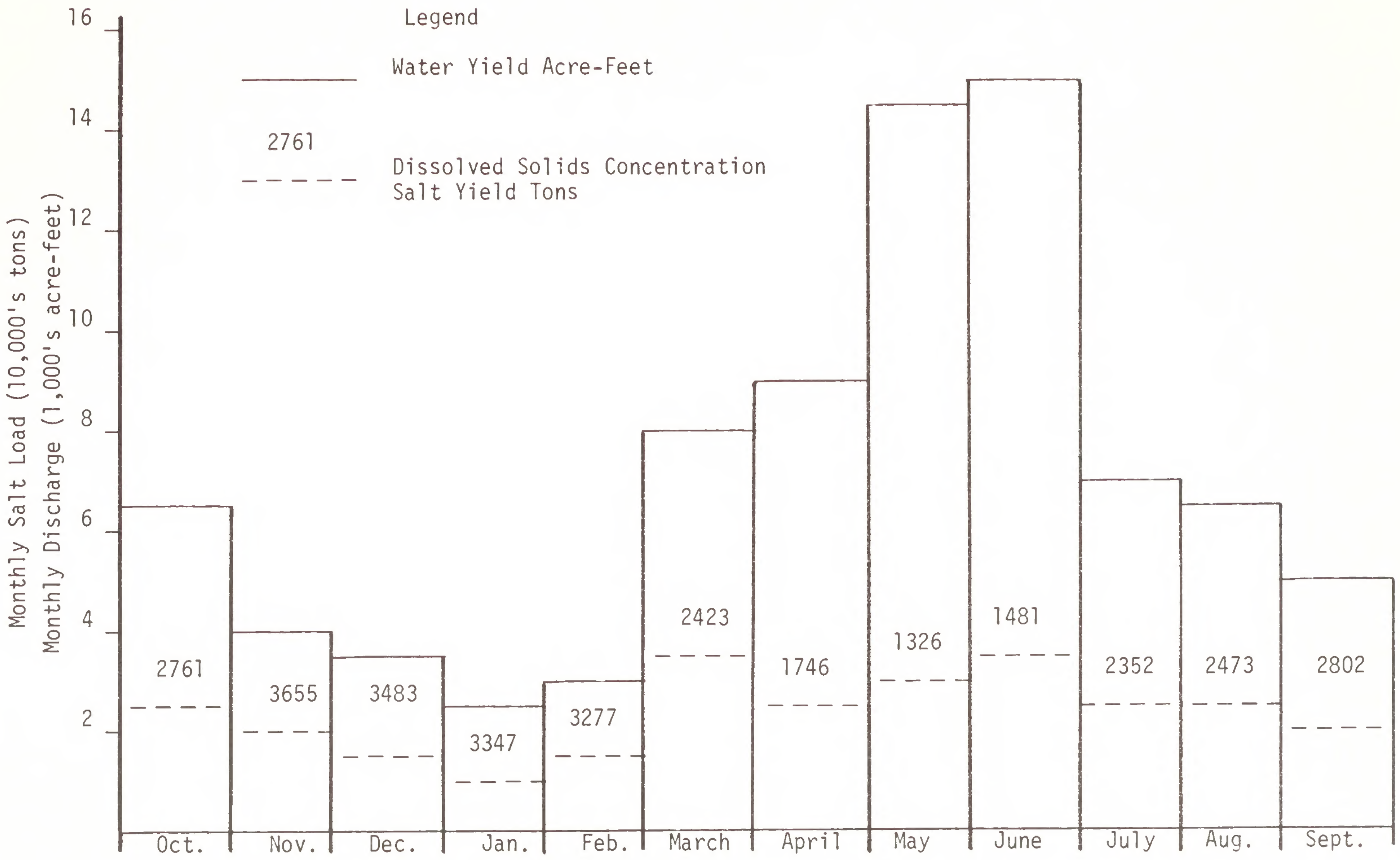


Figure IV-12. Average monthly discharge and salt load for Price River at Woodside, Utah for 1966-1975.

Table IV-12. Calculation of Total Runoff and Salinity Tonnage Based on Total Dissolved Solids Shown in Figure IV-13.

Period	Time Increment	Discharge		Salinity	
No.	Min.	Average (cfs)	ac-ft	Concentration[1/] (mg/l)	Salt Load (tons)
1	20	3	0.083	260	0.029
2	10	12.5	0.172	320	0.075
3	10	25	0.344	400	0.187
4	10	28.5	0.392	580	0.310
5	10	24	0.331	690	0.310
6	10	14	0.193	720	0.190
7	10	12.5	0.172	680	0.159
8	20	4.5	0.124	560	0.094
9	20	2.6	0.072	660	0.064
10	20	1.3	0.036	1030	0.050
11	20	0.4	0.011	1060	0.016
Total			1.95	560[2/]	1.48[3/]

[1/] Concentration of total dissolved solids in milligrams per liter (mg/l) was obtained by multiplying field measured specific conductance readings by 0.65.

[2/] Average dissolved solids concentration for runoff event based on total salt load and discharge.

[3/] The salt load would be 2.2 tons if a correlation factor of 0.95 was used instead of the 0.65.

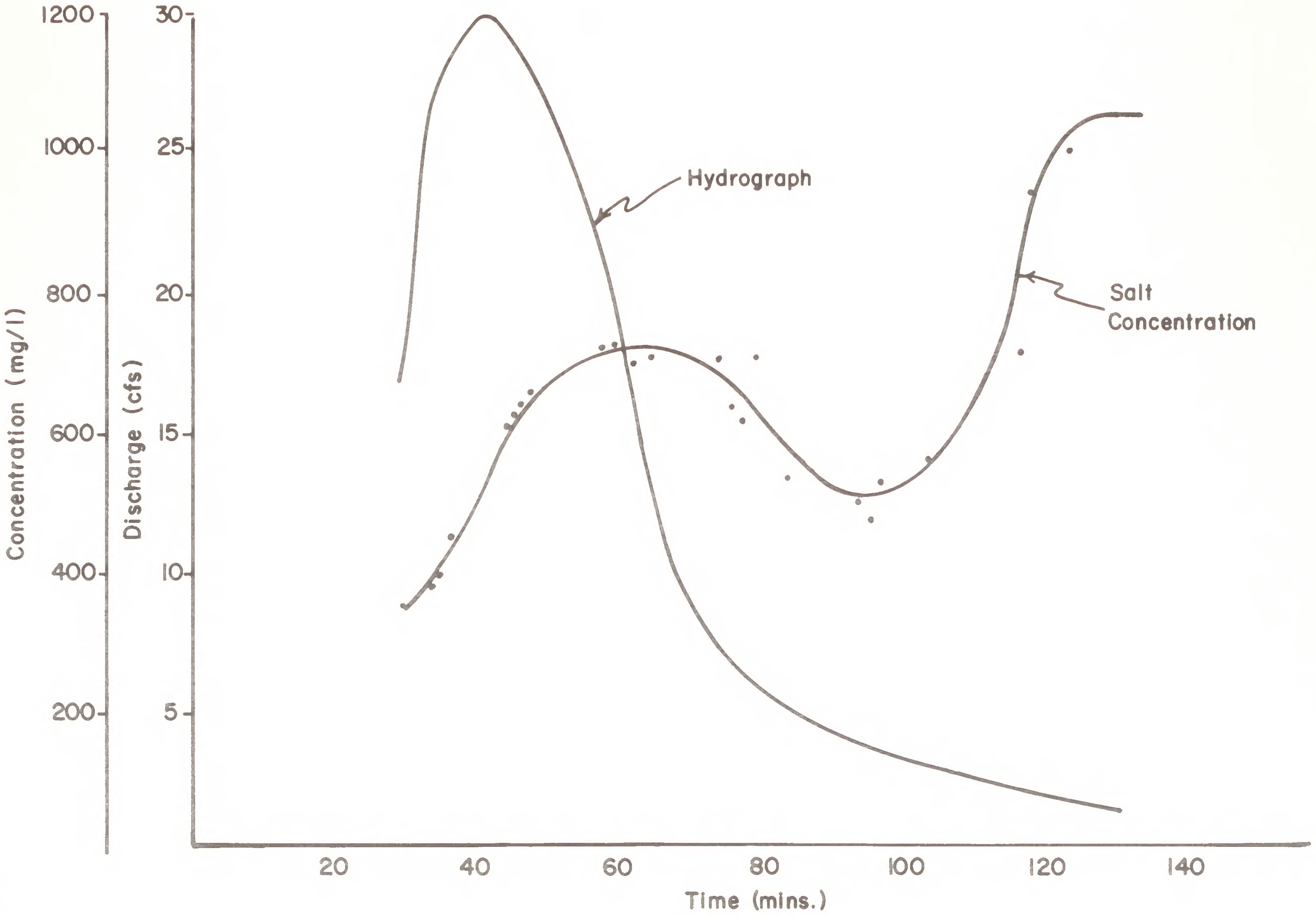


Figure IV-13. Runoff Hydrograph and Associated Salt Concentration for a Runoff Event from Mancos Shale-Derived Soils, 5/26/77.

The GS has collected runoff data from the Saleratus and Browns Washes near Green River, Utah. The runoff data is summarized in Table IV-13 with associated salt yields. The salt yield was determined from water quality data compiled by Iorns et al (102), Utah State University (154, 217, 218), GS, and BLM. The salt yield ranges from 24 to 40 tons of salt per square mile, depending on water yield and salinity concentration. This is representative of runoff from Mancos Shale-derived soils with desert shrub vegetation and would average approximately 30 tons per square mile. Runoff from areas with less soil salinity and higher precipitation would contain lower concentrations of salt.

c. Salt Load from Public Lands

It is difficult to separate the salinity resulting from the use of water by man from that which occurs naturally. The primary man-caused salt load in the Upper Basin is from irrigation. It has two major impacts on salinity. Increases in salt result from (1) consumptive water use which tends to increase the salt concentration without changing the salt load, and (2) groundwater return flow which leaches salts from the subsoil and carries it to streams or regional groundwater. The latter is a phenomenon especially evident when irrigation occurs on moderately saline soils. The EPA (51) found this salt-loading ranged from as little as one-tenth of a ton to as much as 8.5 tons per acre per year. Figure IV-14 shows the range of salt pickup for irrigated areas in the Colorado River Basin. It is impossible to quantify salt production from public lands directly from published data because rangelands and farmlands are often intermixed. Also, gaging stations are not located so that salt contributions from these lands can be isolated.

The EPA (53) estimates average percentages of total salt load originating in the Upper Basin from the following sources as: net runoff from natural lands, 52 percent; irrigated agriculture, 37 percent; natural point sources, 9 percent; and municipal and industrial, 2 percent (see Figure IV-15). Runoff from natural sources (diffuse and unidentified point sources) includes national forests, public lands, national parks, Indian lands, and private and state rangeland. The EPA also estimates that 72 percent of the salinity affecting the Lower Basin is inflow from the Upper Basin (53). Only 4 percent of the total salt load in the Lower Basin is produced by runoff from natural diffuse sources. Figure IV-15 is based on two different 1-year periods, one for each of the Upper and Lower Basins. The salt load varies from year to year depending on streamflow and other hydrologic conditions.

The BLM found large variations in water quality of perennial and ephemeral streams in the Upper Basin, while trying to better quantify salt concentrations and yields from public lands. The concentration of salts in streams originating from groundwater on public lands ranged from approximately 3,000 to 5,000 mg/l, while concentrations of salt in surface water ranged from only 500 to 2,000 mg/l.

Table IV-13. Water and Salt Yields for Saleratus and Browns Washes near Green River, Utah

	Saleratus Wash (1949-70) Watershed Area = 180 sq. mi.			Browns Wash (1949-65) Watershed Area = 75 sq. mi.		
Month	Average Discharge (cfs)	Salt Load1/ (tons)	Salt Load2/ (tons)	Average Discharge (cfs)	Salt Load1/ (tons)	Salt Load2/ (tons)
October	5.8	727	970	6.18	775	1,030
November	2.27	276	366	1.18	143	190
December	0.22	28	37	0.002	0	0
January	0.28	35	47	0.08	10	13
February	0.35	40	53	0.29	33	44
March	0.27	34	45	0.13	16	22
April	0.16	19	26	0.11	13	18
May	1.17	147	195	0.22	28	37
June	5.23	635	844	0.22	27	36
July	5.04	632	841	1.46	183	243
August	8.97	1,125	1,496	4.66	585	778
September	5.33	647	860	3.68	447	594
Total	35.09 cfs	4,345	5,777	18.22 cfs	2,260	3,005
	2,116 ac-ft			1,099 ac-ft		
Yield per sq. mi.	11.75 ac-ft	24	32	14.65 ac-ft	30	40
Yield per acre	0.22 in.	0.038	0.05	0.27 in.	0.047	0.063

1/ Salt load is based on an average concentration of 1,500 mg/l concentration.

2/ Salt load is based on an average concentration of 2,000 mg/l concentration.

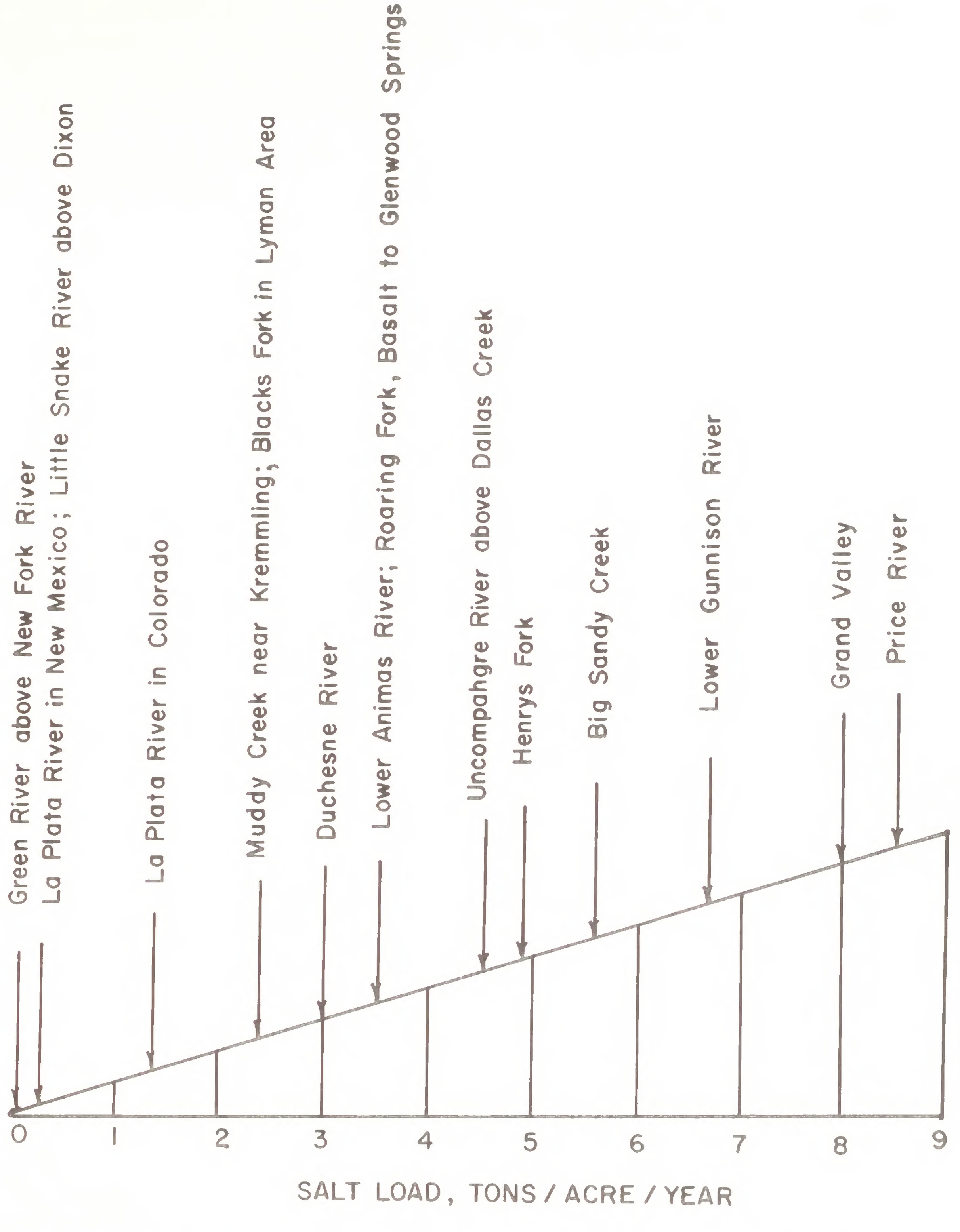


Figure IV-14. Observed Range of Salt Yields from Irrigated Areas in the Upper Colorado River Basin

Adapted from "The Mineral Quality Problems in the Colorado River Basin," Appendix A, Environmental Protection Agency, 1971 (51)

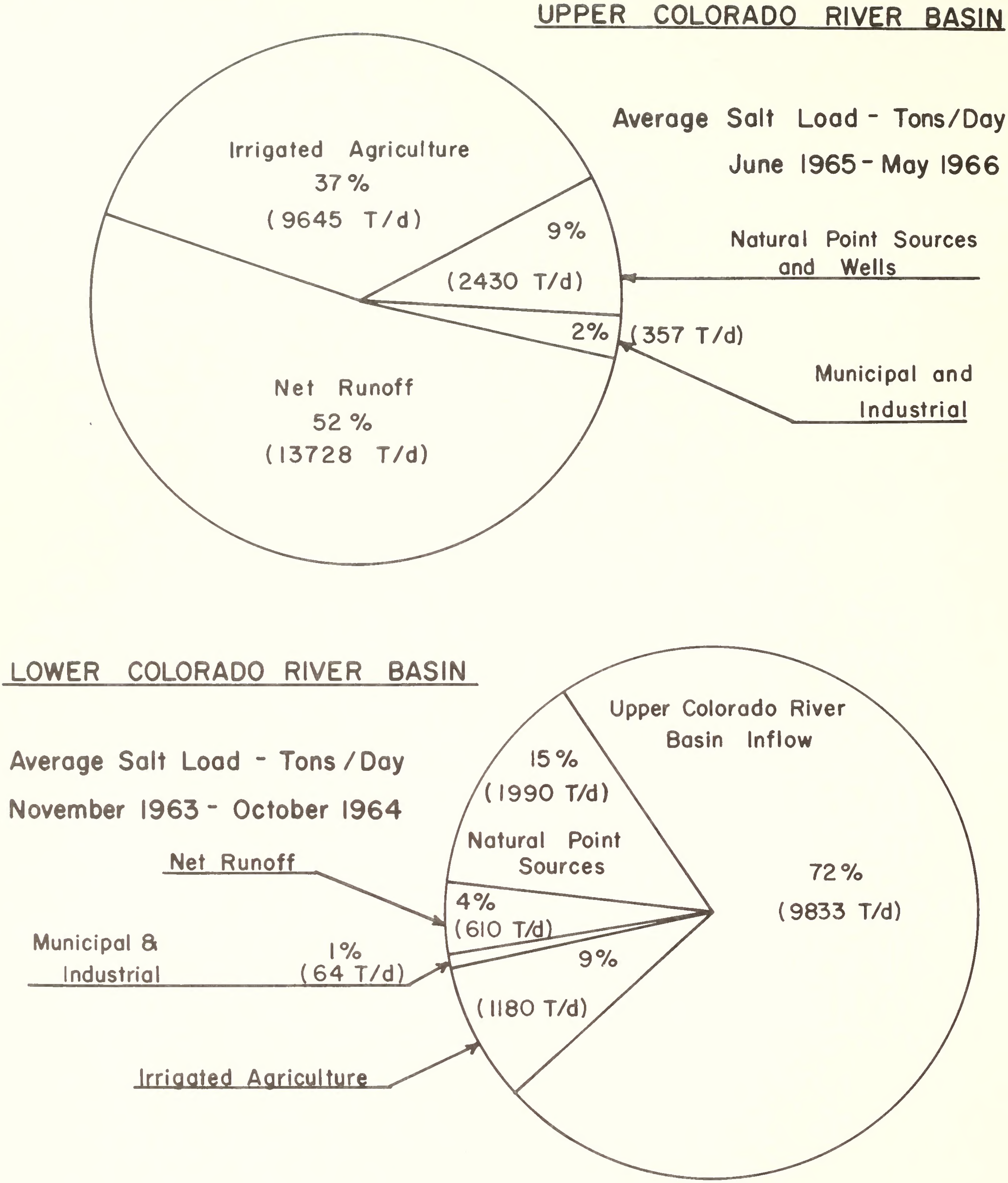


Figure IV-15. Relative Magnitude of Salt Sources in the Colorado River Basin

Adapted from "The Mineral Quality Problem in the Colorado River Basin," Appendix A, Environmental Protection Agency, 1971 (51)

Low flows originating on public lands are primarily from underground sources--such as springs, seeps, and subsurface channel flow--which may surface at isolated points in the channel. The discharge rate is low, E.C. (salinity) relatively high, while the water is generally clear and has a significantly higher sodium content. Underground sources of sodium in marine shales are nearly unlimited.

Low flow often results in evaporites (salt deposits) along stream channels which are picked up during periods of high flow, causing a large increase in salt concentrations. High flow also erodes stream channels, where additional salt is picked up from unleached sediment deeper in the soil profile.

A breakdown showing salt loading from natural lands, by ownership, should be prepared for each river basin or watershed area. An estimate for the Price River drainage is developed below.

While quantifying salinity from natural lands, Ponce (154) found that surface runoff from Mancos Shale yields water of relatively good quality, with average concentrations of approximately 300 mg/l of dissolved solids. It was estimated that approximately 0.5 percent of the salinity of the Price River Basin originates from overland flow. Following this, White (217) found that micro-channels contributed as much as a sevenfold increase in salinity when a quasiequilibrium was reached, and that a flow distance of from 800 to 1,000 feet was required for the quasiequilibrium condition to exist. The distance is related to the chemical and physical properties of the soil and the solubility of the salt-producing compounds. White (217) estimates that micro-channels produce about 3.5 percent of the total salt load of the Price River at Woodside. The estimate of Ponce (154) and White (217) make a combined contribution of 4 percent of the Price River salt load from overland flow. Any additional salt yields would be picked up in major channels and in transported sediment. Laronne (117) concluded that significant quantities of salt would not be released from the sediment until it was discharged into a stream such as the Green River, with lower salinity concentrations.

BLM has estimated salinity yields for two grazing allotments[1/] in the Price River Basin which are representative of highly saline public lands. These yields are based on runoff and sediment production, as shown in Appendix XII-1. The salt yield averages 30 tons per acre, and when extrapolated to the 1,000 square miles downstream from Castlegate, Utah account for 30,000 tons annually. This includes runoff from private as well as public lands and constitutes about 11 percent of the average annual Price River yield shown in Table IV-5.

[1/] A grazing allotment is an area of rangeland allotted for the exclusive use of one or more ranchers and is usually fenced separate from adjoining allotments.

A water balance was developed for the Price River between the confluence with Willow Creek and the GS stream gage at Woodside, Utah. The watershed comprises an area of approximately 1,000 square miles. This analysis is an attempt to isolate runoff yields from an area of rangeland, predominantly composed of Mancos-derived soils, from an area containing some high elevation forested lands, from irrigated farmlands and from residential areas. The analysis utilizes the following water budget.

Outflow = Inflow + Imports - CU + X

where:

Outflow = average annual outflow at Woodside

Inflow = inflow at Heiner, Utah

CU = consumptive use of water by 18,000 acres of irrigated crops as given by the GS at the Woodside gage and is assumed to be 2 acre-feet per acre based on data obtained from the BR. The CU is based on use of the Blaney-Criddle equation, applied at Castle Dale.

Imports = water imported from Huntington Creek in excess of CU required to irrigate 7,000 acres at an efficiency of 50 percent

X = unknown runoff from 1,000 square miles

Table IV-14 summarizes results of the water budget analysis using data from two separate periods.

Table IV-14. Summary of Water Budget Analysis for the Price River Below Willow Creek

	1947-57	1964-67
Inflow (acre-feet)	83,800	74,300
Import (acre-feet)	14,000	14,000
CU (acre-feet)	36,000	36,000
Outflow (acre-feet)	72,800	69,600
Estimated Runoff, X (acre-feet)	11,000	17,300
Yield in inches/square mile	0.2	0.3

The estimated average annual water yield for the watershed is from 0.2 to 0.3 inches per square mile. This estimate is in agreement with the yields from Saleratus and Browns Washes, shown in Table IV-13. This includes natural groundwater inflow, which will be small from public lands, since much of the time Saleratus and Browns Washes are dry.

The EPA (51) reports that about 212,000 tons of salt were produced by irrigation in 1965-66 out of a total basin outflow of 323,000 tons. It attributes natural runoff as contributing 69,000 tons. Data collected for this study would indicate the water quality at Heiner to be about 440 mg/l, while Vaughn Hansen Associates (203) in 208 studies for the Price area found that concentration ranged from 370 to 760 mg/l. Using the inflow at Heiner as 83,000 acre-feet and a concentration of 400 mg/l, the Price River above the irrigated lands would yield a total salt inflow of 45,000 tons. Using EPA's 1965-66 estimate of the contribution of salts from irrigation, about 24,000 tons of salt inflow by surface runoff from natural rangelands can be assumed for the area downstream of farmlands.

Data collected by the BLM indicate runoff contributed by storms and snowmelt would have a concentration of 2,000 mg/l or less. Using this concentration, the salt yield would be approximately 30,000 tons, which is in close agreement with the 1965-66 EPA data and the data on Saleratus and Browns Washes. This would give an average annual yield of 30 tons per square mile, which is probably representative of most high salt-producing watersheds on public lands.

The exercise outlined above shows the need for detailed data collection and analysis to better describe and quantify salt yield from specific areas. Analysis of data at Woodside, Utah in conjunction with the data developed above, would indicate that during periods of below normal runoff, salt is being stored in the basin to be flushed out during periods of high runoff. A strong inverse relationship normally exists between discharge and concentration in perennial streams, as exhibited by the Eagle River in Figure IV-11. However, this relationship is nearly absent in the Price River at Woodside, since some of the higher flows also have high salt concentrations (see Figure IV-12). Data published by Iorns et al (102) show an average monthly flow of 70 cfs with a concentration of 3,230 mg/l during July 1951 and 314 cfs with 3,290 during the following August. The variation and lack of correlation is even more dramatic when daily discharge is considered. The concentration is a function of the origin of runoff, the amount of streamflow diverted for irrigation, and the amount of return flow.

d. Impacts on Salt Concentration at Imperial Dam

Results of salinity control are best measured at Imperial Dam in the Lower Colorado River since the benefits of salinity reductions are a function of concentration at this point. Impact of salinity control in the Upper Basin must be translated into a change in concentration in mg/l of TDS at Imperial Dam. The change is a function of the salt and water maintained on-site (withheld from entering the stream system).

The impact at Imperial Dam was determined from data contained in the 1977 U.S.D.I. progress report number 8 (199). The data on water discharge and concentrations for 1980 conditions at measuring points above Parker, below Parker, and at Imperial Dam, were used to develop an estimate of pre-project conditions. The following assumptions were made in order to predict project impacts: (1) water withdrawal for salinity control is subtracted from inflow to Parker, (2) salt removed is subtracted from salt inflow to Parker, (3) the salt concentration of water released from Parker is equal to the inflow concentration, (4) discharge from Parker and at Imperial would remain constant due to water delivery constraints, and (5) changes in tons of salt at Parker would be reflected in the salt load at Imperial Dam.

Sample calculations showing pre-project and post-project conditions are summarized in Table IV-15. A depletion of 20,000 acre-feet of water, with a concentration of 2,000 mg/l, would result in a reduction of 2.96 mg/l of salt at Imperial.

Table IV-15. Summary of Calculations Showing Impact of Water and Salt Removed From the Colorado River Basin.

	Pre-project Conditions *			Project Impact *		
	Flow (Ac-Ft)	Salt (Tons)	Concentration	Flow (Ac-Ft)	Salt (Tons)	Concentration
Above Parker	9,375,000	10,106,000	792.627	9,355,000	10,051,600	790.046
Below Parker	8,232,000	8,874,000	792.627	8,232,000	8,844,980	790.046
At Imperial	7,208,000	9,194,000	937.888	7,208,000	9,164,980	934.92

* Based on 1980 Colorado River salinity conditions

Salinity Change = 937.888 - 934.92 = 2.96 mg/l reduction due to the project

The curve presented in Figure IV-16 was developed to assist in determining the effect of water, with different concentration of salts, upon the concentration of salts in the Colorado River at Imperial Dam. Total impact of a treatment project is obtained by multiplying the value obtained from Figure IV-16, by the ratio of water yielded from the project to a base of 10,000 acre-feet.

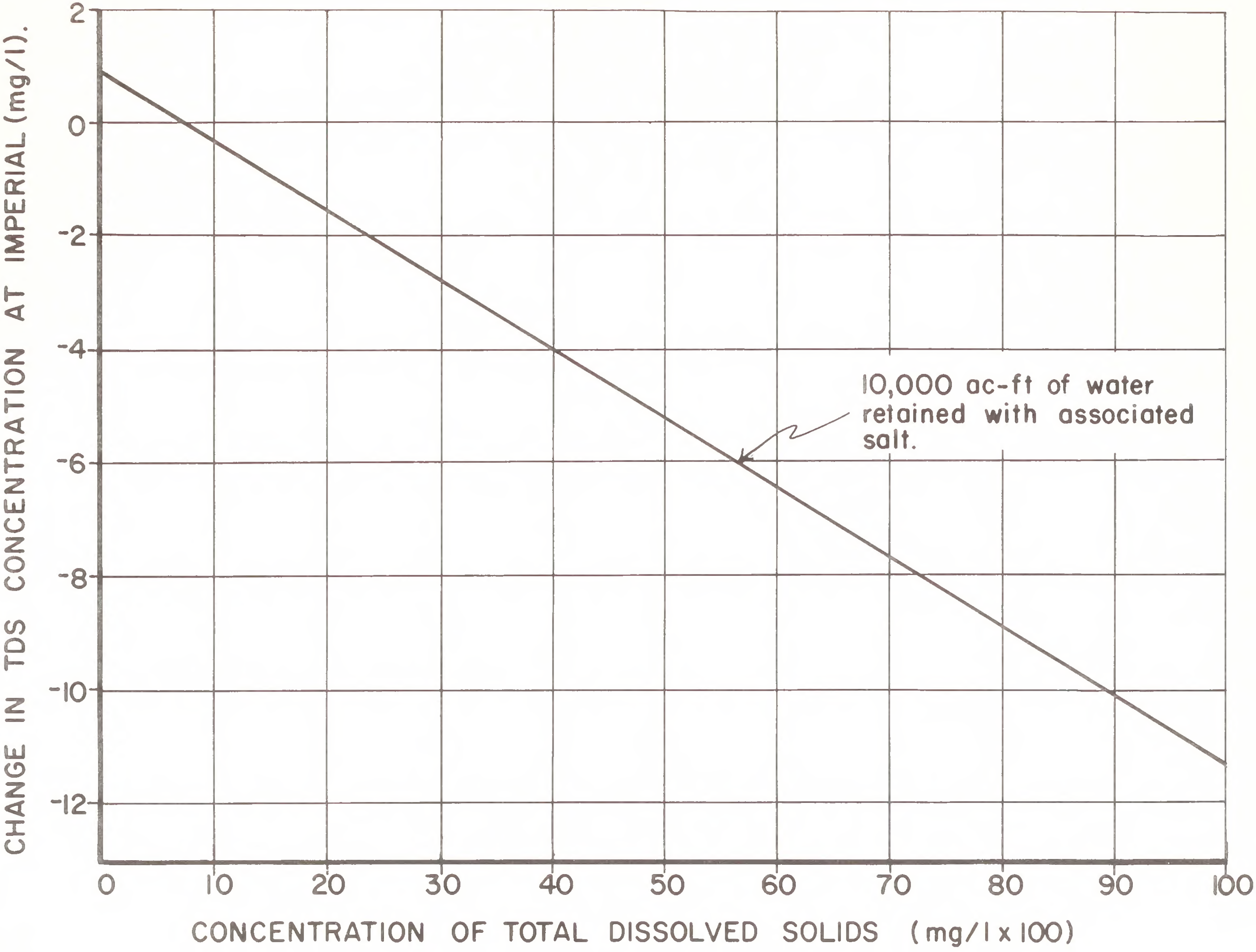


Figure IV-16. Impact upon Salt Concentration at Imperial Dam Resulting from Retaining Water On-site, Using Expected 1980 Salinity Conditions (199).

The following equation can be used for projects that remove salt without consuming water.

$$\text{Salinity Change (mg/l)} = \frac{\text{Tons of Salt Removed}}{10{,}000} \times 0.909$$

However, the concentration of salts in the river at Imperial Dam would be increased if water having a lower concentration is kept on-site (the 1974 present modified conditions at Imperial Dam is 861 mg/l (199)). For example, if 20,000 acre-feet of water with a salt concentration of 500 mg/l is retained on-site, the salinity concentration would be increased by 0.7 mg/l. This result can be seen in Figure IV-16.

e. Summary

Knowledge of the basic environmental factors affecting salinity is fundamental to efforts to control the problem. Salinity of public lands is related to the marine geologic formations and derived soils containing salts, erosional processes related to climatic fluctuations, and the amount of vegetation protecting soils from runoff. The runoff provides a medium for salt and sediment transport and is a function of the amount and intensity of precipitation. Salts are dissolved from the soil surface by runoff, from evaporites in channels, and absorbed from sediment particles being transported in channel flow. Groundwater from saline geologic formations was found to contain salts in concentrations two to five times greater than in surface discharges.

Salt yield was estimated on six typical allotments in the Upper Colorado River Basin. Three allotments represent 3 million acres of highly saline lands, two allotments represent nearly 6 million acres of moderately saline lands, and one represents 18 million acres of nonsaline to slightly saline lands. The total salt yield is approximately 700,000 tons contributed by surface runoff from overland flow. This is nearly 8 percent of the Upper Basin yield measured at Lees Ferry, Arizona. It should be noted this estimate does not include groundwater contributions to the salt load.

B. Land Use

1. Grazing and its Influence on Vegetation, Infiltration, Runoff, and Sedimentation

a. Vegetation

Gifford (68) states "There is little doubt that grazing has an impact on hydrologic behavior of rangeland . . . magnitude and duration of that impact is a reflection of the intensity and management of the grazing activity." Studies of Great Plains rangelands during the severe droughts of 1933-39 and 1952-55 show that grasslands weakened by overgrazing are extremely sensitive to prolonged periods of deficient soil moisture. During these droughts, loss of vegetative cover on heavily grazed ranges averaged nearly double that occurring on moderately grazed ranges, and more than double the losses occurring on ungrazed ranges (1). Gardner (61) found that long-term protection from grazing in a desert grassland resulted in a doubling of the grass cover and greatly improved watershed condition. Gullies were healing in the protected area, while gullies in the heavily grazed area were raw and eroding. Following a 2-year drought in 1947-48 vegetation losses on both sites were severe. However, total vegetative cover on the protected area was still 62 percent greater than that on the grazed area.

Many rangelands in the west are in only poor or fair condition as a result of a long history of overgrazing (133, 151, 184). Drought is also a factor, especially when grazing persists during dry years, a practice which compounds the problem. Chapline (35) states that in the arid southwest, droughts may occur in 3 or 4 consecutive years out of a period of 8 or 10 years and that droughts in the semiarid southwest, intermountain region, and southern Great Plains are almost as frequent. Smith (180) recognized very early the need to stock rangeland at the maximum number of cattle which could be supported during a "poor" season. The most disastrous mistake made by cattlemen was overstocking. Hickey (93) in a discussion of modern grazing management states that proper stocking rate should be the first item to be considered in developing management systems. Knoll and Hopkins (115) found during the third driest year on record, grasses on a heavily grazed pasture showed definite signs of moisture stress late in June, while grasses on a moderately grazed pasture showed only slight evidence of stress, and plants in an ungrazed exclosure showed no moisture stress.

Paulsen (151) quotes the belief held among most range managers that use of individual forage plants in excess of 40 percent is considered to be detrimental. Martin (133) believes that yearlong grazing is not detrimental on semidesert ranges if utilization of forage does not exceed 40 percent. However, the main deficiency of this practice is the inherent uneven distribution of livestock and utilization of forage. Martin reports that the only successful grazing systems are those which include relatively long rest periods. These are usually one-third to two-thirds of the total grazing period, especially including the spring and summer growing seasons.

Studies since 1934 on the Desert Range Experiment Station (West Central Utah) have shown that some grazing treatments result in a downward trend in range condition (49, 80, 96, 98, 99). Briefly, these studies indicate that grazing at any intensity during late winter-early spring (March-April) is harmful to desirable plants and results in an increase of less useful species (annual forbs), and that ranges can be improved (herbage production increased) when grazed under a moderate stocking rate during early and mid-winter. According to Holmgren and Hutchings (96) the salt desert is a winter range. It serves as a "holding area" for maintenance of breeding or gestating livestock. The salt desert is primarily a browse range, and shrubs and half-shrubs provide most of the feed for livestock, mainly sheep. Spring grazing is detrimental to plants in the arid desert, because of the lack of dependable soil moisture for herbage production and recovery after grazing.

Spring grazing has been especially harmful to cool season grasses in the juniper-pinyon woodland. Important species such as muttongrass, western wheatgrass, and bottlebrush squirreltail (Sitanion hystrix) have disappeared from many woodland sites (151). Springfield (184) indicates grazing systems on juniper-pinyon woodlands should be designed to include rest for both cool and warm season grasses. These would occur during the growing period for 1 to 3 years to improve range condition. Currie (41) recommends that livestock removal of the current year's growth of forage not exceed 35 percent on flat open areas and gentle slopes on ponderosa pine-bunchgrass ranges. This statement implies that steep or densely-timbered areas should not be grazed. Further, it was reported that the removal of about 50 percent of all herbage will subject soils of the pine type to accelerated erosion.

Marquiss and Lang (131) made a study of two relict (ungrazed) areas on shallow soil sites in Sweetwater County, Wyoming, and similar adjacent grazed areas. It was found that grazing had caused a shift in species composition and percent ground cover. Grazed areas had a greater number of forb species, shrub ground cover had increased, and grass cover was reduced. Results of several years of study on the same sites showed climatic fluctuations resulted in proportional changes for species composition and ground cover. However, variations were greatest on grazed areas. Relict areas were less affected by changes in amount of rainfall. Soil analysis showed that only slight differences in soil properties existed between sites.

Baxter (8), studying a relict juniper woodland covered mesa found that the ungrazed area had only 8 percent bare ground, as opposed to 65 percent on a continuous grazing range, and 25 percent on a rest rotation grazing range. The relict area contained 60 percent cool season grasses (desirable) in the species composition as opposed to 35 percent on the rest rotation grazing range, and zero on the continuous grazing range. Baxter (8) states that depleted ranges will never have the potential of producing at the level of the mesa because too much top soil has been lost, soil fertility reduced, a seed source no longer remains, and soils have become compacted. However, ranges can be improved over existing conditions. "The longer the woodland continues to be abused, the lower its potential will be and the longer it will take to reach that potential."

Hickey and Garcia (94) report that range deterioration was halted and increases in ground cover of desirable grasses resulted when yearlong grazing was changed to a summer deferment system. Aldon and Garcia (3) found that bare ground decreased from 78 percent to 58 percent; runoff remained constant, and sediment production decreased by 71 percent when grazing was changed from yearlong to a summer deferred system and a maximum forage utilization on the key forage species, alkali sacaton (Sporobolus airoides), was established at 55 percent. Perennial grass production increased from 73 pounds/acre in 1956 to a high of 721 pounds in 1969. Sediment reduction can be attributed to a reduction in floodwater velocities caused by increased plant size and numbers, and a 300 percent increase in litter (2).

Research data collected at the 9,000 to 10,000 foot elevations on the Wasatch Mountains, Utah--and at somewhat lower elevations on the Boise River watersheds in Idaho--show the percent of total ground cover including live vegetation and litter, and the maximum size of bare soil openings are directly related to the amount of water retained on-site and total runoff. Packer (146) suggested that management of bluebunch wheatgrass ranges on slopes from 33 to 66 percent, should strive to maintain a cover of at least 70 percent with bare openings of 4 inches or less. Marston (132) suggested at least 65 percent cover as a minimum to protect high mountain ranges in Utah. Packer (149) found that erosion on Montana elk ranges increased rapidly as ground cover decreased below 70 percent.

Studies by Potter and Krenetsky (155) of grazed areas and adjacent exclosures in New Mexico over a 25-year period from 1939 to 1964 yield several interesting effects of rest from grazing on six diverse plant communities. These included desert grassland, grassland, sagebrush, juniper-pinyon, ponderosa pine, and fire climax on a mixed conifer site dominated by an overstory of aspen. Data showed several benefits from nongrazing, including increased grass cover; stand composition containing a greater percentage of higher order plants in the successional stage; a greater variety of species; and reduction of noxious plants. The studies also indicated that management of livestock had improved over the years. Increases in plant cover were found on both grazed and ungrazed sites; however, increases were greater on the protected sites. In the case of the aspen sites, grasses doubled under grazing but increased twenty-twofold under nongrazing. Total percent ground cover on the two sites was similar because of a tenfold increase in common juniper (Juniperus communis).

b. Infiltration

Dee et al (42) found that infiltration rate was influenced by the stage in the successional development of plants. Rhodes et al (167) found after 20 years of grazing that infiltration rate was inversely proportional to grazing intensity. Rauzi and Smith (163) found infiltration rates on a sandy loam soil during the first 15 minutes of simulated rainfall were significantly higher on lightly and moderately-grazed pastures than for the heavily-grazed pasture. Infiltration increased slightly after 25 minutes on the lightly and moderately-grazed pastures but continued to decrease on the heavily-grazed pasture.

In further support, work by Rauzi (159) found that ranges in "high" (presumably good to excellent) condition had water intake rates three times higher than ranges in "low" (presumably poor to fair) condition. The increases were attributed to greater standing vegetation and mulch and decreased bare soil. Work by Rauzi (160) showed increases in grazing from ungrazed to moderate to heavy grazing reduced infiltration by 1.6 times. Similarly, Sharp et al (175) found that runoff from heavily-grazed pastures was 10 times greater than from lightly-grazed pastures and 1.5 times more than that measured from moderately-grazed pastures.

Infiltration studies on the semiarid Walnut Gulch watershed in southeastern Arizona by Kincaid et al (110), have shown that water penetration time decreased (infiltration increased) linearly with an increase in the percentage of gravel (erosion pavement) in the soil crust. A rise in infiltration rate also accompanied an increase in the ground cover of all plants, including shrubs and half-shrubs. A good correlation with litter was not found because of the small amounts present; however, litter did improve the correlations of plant cover and erosion pavement combined. The importance of erosion pavement was theorized to decrease as plant cover increased. Tromble (194) reported later that these findings were still valid.

Meeuwig (137, 138) also reported on the importance of plants and litter in increasing water retention of soils. It was found that erosion was also correlated with the content of organic matter in the soil as well as plant and litter cover. The fibrous litter provided by grasses was superior to that of broadleaf herbs in protecting the soil because it remained intact longer. Knoll and Hopkins (115) also found mulch to be important in preventing destruction of soil structure by raindrops. Heavy grazing resulted in a twenty-sixfold reduction in litter from ungrazed sites, while moderate grazing reduced litter only 2.6 times over the ungrazed areas.

Juniper-pinyon woodlands and chained areas in southeastern Utah, which had been rested from grazing for approximately 5 years, had significantly higher infiltration rates than areas being grazed. Chained areas recovered more slowly than woodland sites. A trend toward increased erosion was found on grazed areas (23). Gifford and Busby (70) found that grazing on big sagebrush sites converted to seeded grass eliminated normal seasonal trends in infiltration rates so that they were " . . . at the low end of the scale throughout the year." Under conditions existing previous to sagebrush removal by plowing and grazing, infiltration rates were highest during the spring and then decreased during the summer following thundershowers. Buckhouse and Gifford (22) found that under the stocking rate used on test sites, impact of trampling by grazing animals was sufficient to "significantly depress the infiltration process." Infiltration rates on the grazed sites decreased significantly ". . . at certain time intervals within the 28-minute simulated rainstorm, . . ." as compared to the ungrazed site.

On porous granitic soils in central Arizona, Rich and Reynolds (169) found that destructive grazing did not produce additional runoff. However, it was stated that moderate use at a level of 40 percent of perennial grass production did provide sufficient cover to maintain a stable soil. Johnston (107) found that heavy livestock use of grasslands on rolling hills in southwestern Alberta did not decrease water intake of soils where range condition was still considered to be fair. However, very heavy grazing did decrease infiltration and greatly increase soil loss. Heavy and very heavy grazing did cause a decrease in soil moisture, especially in the first 12 inches, and an increase in soil temperature at the 8-inch depth. Buckhouse and Coltharp (21) found that foliage removal, by clipping at an extreme level, resulted in a significant decrease in soil moisture depletion. However, compaction by livestock, a characteristic of heavy grazing, would not have been a factor. Clipping at a moderate or light level caused no significant change in soil moisture patterns.

c. Compaction and Bulk Density as They Relate to Runoff and Sedimentation

Smeins (179) stated that trampling by livestock ". . . can disturb the soil surface, cause compaction, and destroy not only aboveground but also underground portions of plants. Through time this can reduce the amount and vigor of the vegetation and increase potential for runoff and erosion." Rhodes et al (167) found that bulk density of the soil was greater on grazed sites to a depth of 3 feet than on nongrazed sites. The heavy stocking rate had the highest soil bulk density of all treatments. Orr (145) found that grazing compacted soils to a depth of 4 inches; the most significant increases in bulk density occurred in the 0-2 inch soil layer. Zander (226) reported that the effects of compaction diminished with soil depth and disappeared at a depth of approximately 16 inches.

Knoll and Hopkins (115) found that bulk density was 1.08 grams/cubic centimeter (g/cc) on ungrazed, 1.17 g/cc on moderately grazed, and 1.27 g/cc on heavily grazed areas. This was translated into infiltration rates of 2.58 inches on ungrazed, 2.08 on moderately, and 1.58 inches on heavily grazed areas. Soil aggregates also were relatively unstable under both levels of grazing. Lull (122) agrees that trampling destroys soil aggregates. Read (164) found that heavily-grazed areas had 46 percent less large pore space than protected areas, a significant factor in water intake into the soil.

Bulk density and percent of ground cover were highly correlated with grazing intensity on Montana elk ranges. Pristine areas had bulk densities averaging 0.72 g/cc while grazed ranges had densities of 1.32 g/cc. Ground cover of vegetation and litter was highly correlated with bulk density and erosion. Ground cover on the pristine areas was 97.5 percent and 33 percent on the grazed areas. Erosion increased slowly as bulk density increased from 0.70 to 1.10 g/cc, but it accelerated rapidly with further increases in bulk density (149). Packer (148) quoting research done in the Wasatch Mountains of Utah, states that during an applied rainfall of 3 inches, sediment yields increased as bulk density increased, irrespective of ground cover.

Rauzi et al (161) state that "Generally, . . . rangelands with comparable soil texture in good or excellent range condition have a crumbly or granular surface structure conducive to a high rate of water intake; while ranges in poor or fair condition have a platy or dispersed soil surface with correspondingly slower water intake." Tromble (194) found removal of vegetation by heavy grazing allowed raindrop impact on bare soil to increase. This resulted in the sealing of the soil surface and reduced infiltration. Rauzi et al (161) also reported that differences in infiltration rates were usually traced to " . . . good or poor soil structure related to recent history of grazing use."

Packer (147) found that artificially-applied trampling treatments using a "steel hoof" caused decreases in ground cover of plants and litter. Trampling effects were translated into percent of disturbance. On areas where ground cover was as high as 85 percent, a disturbance (trampling) of 20 percent caused no increases in erosion, but 40 and 60 percent disturbance did increase erosion. On areas with 70 to 75 percent ground cover, all but the 10 percent level of disturbance caused accelerated runoff and sediment yields. These data suggest that trampling and soil disturbance by livestock cause accelerated runoff and erosion on high mountain ranges, where ground cover is less than 75 percent, irrespective of the degree of disturbance. Packer suggests that ranges with ground cover below 70 percent should be only lightly grazed. Any criticism of the artificial nature of trampling and rainfall application should be tempered by the fact that no vegetation was consumed (removed from the sites). Aerial plant parts destroyed by trampling were left on the ground as litter, adding somewhat to the protective cover (147).

Schumm and Lusby (173) observed several aspects of soil characteristics on steep to moderately steep slopes, affected by season. These were soils derived from the Mancos Formation in western Colorado. Crown cover of living plants was 8 to 15 percent. As a result of frost heaving, the soil surface was loosened, forming a friable, highly permeable aggregate material (see Figure IV-17). All trace of rills formed by erosion during summer thundershowers was obliterated. However, during the summer rainfall, the edges of the aggregates were destroyed as fine soil particles were washed into interspaces between the aggregates, partly closing them. A crust also formed on the outer surface of the aggregates. Lusby et al (129) found that larger cracks formed in the soil in addition to the friable surface. These cracks formed as the montmorillonitic soils dried (see Figure IV-7). On the grazed watersheds, these cracks were destroyed by livestock trampling. Turner (197) observed that the friable "waffle-like" soil surface covered small rocks creating a partial erosion pavement. This loose soil was washed away by summer rains so that the pebbles reappeared in the late fall. Infiltration was maximum during the spring and decreased as summer progressed. During the fall, runoff greatly exceeded spring runoff. The ratio of runoff to rainfall on hill slopes also increased from spring to fall (173).

Figure IV-17. Typical Open, Friable Surface on Mancos Shale-Derived Soil Following Winter Frost Heaving.

Lusby (123) reported that, during the period from 1954-61, average runoff from heavily grazed watersheds was 20 percent greater than from ungrazed watersheds. At the same time, sediment yield from ungrazed watersheds was 18 to 54 percent less. During the study period no significant changes in vegetative cover had occurred (123, 197). Therefore, vegetation was not the controlling factor. Lusby (123) suggested trampling by grazing animals during the winter and spring compacted soils derived from the Mancos Formation. They would normally have been loose and friable as a result of winter frost heaving. Compaction, therefore, reduced infiltration. Trampling was listed as a cause of increased bare soil on grazed areas by Branson and Owen (18).

Lusby (124) reported on additional data collected during an extension of an earlier study through 1966 and integrated with previously collected data. It was stated that runoff in the hilly Mancos Shale area at Badger Wash "occurs almost wholly in response to summer rains." Gullies draining heavily grazed watersheds had nearly twice as much erosion as those from ungrazed watersheds. Heavily-grazed watersheds produced 30 percent more runoff and 45 percent more sediment than ungrazed watersheds. Maximum reduction in sediment load occurred after 3 years of exclusion from grazing. At the beginning of the study, no significant differences in vegetative cover were measured across the watersheds. At the end of the study, percent shrub, litter, and moss cover were lower and bare ground was higher on grazed watersheds. In contrast, plant growth was accumulating on ungrazed watersheds (128). Several dry years had been recorded, but this did not cause a similar deterioration in vegetation on the ungrazed watersheds (126).

The research findings listed above indicate that heavy grazing increases sediment yield. Turcott (195) quotes Jensen (105) in stating that "over 6 million acres of BLM-managed frail lands are in an extremely hazardous condition." Another 44 million acres are in a critically eroding condition. Some of the most deteriorated lands occur on the Mancos Shale of the Colorado Plateau. Approximately 3 million acres of highly erosive, highly saline lands occur in the Upper Basin states of Colorado, Utah, and Wyoming (see Figure IV-1). Each year, erosion on public land yields millions of tons of sediment and large amounts of soluble salts to the Colorado River (195).

Turcott et al (196) suggest that the answer to the salinity problem lies in keeping soils in place, reducing the dissolution of salts which occurs when soils erode. Turcott (195) points to improvement of watersheds through better livestock management as a solution to the erosion and salt problem. It is suggested this management could include rest of areas from livestock grazing when plants are growing, total exclusion of livestock is some cases, fencing of critical areas to exclude livestock, treatment of potentially high forage production areas for the livestock displaced, and stringent control of big game numbers. In a report to the U.S. Senate on range condition of public lands, the BLM states that "about 10 million acres are unsuitable for grazing either because of physical and ecological limitations or because certain lands presently grazed will be designated for other higher priority uses" (29).

2. Off-Road Vehicles

Off-road vehicle (ORV) use by hunters and other recreationists, using 4-wheel drive vehicles and motorcycles, is growing on public lands in the Upper Basin. Off-road vehicle use relates to salinity in terms of the damaging impact it has on soils, plant cover, and the hydrologic process. Runoff and erosion increase as a result of increased soil compaction and reduced plant cover. According to Snyder et al (181), the severity of the impact is related to the intensity of use. The effects of ORV on the desert environment are both serious, long-lasting, and are highly visible (see Figure IV-18).

Eckert et al (46) found that ORV use reduced infiltration by 18 to 37 percent on soils with vesicular surface horizons. Increases in sediment as a result of ORV use ranged from 50 to more than 500 percent, depending upon site and whether simulated rainfall included plant clumps or interspaces between plants. Snyder et al (181) found that watersheds used by motorcycles produced 8 times more runoff than unused basins. Sediment loss, during the study period, was too small to measure on the unused basins and 3.47 tons per acre per year on used basins. Inspection of motorcycle trails showed they had become the focal point for development of rills. Piping occurred as a result of excessive runoff from the compacted soil on trails. Headcuts extended initial gullies uphill. Damage was greatest on slopes exceeding 25 percent.

Motorcycle traffic increased bulk density of surface soils by 37 percent and 12 percent at depths as great as 47 inches. No significant decrease in bulk density was observed 4 years after the ORV area was closed to motorcycle use. The force with which soil particles hold water (moisture-sorption force) increases as the distance between particles is reduced, a feature of compaction. The wilting point of a soil increases as this force grows, making a compacted soil more arid for plants. The moisture-sorption force was found to be 50 percent greater in soil under motorcycle trails than on unused areas (181).

Plant cover increased 95 percent (from 20 to 39 percent) on basins formerly used by motorcycles after 4 years of rest. However, much of this increase came from annual plants. A slight increase of 13.6 percent in plant cover was also measured on the unused basins, which were protected from grazing as well. The improved cover on the formerly used basins (39 percent) was still significantly lower than the 75 percent existing on basins unused by ORVs (181).

Dee et al (42) reported that infiltration was greatest on sites where plant species included individuals at the top of the successional stage of vegetation community development. Eckert et al (46) found that vehicle traffic had the greatest impact on the dominant and most desirable shrubs in the plant community. These plants were severly damaged initially, regrowth was low (10 to 20 percent), and many plants were dead 1.5 years after being damaged. In contrast, undesirable shrubs were only temporarily injured. Rapid and vigorous regrowth was made with 60 to 80 percent of shrub crowns being restored after injury.

Figure IV-18. Off-road Vehicle Damage to Highly Erosive Desert Soils.

Off-road vehicle use should be controlled on arid and semiarid sites where plants are easily damaged and effects are long-lasting, or where soils are subject to damage by compaction and are derived from marine (saline) geologic formations. Increased soil disturbance yields increased quantities of runoff and salts. This condition can best be controlled by confining vehicles to existing roads and trails.

3. Mineral and Energy Exploration and Extraction

The development of coal, oil shale, and oil and gas energy resources in the Upper Basin potentially may have a significant affect on salinity in the Colorado River. Refining and retorting activities can consume large quantities of good quality water. Such a loss from the Colorado River system would raise salt concentrations for downstream users.

The quality of groundwater, which surfaces in drainage channels below mined areas, is modified by contact with spoil material as it passes through disrupted portions of aquifers. McWhorter and Rowe (135) estimated that approximately 99 percent of the annual salt load yielded by a study watershed was produced by groundwater surfacing as base flow in stream channels. The mined areas covered only 14 percent of the land surface in the watershed. However, water yielded by these disturbed soils yielded 52 percent of the total dissolved solids in 1975, for a total salt yield of 2.36 tons/acre. The mean concentration of dissolved solids in the combined flow from groundwater and surface runoff was 2,500 mg/l greater from mined lands than from undisturbed areas. McWhorter et al (136) found that overburden from mines in the Fruitland Formation was capable of yielding a cumulative total of 1.7 percent salt by weight when subjected to a series of laboratory leaching treatments. The Fruitland is not an especially saline formation.

Sediment is an important pollutant (60, 139). When the salt content of sediment is high, the salinity problem is aggravated. Surface mining is a significant contributor to sediment loss and increased salt production (see Figure IV-19). Haul roads and spoil piles with steep surface gradients cause excessive runoff and soil loss. Research in forests has shown that as much as 90 percent of the sediment produced by a watershed originates on roads (139, 168). During mining, large volumes of overburden material are fragmented, displaced, and exposed to the atmosphere where the materials weather rapidly. "In the western coal fields, overburden materials are frequently highly saline, containing toxic concentrations of sodium attached to clays." (139).

Lusby and Toy (127) reported that slopes on rehabilitated areas were 5 percent steeper than those existing on natural areas. The topsoils used to cover reshaped spoil banks were higher in clay content than natural soils, resulting in reduced infiltration. Both of these conditions resulted in increased runoff from 45 to 530 percent and a rise in sediment of 324 to 630 percent from rehabilitated areas. Frickel et al (60) estimate that potential areas in the Piceance Basin associated with oil shale retorting, refining and service facilities, and roads would yield increases in sediment of 5.8 to 11.6 tons per acre per year during initial construction of sites and 2.9 tons per acre per year after construction.

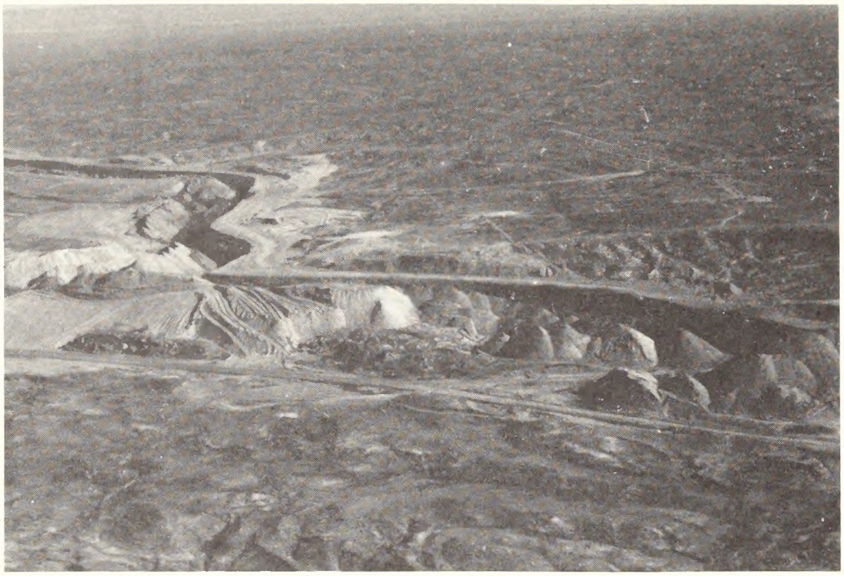
The high peak flows from such uncontrolled areas as spoil piles, drill pads, roads, pipelines, etc., cause accelerated erosion in downstream reaches of gullies and stream channels. Many mine haul roads are designed to shorten the distance materials must be moved. Drainage of water from steep grades or road cuts is of secondary importance in such cases. Access trails for seismic investigations often follow straight lines which may conform to land ownership boundaries. They can cross hills and canyons at right angles disturbing soils on steep slopes. Pipelines are usually constructed between points, covering the shortest distance to conserve materials. Topography is generally not an obstacle. Drill pads, access roads, and pipelines associated with oil and gas fields often disturb soils on a significant portion of the total acreage involved (see Figure IV-19).

Erosion and chemical pollution from mine spoils can be reduced by storing topsoil for future use, burying toxic materials, regrading spoil pile slopes (below 30 percent), and revegetating the disturbed area as soon as possible (139). Rowe and McWhorter[1/] suggest that groundwater recharge through saline spoil piles at elevations above 7,000 feet may be reduced, while keeping water on-site (reducing runoff), by maximizing evapotranspiration. This can be done by preparing the site as outlined by Cook et al (40) and establishing a dense cover of healthy vegetation. Cook et al (40) state that rehabilitation may be only partially successful on saline-sodic soils in desert basins. Only a relatively few species are adapted to these arid, saline conditions. Even the addition of fertilizers and artificial watering may not produce a stand of vegetation capable of protecting disturbed soils from erosion.

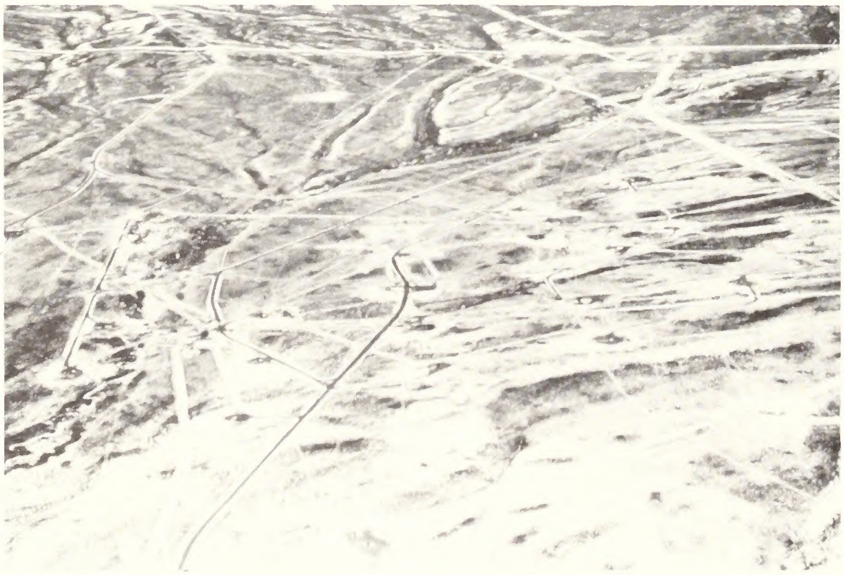
Excessive runoff and salinity from drill pads, roads, seismic trails, and pipelines can be reduced by careful attention to proper design criteria and construction techniques (200). In recent years BLM has required that seismic operations be conducted without constructing trails where topography and vegetation will permit access. Roads and other rights-of-way should be constructed on minimum slopes and provide for maximum control of drainage from roadbeds, cutbanks, and runoff from uphill areas. Drill pads and other large areas of exposed soils should also be constructed so that runoff is confined and allowed to flow onto undisturbed areas in a controlled manner. Mud pits associated with oil well drilling should be protected so that runoff from the drill pad will not fill the pit and cause a breach of the dike or overflow of its contents.

Exploration and extraction activities should be carried out in accordance with approved techniques that will minimize surface disturbance. Sediment and chemical pollution should be a consideration in design, location, and construction of facilities. Spoil piles should be properly graded to reduce slopes to a minimum, the surface covered with stockpiled topsoil, and a vegetative cover established as quickly as possible. Toxic materials, including those high in salts, should be buried to minimize leaching.

1/ Rowe, J. W. and D. B. McWhorter. Salt loading in a disturbed watershed-field study. Submitted for publication.



a. Soil Disturbance Resulting From Strip Mining.



b. Soil Disturbance Resulting From Access Roads, Pipelines, And Drill Pads Associated With An Oil And Gas Field.

Figure IV-19. Effects of Mineral and Energy Extraction on Soil Disturbance.

V. TECHNICAL FEASIBILITY OF CONTROL MEASURES

This section discusses common land treatment practices and control of livestock. It also assesses their effectiveness in changing hydrologic characteristics. Current literature indicates the strengths and weaknesses of presently accepted watershed stabilization practices relative to impacts on the environment, site adaptability, and longevity.

Salinity was generally not a concern of range and watershed researchers. However, the authors of this study theorize that the major controllable salinity transport mechanisms are runoff (salt in solution) and erosion (salt in sediment) from upland and channel areas. Salinity control measures should be designed to change the present hydrologic characteristics of watersheds or halt saline runoff and sediment somewhere short of perennial streams. Possible effects upon salinity based on reduced sediment loss, changes in volume of runoff, and increased vegetative cover are projected.

A. Juniper-Pinyon Control

For years, control of juniper-pinyon stands has been attempted on many acres throughout the West for purposes of increasing livestock and wildlife forage and improving watershed conditions. The justification has been that grass can protect the soil from erosion better than trees and shrubs. However, Gifford (66) found that after 5 years there was no difference in water or sediment yield between chained juniper-pinyon sites and adjacent nonchained woodland in Utah. Where trees were chained and windrowed and the areas seeded to grass, water and sediment yields increased over yields measured on adjacent native juniper-pinyon woodland stands. This occurred even though ground cover made up by grass, forbs, and litter was higher on the chained, windrowed, and seeded sites.

Clary (36) quotes the work of several researchers to indicate there is little opportunity to increase runoff from juniper-pinyon woodlands through land management strategies. Collings and Myrick (38) found no increase in runoff after removal of 38 percent of the juniper-pinyon woodland in the 20-inch precipitation zone in Arizona. Trees were cleared only on slopes less than 20 percent, where commercial timber would not be destroyed, and on soils relatively free of rocks. Clary (36) and Brown (20) also found little effect on runoff and sediment yields from removal of juniper-pinyon overstory. Gifford and Tew (73) found that, during the first year, chaining and windrowing of juniper-pinyon significantly increased permeability of surface soils. However, they also found that percolation rates were not influenced by chaining. They concluded that "increased soil permeability is no asset if water is unable to enter the soil . . .". Loope and Gifford (121) found that cryptogams normally growing on soils in the woodland significantly increased infiltration rates. When the cryptogamic layer was disturbed during the chaining process, sediment production increased.

Williams et al (221) and Gifford et al (75) found there were no significant differences in infiltration rates or sediment yields on chained and seeded areas as compared to adjacent native woodland areas. Gifford (69) indicates that the juniper-pinyon woodland provides a good watershed cover, one not usually improved upon by eradication of the trees and conversion to grass. Gifford states that ". . . if you are trying to manipulate the pinyon-juniper type, your goal, from a hydrologic standpoint, ought to be to get back to where you started initially." (69). These findings tend to discourage use of the practice of juniper-pinyon chaining for improvement of hydrologic conditions. Aro (6) states that the greatest problem with juniper-pinyon chaining is the almost universal failure to kill enough trees in the woodland stand to consider the process as successful in reaching its goal of eradicating trees.

Gifford and Shaw (72) found that ". . . vegetation densities as measured in this study had no measurable effect on soil moisture patterns." Soil moisture did increase on the debris-in-place chained sites but ". . . there was no indication of any excess moisture for eventual deep seepage." Gifford (67) found that deep seepage was zero in two juniper-pinyon sites of southern Utah during a 3-year study. Interception by woodland overstory was estimated to be 22 to 29 percent of total precipitation. This compares well with the 17.2 percent reported by Skau (178). West and Gifford (215) found that big sagebrush and shadscale at densities of 19.1 and 16.8 percent would intercept 4 percent of the total annual rainfall. Hibbert et al (92) calculate that in the chaparral zone of central Arizona, where annual precipitation ranges from 16 to 25 inches, annual evapotranspiration varies between 45 and 60 inches. Zander (226) and Gifford (64) found that juniper tree crowns and associated duff and litter layer were very effective in reducing the volume of water reaching the soil surface. Litter was also an important factor in reducing evaporation of water in the soil. Evans et al (50) state that the quantity of litter falling each year from the woodland trees exceeds the rate of decomposition.

Clary et al (37) state that the greatest sediment yields recorded on the Beaver Creek experimental watershed in Arizona came from a 100 to 150 year recurrence interval storm falling on a cabled juniper-pinyon area. Because this was such an extreme event, these data were dropped from a determination of mean runoff and sediment yields. Such an event does indicate that native woodlands may be as well suited to controlling erosion as areas altered by man. Removal of the overstory increased the TDS in runoff 2.4 times over the untreated watershed. Overstory removal did increase herbage production in the Utah juniper community by severalfold with a variable increase in livestock and wildlife forage values. In contrast, Blackburn and Skau (11) found that the singleleaf pinyon-Utah juniper community consistently yielded more sediment that other communities sampled.

Clary et al (37) state that the only significant increase in streamflow resulted from the killing of overstory vegetation by herbicide. Tree skeletons were left standing and no soil disturbance occurred. Wright et al (224) found that runoff and sediment increased on moderate (8 to 20 percent) and steep (37 to 61 percent) slopes in central Texas after dozed juniper slash was burned. Soil loss was attributed to bare areas. As these areas became revegetated, runoff and sediment yields diminished. Recovery was slowest on the steep slopes. It was recommended that slopes over 20 percent not be converted from shrubs to grass. Busby (23) states that juniper-pinyon rangelands with sandy loam soils and less than 5 percent slope can be converted from woodland to grass for livestock. This would not cause a deterioration in watershed condition if debris were left in place. These constraints greatly reduce the number of sites suitable for treatment.

Measurements were made by BLM personnel in the juniper-pinyon type on the sandstone plateau forming the northern boundary of the Dry Creek Basin, south of Naturita, Colorado. The area supports a very dense stand of juniper-pinyon trees. A large portion of the woodland was chained in 1971 and seeded to crested wheatgrass (*Agropyron cristatum*). Three years later, part of the area was burned and aerial seeded. Step point transects (190) were located in each of the three vegetative communities. Species composition and percent ground cover of live vegetation, litter, and rocks were recorded, as shown in Table V-1. The climate, elevation, topography, geology, soils, and natural pretreatment vegetation are comparable for all three sites.

The data in Table V-1 show that the natural juniper-pinyon stand supports a greater ground cover of live vegetation as well as total ground cover, including litter and rocks, than either the chained and seeded or chained, burned, and seeded areas. The amount of litter on the two treated sites is primarily the result of the chaining operation, in the form of residual material from dead trees. Figure V-1 graphically illustrates the volume of cover and litter on both the natural woodland and chained sites. Litter on the burned area was reduced as a result of the fire. The percent of rock is essentially similar for all sites.

The hydrologic condition on the natural and chained juniper-pinyon sites is very good. Rain drops have a high probability of being intercepted before striking the ground. The litter cover is sufficient to retard most overland flow. The ground cover of live vegetation on the chained site, however, is providing less protection than the natural woodland. The woodland has the opportunity to maintain cover for a longer period because of the large percentage of live matter. The dead material on the chained area will deteriorate with time. The young trees on the chained area may provide the necessary overstory before litter deteriorates. The burned area provides the least protection for the soil.

The results cited above, indicate that removal of juniper-pinyon overstory may not always be a viable means of controlling erosion and salinity of overland runoff.

B. Big Sagebrush Control

The big sagebrush community has been treated much the same as the juniper-pinyon woodland. It has been a common practice to spray or burn big sagebrush in order to release remnant native grasses in the stand and thereby convert the site to grassland. Where remnant grasses are too few, the area is plowed to kill sagebrush and grasses are planted. The desired result is a site producing several times more forage for livestock and also yielding clear water and less sediment.

Table V-1. Percent Ground Cover and Species Composition on a Natural Juniper-Pinyon Site and Two Former Woodland Sites Altered by Chaining, Burning, and Seeding

	Number of Hits on Vegetation and Other Forms of Cover by Site					
	Natural Juniper-Pinyon Woodland		Chained and Seeded		Chained, Burned, and Seeded	
Species	Overstory	Understory	Overstory	Understory	Overstory	Understory
Trees						
Pinus edulis	28	2	1	-	-	-
Juniperus osteosperma	11	-	1	-	-	-
Shrubs						
Amelanchier alnifolia	T*	-				
Atriplex canescens			T	-		
Xanthrocephalum sarothrae			2	-		
Purshia tridentata			1	-		
Yucca spp.	T	-	T	-	T	-
Forbs						
Chrysopsis villosa	T	-	T	-	T	-
Chrysothamnus viscidiflorus var. pumilus	5	-	T	-		
Haplopappus armeroides	T	-	T	-	T	-
Mertensia fusiformis			1	-		
Melilotus officinalis			T	-	T	-
Phlox spp.	T	-	T	-		
Salsola kali					T	-
Solidago petradoria			T	-		
Grasses						
Agropyron crystatum			2	-	8	-
Agropyron smithii					T	-
Bouteloua gracilis			1	-		
Bromus tectorum					T	-
Oryzopsis hymenoides			T	-		
Poa secunda	T	-	1	-	T	-
Sitanion hystrix	T	-	3	-	T	-
Other						
Bare ground	16	3	24	-	47	-
Litter	23	31	50	2	29	-
Small rock < 2"	9	2	8	-	6	-
Large rock > 2"	8	3	5	-	10	-
TOTAL HITS	100	41	100	2	100	0
Ground cover of overstory live vegetation	44 percent		13 percent		8 percent	
Ground cover including litter and rocks	84 percent		76 percent		53 percent	

* Note: T = trace

a. Natural Woodland - Note Dense Tree Crown Cover and Ground Litter.

b. Chained Site - Note Many Young Live Trees and Ground Litter.

Figure V-1. Volume of Plant Cover and Litter on Natural and Chained Juniper-Pinyon Sites.

Gifford (65) and Busby (70) found that plowing of big sagebrush in Idaho reduced infiltration and increased soil loss the first year after treatment. However, Gifford (65) found that there was no significant difference in infiltration rates and sediment yields between the cleared and natural big sagebrush stand after the first year, even though percent ground cover on the cleared and seeded site was greater the second year than on the untreated site. Shown (176) found that bulk density on plowed and seeded sites averaged 0.15 grams/cubic centimeter (g/cc) less than on sagebrush sites. He attributed this reduction to tillage practices and the fibrous roots of grasses. Blackburn and Skau (11) found no significant differences in infiltration rates and sediment yields between plowed and seeded sites and untreated big sagebrush stands.

Shown et al (177) found on Boco Mountain that evaporation from the soil surface was greater from big sagebrush stands (46 percent bare ground) than from the grass stands (31 percent bare ground). Transpiration was also greater from sagebrush sites because of the evergreen growth of sage as opposed to grasses which are dormant during much of the year. Grasses tended to use more water from the 4 to 24 inch soil depths, while sagebrush used more water at the 24 to 40 inch depths. This reflects the shallow roots of grasses and deep roots of sagebrush. Runoff during the growing season did not vary significantly between natural sagebrush and seeded grass sites.

Shown (176) found sediment yields from seeded grass watersheds were greatly reduced compared to paired sagebrush watersheds. Average annual runoff was not significantly different between treatments. Runoff came during the summer from thunderstorms. Snowmelt during the winter came when soils were frozen so that soils were not disturbed. Lusby[1], in unpublished data, found that seeded grass watersheds yielded more runoff from snowmelt, while the sagebrush watersheds yielded more runoff from summer rainfall. Seeded grass watersheds yielded eight times less sediment than the sagebrush watersheds. Sediment came from upland sites, primarily as rill erosion (176). This is in contrast with work by Johnson and Hanson (106) who found sediment was primarily the product of large channel erosion in downstream areas. Sturges (188) found that the largest quantities of sediment came from spring snowmelt.

Recent studies on big sagebrush sites converted to grass in northwestern and south-central Wyoming, recorded a slight increase (15 percent) in soil moisture at the 3- to 6-foot depth (188). This also was reflected in a similar slight increase (13 percent) in annual streamflow. These sites are on deep soils receiving 15 to 20 inches of annual precipitation. In support of these findings, Sturges (189) reported a 67 percent reduction in withdrawal of soil moisture at the 3- to 6-foot depth after the first year of treatment, decreasing to a 40 percent reduction in the fifth posttreatment year.

Sturges (188) observed no increase in sediment yield due to land treatment. Similar results were found in Nevada (11). The similarity of sediment yields on natural sagebrush and seeded grass stands indicates that native big sagebrush may protect the soil from erosion as well as grass on some sites. In Nevada, where plowed sagebrush sites failed to support a successful stand of seeded grass, infiltration rates were lower than controls and sediment production was higher (104).

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[1] Personal communication, summer 1977.

Sturges (187) states that "the 13 percent increase in streamflow is probably about the maximum that can be expected from sagebrush conversion at any location." Much of the land supporting big sagebrush will not give increases in water yield after conversion to grass, because of low precipitation (below 15 inches annual) and shallow soils. Soil moisture in the 0- to 3-foot depths will be utilized by grasses.

Total biomass is less on treated sites than on native big sagebrush areas. Sturges (187) found a 63 percent reduction in total biomass during the year of treatment and a 30 percent reduction the following year. Sturges quotes Pechanec et al (152) as measuring a decrease in total vegetative production of 19 percent on a burned sagebrush site in Idaho, 4 years after the fire. This reduced production may be related to the increased runoff observed. A mixed stand of deep rooted shrubs and shallow-rooted grasses and forbs makes more complete use of available soil moisture throughout the soil profile.

Big sagebrush is an effective obstacle to wind movement, reducing velocity at the interface with the tops of shrubs. This reduced velocity causes snow to be deposited and held in place. Wind-carried snow moving across herbaceous vegetation stays suspended in the air and much of the moisture is returned to the atmosphere. A substantial amount of the snow trapped in stands of big sagebrush is stored there until the spring melt period, when it provides water for runoff and soil moisture recharge (187).

Rosa and Tigerman (170), analyzing data from several sites covering the years from 1941-47, found that sediment yield in big sagebrush stands was directly correlated with range condition. Range condition is an indicator of the number and variety of species of plants found on a site. This is in reference to what that range is naturally capable of producing (116). Rangeland in good condition would support a mixture of grasses, forbs, and other shrubs intermingled with the big sagebrush plants. Poor condition range would have very few understory plants mixed with big sagebrush. Rosa and Tigerman (170) found that poor condition (range) sagebrush sites produced three times more sediment than sagebrush sites in good condition.

An inspection of the Chaffee Gulch range near Montrose, Colorado, was made by BLM personnel in early February 1977. Vegetation of the area consists of juniper-pinyon on hill slopes and big sagebrush in the valleys. Average annual precipitation is 12 inches. The soil is derived from the saline Mancos Formation. Range condition and hydrologic condition are excellent. The area has not been grazed by livestock since it was purchased by the Colorado Division of Wildlife in 1955. Small lateral channels draining into the Chaffee Gulch are healing; very little evidence of overland flow can be seen. A dense stand of perennial grasses and litter fill the interspaces between big sagebrush plants, and snow has accumulated even though precipitation is below normal (see Figure V-2).

Statements by personnel in the Montrose BLM office indicate that range condition of the Chaffee Gulch valley was very poor, prior to 1955, because of heavy concentrations of livestock. Such examples of improved plant cover in sagebrush stands, resulting from livestock control, should serve to alert resource managers to the potential of natural plant communities.

Figure V-2. Dense Stand of Perennial Grasses and Litter Intermixed with Big Sagebrush.

The data reported above indicate that individual sites should be carefully analyzed before conversion is attempted from native big sagebrush to seeded grass. Ranges in poor condition because of heavy livestock use may respond sufficiently to grazing management. This includes reduction in livestock numbers and periodic rest of pastures.

C. Ripping, Pitting, and Contour Furrows and Trenches

Mechanical treatments have been used on public lands to artificially break up compacted soil crust, increase infiltration, retain water on site, and reduce sediment loss. Work has been attempted on a variety of sites having different soil characteristics, slope, vegetative type, and climate. Frevert et al (59) indicate that ripping has not greatly improved soil conditions. In contrast, a 3-year study on saline Mancos-derived soils in New Mexico showed a 97 percent reduction in runoff the first year and 83 percent during the third year after ripping with an auger ripper. At the same time, however, reductions in sediment dropped from 86 percent the first year to 30 percent during the third year after treatment (44).

Branson et al (70) report a more arid environment, evidenced by reduced plant cover, on the same New Mexico auger ripping treatment site. The Forest Service (57) is quoted as finding subterranean channels or pipes under the ripped land leading to open gullies. This indicated that water entering the fractured soil profile was only temporarily detained from entering the ephemeral stream system and may have resulted in greater erosion than created by normal runoff. Heede (84) found that soils with a high exchangeable sodium percentage are most susceptible to piping. Gates et al (62) and Wein (211) found that exchangeable sodium increased with depth in salt desert shrub soils. Therefore, it would seem to follow that treatments such as ripping, which allow concentrated volumes of water to enter the soil profile along restricted paths, would be questionable on sodic soils.

Barnes et al (7) found that pitting increased forage production but that the life of pits may not extend much beyond 10 years. Pitting in desert areas was not practiced on slopes greater than 8 percent, or where soils were rocky or covered with large shrubs. Branson et al (15) found that after an 8-year period, pits were no longer visible but that grasses seeded during the pitting operation were still alive. Results led to the conclusion that pitting "is of questionable value as a land-treatment practice." This conclusion was based primarily on the failure of forage production to increase on untreated interspaces between pits. Wight (219) quotes a variety of authors to indicate success of pits in retaining runoff on rangelands. Rauzi et al (162) suggest that pits be rebuilt every 10 years on Wyoming rangelands. Nichols (144) concluded that pits were relatively short-lived on dense clay soils, because silt from loose soil created by freezing and thawing filled the depressions.

Pits constructed on Mancos-derived soils in New Mexico ceased to be effective in reducing sediment loss by the end of the third year after construction. Sediment loss from pitted sites on south slopes even exceeded untreated areas by 4 percent (95). Thomas (191) found that large pits in the Cisco Basin, Utah were effective in halting all runoff and sediment from Mancos-derived soils when used in conjuntion with contour trenches. King (112), in

1966, reported that pits constructed in 1954 on erosive soils in southeastern Utah were largely filled with sediment and no longer functional. Measurements made by BLM in 1977 on the Nuttall saltbush-woody aster site at Cisco indicate that large pits are capable of storing 0.30 inches of runoff and the contour trenches provide an additional storage for 0.35 inches of runoff. However, measurements of sediment in pits indicate a life expectancy as short as 14 years (191).

Wein (211) found the bulk density of soils increased in the bottom of pits and furrows as a result of fine-textured sediment washing into the structures. Wein and West (213) found that infiltration in pits was very low and that most of the water evaporated from a free water surface similar in rate to pan evaporation. Hancock (79) states that "free water collecting in the treatments, often stood on the soil surface for days or even weeks, until it eventually evaporated." Seedlings were drowned in the bottoms of pits because of the standing water. However, native plants became established along the high water line in pits (213). Coltharp (39) states that any possibility of increased vegetation around the periphery of the pits was nullified by the large area of natural vegetation disturbed during construction of the pits. Wein and West (214) theorize that since infiltration in pits and furrows is very low, a buildup of salts appear inevitable. Coltharp (39) and Hancock (79) reported that pits and trenches in the tight clay soils of Cisco increased moisture storage immediately below treatment depressions, but there was no lateral movement of water. The preceding results argue against increases in recharge of groundwater as a result of keeping water on-site. If groundwater recharge were increased, the potential salt load from a region also would increase.

In contrast to the findings on ripping and pitting, Wight and Siddoway (220) reported that contour furrowing on saline heavy clay soils in southeastern Montana increased soil water content 43 percent in the top foot of soil over nonfurrowed plots during a 3-year period. This was on seven dates tested and coincided with periods following snowmelt or high rainfall. However, storage capacity of furrows deteriorated within 10 years to 29 percent of the maximum after construction. Branson (13) states that contour furrows were the most effective treatment for retaining water on-site, removing salt from its effect on plants through leaching (increased soil moisture available to plants), increasing plant yields, and reducing salt content of runoff.

Furrows in Mancos-derived soils held water for up to 2 days before it finally infiltrated. At this time, the soil was at field capacity. Seven days after the storms, the soil moisture had returned to the wilting point (213). The seeding of exotic species, such as crested wheatgrass (Agropyron desertorum), was a failure. However, native plants were more robust than plants on undisturbed sites; had increased plant vigor; produced larger seeds; initiated growth earlier in the spring; and continued to grow later in the fall (212).

Branson et al (15) state that contour furrows are most successful on medium- to fine-textured soils, from the standpoint of increasing forage. Treatments on very fine soils were less successful. Vegetation on coarse soils was decreased by contour furrowing. Examples of plants killed by contour furrows are blue grama, galleta grass, black grama (Bouteloua eriopoda), needle-and-thread, and winter fat.

Contour furrows constructed with the Model B (Arcadia) furrower are most effective at intervals of 3 to 5 feet and depths of 8 to 10 inches. Furrows more than 5 feet apart ". . . often became breached by runoff that exceeded furrow storage capacity." This was found to be true even in areas where annual precipitation was 10 inches or less. Furrows were able to store 2 inches of precipitation when newly constructed, with storage capacity decreasing rapidly during the first 5 years to less than 1 inch. They were able to hold only 0.5 inch after 9 years, or 25 percent of the original capacity. The BLM (25) cautions that storage capacity of furrows may be reduced to one-half after 5 years and one-fourth after 10 years as a result of soil sloughing from the area immediately above the furrow or trench. The rate of loss in capacity is dependent upon slope, soil type, as well as frequency and intensity of rainfall.

King (111) found that during the construction of contour furrows, the tendency to deviate from the contour was greater as slope increased. It was suggested that furrows should not be used on slopes steeper than 10 percent. Wight and Siddoway (220) found that furrows constructed on slopes in excess of 7 percent, or not closely following the contour, lost most of their water retention capacity within 3 or 4 years. Thomas (191) found that even a 0.5 percent slope of a furrow was enough to cause its early failure (furrows must be level). It was also found that the life of furrows on the frail Cisco area ranged from 6 to 12 years(74,191). It was apparent from study results that life expectancy of furrows would lengthen if the density of furrows was increased (74). The BLM (24) states that the Model B furrower was specifically designed for nearly level sites or for modest slopes. The greatest success is obtained on slopes less than 10 percent. It is also reported that the terrace offset-disc trencher will operate on slopes up to 45 percent, but when used on slopes greater than 10 percent, the resulting storage capacity of the trenches is greatly reduced. The BLM (25) estimates the maximum life of contour trenches is 15 years, but will be less in areas of severe erosion, i.e., highly erosive soils.

Contour furrows are not effective on rocky soils, especially those occurring on slopes (24). Soils must be deep enough to permit a furrow or trench of adequate depth without exposing parent material. Furrows deteriorate most rapidly on loose, sandy soils or tight, clay soils subject to extensive frost heaving or shrink and swell (see Figure V-3). Infiltration will not be increased on tight, clay soils (25).

Figure V-4 shows furrows on a hilly site with Mancos-derived soils and a sparse cover of mat saltbush. The furrows are not on the contour in all locations and erosion is beginning to occur. Spacer dams within the furrows are being overtopped. Water also collects in furrow low spots causing them to overflow and breach the downstream furrow ridge, emptying the contents of one furrow into the next furrow downslope. The second furrow also floods and this successive failure causes a concentration of water to cut through the furrowed area in excess of natural runoff (111).

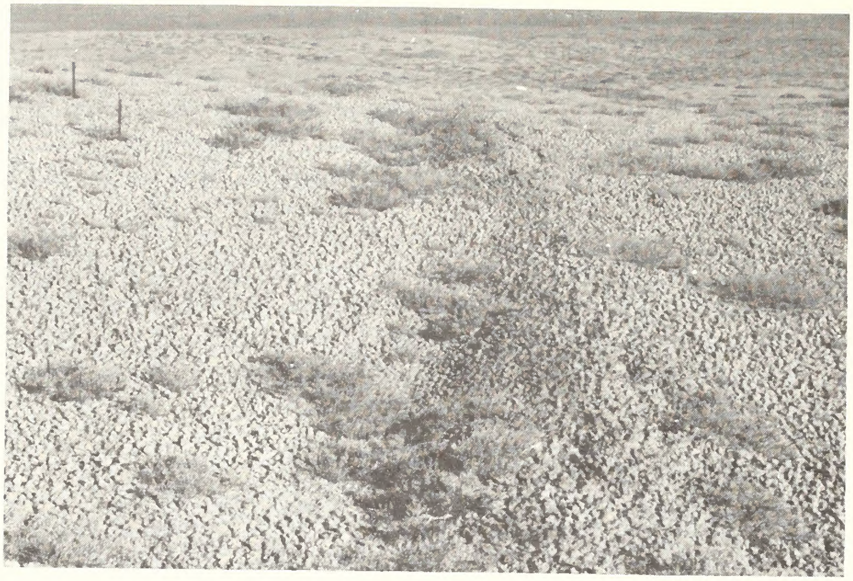

Figure V-3. Furrow Deterioration on a Fine-Textured Clay Soil.

Figure V-4. Contour Furrows on a Hilly Site with Sparse Vegetation.

Fletcher and Carroll (56) found that in some soils the increased soil moisture resulting from contour furrows may lead to soil piping. Analysis by BLM of contour furrows in Peach Valley, north of Montrose, Colorado, showed some evidence of piping in contour furrows on deep Mancos-derived soils. The greatest problem, however, was the filling of furrows with sediment and breaching of furrow ridges.

Studies cited above indicate that pits and contour furrows, located on saline soils below 10 inches of annual precipitation, may not always increase vegetative cover. Data collected by BLM during the course of this study indicate that contour furrows destroy approximately one-third of the existing vegetation. However, the improved microclimate created by the furrows results in a reestablishment of the destroyed native species. No increases in plant cover were recorded in excess of the native stands. Areas barren of perennial vegetation prior to treatment have remained barren following contour furrowing. At the upper limit of precipitation, some establishment of seeded introduced grasses was observed.

Because of the limited useful life of pits, contour furrows, and trenches on highly erosive soils, retreatment will be necessary. No data exist to show the effects of periodic soil disturbance and loss of plants as a result of construction of treatments. However, a knowledge of these regions gained through investigations during the past 2 years indicates several potential problems. Frequent disturbance of the soil to a depth of 8 to 12 inches brings saline soils to the surface, exposing them to wind and water erosion. This farming also tends to destroy soil aggregates causing a increased potential for erosion. Plants destroyed in the construction process may not always become reestablished, especially if treatment is followed by a protracted drought. Also, perennial plants may be replaced by annuals or other plants less able to retard erosion.

Plantings of both native and introduced species in the arid shadscale zone have generally failed because of the low annual precipitation, salinity of soils, insects and rodents, and frost damage. Introduced grasses have not been successful in adapting to the harsh sites (12). Judd and Judd (108) found that only 12.5 percent of exotic and native plants artificially seeded in the arid Southwest survived after 30 years. Problems associated with using native seed include low percent viability and difficulty in breaking dormancy. In some seedings where a good stand of plants became established the first year, insects, rodents, and rabbits moved into the area and completely ravaged the new vegetation (12).

D. Water Spreading and Gully Plugs

Gifford (65), reporting on work by several authors, states that water spreader dikes should cover an area large enough so that exceptionally large flows will not overtop dikes. Most of the sediment will settle on the upper 20 percent of the system. Spreader dike systems should not be constructed as a control measure for stopping sediment yielded by highly erosive areas. Spreader dikes should be constructed on areas having a slope no greater than 5 percent.

Miller et al (140) state that spreader dikes are most useful in medium-to-fine textured soils. Salt levels were lower in the A horizon and higher in the B_2 and B_3 horizons on flooded areas with fine-textured soils. Whether or not salt levels would build up in the lower soil horizons enough to harm plant growth was not stated. However, the report implies that salinity was not a factor in selecting potential spreader systems obviously designed for forage production rather than flood control.

Water spreader dikes could conceivably be designed for sediment and salinity control. However, sites with physical characteristics suitable for spreader dikes are limited. Also, spreader dikes are expensive to design, build, and maintain. Peterson and Branson (153) found that many spreader systems had failed because water retarding dams and diversion structures on the main channels had been washed out. Improper design and inadequate construction techniques, including a lack of proper compaction of earthfill and poorly protected spillways, were cited as reasons for failure. Miller et al (140) state that "Maintenance of earth structures must be considered a continuing process." This was obvious because of the damage caused when breaks in structures were allowed to remain until new floods came. Runoff from heavy thunderstorms entering a system in poor condition may cause damage so extensive that maintenance efforts could approach those expended on initial construction.

Gully plugs have been constructed by the BLM as a means of stopping movement of sediment and stabilizing gullies. Small reservoirs have been constructed for livestock water; however, they also trap sediment suspended in the water. Gifford (65) cites studies which show that earth-fill structures are susceptible to failure if construction does not follow rigid specifications. In one instance, where gully plugs were constructed in central Utah, storage reservoirs for silt were filled in 10 years and little storage capacity remained. Investigations by the BLM point to many failures of structures constructed from a variety of materials and located on a variety of soil types and vegetative communities. Figure V-5 shows examples from juniper-pinyon and salt desert shrub (Mancos) sites.

Where dams remain intact, Lusby and Hadley (125) found that, after reservoirs behind dams were filled with sediment, deposition of sediment continued upslope in the gully channel. At Sheep Creek in southeastern Utah, 47 percent of the silt deposited behind a dam was above the elevation of the spillway and the deposition of silt was continuing. The slope of deposited sediment was 30 to 60 percent of the original streambed gradient. The stability of sediment in the gully (ability to stay in place) depends upon the continued existence of the dam which caused the original deposition, and the continued reduction in velocity of flood water below the energy necessary to cause channel cutting. Vegetation established on the new sediment in the gully also will help reduce the velocity of water (87). The gully plug must also effectively stop underground flow. If water cuts under the dam, underground flow will cause a loss of sediment through piping, one of the first stages of gully erosion. Gully plugs may not completely stop the movement of salts in water moving downstream even though sediment remains trapped behind dams and in gullies upstream. Salt trapped in sediment may be leached into channel sediments and move downstream as subsurface flow during periods of runoff.

a. Juniper-Pinyon Watershed.

b. Salt Desert Shrub Watershed.

Figure V-5. Washed Out Gully Plugs on Juniper-Pinyon and Salt Desert Shrub Sites.

Heede (86) offers a very good outline of criteria important to the proper location, design, and construction of several types of porous and nonporous check dams (gully plugs) designed to reduce erosion and trap sediment. Proper construction requires heavy equipment such as a caterpillar or backhoe and quantities of materials, such as galvanized wire mesh, steel posts, well graded (as to size and shape) rock, and/or prestressed concrete slabs. The porous dam design reduces the incidence of piping common in saline soils and would be successful in controlling sediment.

Nonporous dams create additional design problems relating to the need for proper control and disposition of the trapped water. It is suggested that released flow be spread over a stable land surface, if possible, or drain onto a protected surface such as a gravel field. This procedure is necessary in order to reduce the chance of downstream erosion from overflow. Stand outlet pipes or culverts are not recommended because openings could become clogged with debris.

Gully plugs can create man-made aquifers, as runoff percolates through sediment trapped in the gully upstream of the dam. Heede (87) cites examples of this phenomenon on the Alkali Creek watershed (Colorado) where annual precipitation averaged 18.5 inches in 1962 and 1963, and soils are derived from marine shales (84). Ephemeral flow converted to perennial flow in the seventh year of treatment. Heede (85) states that the leaching of sodium through the soils after mechanical disturbance creates an environment more suited to plant growth. The stable gully floor, created by sediment deposition and increased soil moisture, fosters a dense stand of vegetation. This, in turn, further stabilizes the gully. However, the possibility of salts leached from saline sediment discharging through porous dams could increase the yield of salt.

Peterson and Branson (153) underscore the importance of placing check dams on sound foundations in order to eliminate piping or other forms of subsurface erosion. This means safeguarding structures from failure. Heede (86) emphasizes the need for key trenches in the side slopes and core trenches in gully bottoms when placing check dams on highly erosive soils. A nonporous foundation is an important factor in reducing subsurface downstream flow of potentially saline water. If gully plugs cannot be built to trap surface and subsurface flows, other control measures must be substituted. These can include a variety of methods to control runoff from upland sites or large dams on main channels.

E. Detention - Retention Dams

BLM has constructed many detention dams for erosion control and retention dams for livestock and wildlife water. Detention and retention dams can also fulfill the same purpose as gully plugs by trapping sediment in reservoirs behind the dams. As the reservoirs fill, sediment aggrades upstream in the gully channel. Hadley (78) found that sediment in gullies behind large dams reduced the slope of the channel gradient and that 8 percent of the deposition was above the spillway level. It is also stated that "in similar drainage basins the sediment yield decreases with increase in size of drainage area." This is in agreement with results reported by Lusby and Hadley (125) on smaller areas, except that the relative volume of sediment was reduced.

Detention and retention dams must be properly located, designed, and constructed. As a normal practice, dams should not be located on channels where the gradient exceeds 5 percent. The height of the dam and cross sectional area of the spillway are greatly increased as channel slope increases. Size of drainage area, length of straight portions of channel, vegetation, porosity of soils, slope of uplands, hydrologic condition of the watershed, and intensity and duration of storms are all important factors to be considered in designing dams.

A detention dam differs from a retention structure in that it contains an outlet pipe allowing water detained in the sediment reservoir to discharge downstream at a controlled rate. Detention dams are capable of storing sediment and retaining salts in the sediment as long as leaching does not occur. Salt in solution in runoff is discharged downstream through the outlet pipe.

Retention dams store salt from both sediment and runoff. Investigations by the BLM revealed several striking effects of seepage under retention dams. Figure V-6 shows an aerial view of a retention dam on the Coal Creek allotment just north of Wellington, Utah. The evaporites visible in the channel below the reservoir are in contrast to the "clean" channel above. Measurements of the salinity of seepage below several reservoirs showed concentrations well above those found in normal channel flow following thunderstorms. Laronne (117) found that sediment in reservoirs and in aggraded channel deposits above dams did not contain salts in greater concentrations than found on upland soils throughout the watershed. Salt concentrations measured in sediment and seeps in channels below dams were much higher, indicating that leaching was taking place. Data collected by the SCS in Badger Wash, Colorado also show lower salt contents in sediment behind dams than occurring on upland sites (48).

Reservoirs behind detention and retention dams must be completely sealed to be effective as a means of controlling salinity. This can be accomplished naturally if the dam is properly anchored and soils under the reservoir are of the swelling variety (montmorillonitic). The addition of materials such as bentonite can also eliminate seepage.

Spillway design and construction is a critical feature in building retention and detention dams. The spillway must be designed to pass extreme runoff events (100-year storm or greater depending on the risk to downstream areas) without damage to the structure or channel downstream. The spillway also must be able to pass extreme runoff events after the reservoir has filled with sediment to a height of the spillway crest without costly or too frequent maintenance. Damage to the downstream environment from floods created by dam failure must be avoided.

To effectively control salinity by the use of large dams, a relatively large number of structures must be constructed. The large amount of sediment yielded by soils, such as those derived from Mancos Shale, is only one factor which determines the size of watershed to be controlled by a single dam. The heavy equipment required in the construction of large dams necessitates the location of access roads. Such a road network also will be required for periodic maintenance and reconstruction when dams are destroyed or filled with sediment. The design of roads will be critical in order to reduce the erosion from road surfaces and resulting impact on the salinity problem.

Figure V-6. Salt Buildup in a Gully Below a Retention Dam, Created by Seepage Water From the Reservoir.

One of the greatest problems facing the use of large structures to control salinity on highly erosive soils is the very high rate of sedimentation in reservoirs (112). As sediment fills the reservoir, storage capacity is reduced. This increases the danger of a high runoff event overtopping the dam, causing damage to the structure. King (111) discusses the belief of many conservationists that the time is overdue for an appraisal of the effectiveness of detention reservoirs in controlling the sediment problem from rangelands. The argument is presented that such structures, at best, postpone the inevitable and may result in greater damage when they ultimately fail. This same philosophy has been relayed to the authors of this report by BLM engineers, conservationists, and hydrologists working in the Upper Basin. These same individuals have been involved in the design and construction of dams in the past. Objections to further construction of structures are based upon experiences with failure of existing dams. Engineers and hydrologists especially warned against the planning of future structures in areas of highly erosive soils.

King (111) states that ". . . too little thought has been given to the ultimate consequences of the construction of large reservoirs in areas of high sediment yield." It is suggested that ". . . the simplest solution to the problem of reservoir aggradation is to prevent sediment from entering a structure initially." This can be done in at least two ways. The most obvious is to build dams in areas where sediment yield is low. This would have a reduced effect on the control of salt from public lands since those lands yielding the greatest quantities of salt often yield large amounts of sediment. The other solution is to reduce the sediment yield from the watershed by maintaining sediment on-site.

F. Selective Withdrawal

Water quality of perennial streams can be improved by selectively withdrawing the base or low flows with high salt concentrations and bypass good quality water in high flows. The base flow is diverted to an evaporation pond for total consumption. The evaporation ponds must be sealed or lined so that seepage does not return saline water to the stream through the groundwater. Ponds must also be protected from surface runoff which would cause overtopping and spilling of the concentrated brines back into the stream system.

G. Livestock Management

Reynolds and Packer (166) suggest that effective livestock management requires the development of quantitative criteria relating to the degree of trampling disturbance which can be tolerated by rangelands. It is stated that consideration should be given to the ". . . critical measurement and proper interpretation of the complex interrelationships among climate, vegetation, soil, water, and animals." Two of the most important effects of livestock grazing on rangeland are, defoliation of plants and compaction of soils through trampling.

Moderate grazing (removal of 35 to 40 percent of the current year's growth of forage plants) provides nearly as much protection for soils as nongrazing, especially on areas where vegetation is a key factor in controlling infiltration and runoff. However, the vast quantities of research accumulated over the last 80 years clearly illustrate that improper grazing by livestock alters the soil and vegetation on rangelands. The severity of this influence depends upon many components of the range environment. Not the least of these is the degree of use made by livestock, specifically the amount of forage removed by grazing and the extent of compaction by trampling. Heavy grazing reduces infiltration, increases runoff, and causes accelerated erosion.

Plant succession under natural conditions is an orderly process. Plant communities evolve slowly, changing species or ecotypes in response to changes in the environment, grazing by wildlife, or disasters such as wildfire. With the advent of man and his domestic livestock, plant communities have been altered drastically (186). The most detrimental aspect of past livestock grazing has been season or yearlong use of the same range areas, continuously over a period of many years. Heady (83) defines continuous grazing as being ". . . unrestricted . . . through the whole of the grazing season . . .". Hormay and Talbot (97) found that some plants were killed and forage production was lowered under continuous seasonal grazing. Livestock tend to use some plants and range areas more closely, creating uneven utilization. These use patterns are much the same from year to year because of a preference for certain plants or variations in the rangelands. Selective grazing is the main cause of range deterioration.

Factors which affect livestock distribution include topography (steepness of slope), rocky soils, natural barriers (rock ledges), barren lands, dense timber, concentrations of unpalatable or poisonous plants, distance from water, trails, salt, class of livestock, and breed of animal (185). Range suitability is an important consideration influencing the number of grazing animals that an area will support. The forage produced on areas which cannot be utilized by livestock, or is not presently being used, should be subtracted from the grazing capacity of the total allotment or pasture.

Many public lands in the Upper Basin are characterized by steep, rocky, juniper-pinyon covered slopes and canyons; dense juniper-pinyon woodland stands; barren Mancos Shale badlands; scenic sandstone ledges or buttes; and areas poorly watered. Utilization surveys made during the salinity study found these areas were unused or lightly used. Determinations of grazing capacity should include only those areas that can be utilized by livestock. Grazing capacity for areas which have a potential for use through construction of watering places, trails, fences, or increased forage can be reserved until construction of needed facilities.

Any degree of defoliation of plants by grazing animals has an influence on their metabolism. The reduction of photosynthetic tissue results in a reduction in carbohydrate reserves and an influence on volume of forage and roots (185). The extent of the reductions is a factor of the degree of defoliation, length of rest between defoliations, and the season when defoliation occurs. Hormay and Talbot (97) found that a single season of defoliation of four species caused a reduction in the basal area the following year. Clipping when the plants were actively growing reduced the total herbage yield during that year. It was also found that clipping of plants, after seeds were ripe and the foliage was dormant, was harmful to carbohydrate storage.

Periodic rest of plants from defoliation by livestock is the most important element in maintaining vegetative cover on rangelands. Hormay and Talbot (97) outline the most important periods for rest during the phenology (stages of plant growth and development) of plants. These include rest during the growing season to restore plant vigor after grazing, rest until seeds ripen, and rest for seedling establishment. It was suggested that fairly heavy stocking is desirable on rangelands grazed under rest-rotation principles. This premise is built on the desire to force livestock into less accessible areas and a greater use of less palatable forage species. It also assumes that close cropping of vegetation and intensive trampling can be tolerated with subsequent rest of grazed pastures. Such a consideration recognizes effects on plants, but tends to underestimate effects upon soil compaction.

Gifford and Hawkins (71), in a review of the literature, found only nine references that indicated in some way the impacts of grazing management on factors influencing hydrologic condition. The published data (71) failed to show any consistent or significant increases in plant and litter cover as a result of grazing management. Grazing systems appeared to produce results which were specific to given plant species, indicating that when the density of one plant increases another plant may decrease. In all but the most severely-grazed areas, rangelands may be supporting the maximum percent of vegetative ground cover capable for that site. However, an increase in climax species may improve watershed conditions (42).

The data presented in section IV.B.1. present the effects of heavy grazing on vegetative cover, soil compaction, runoff, and sedimentation. These results indicate a need to analyze the objectives of livestock forage production and watershed protection and identify areas of potential conflict. Intensive grazing management is designed to maintain a maximum level of livestock production while maintaining the forage resource in good-to-excellent range condition. Hydrologic condition seeks to maintain soil in place by increased infiltration and produce clear runoff at a rate which will minimize downstream damages. Hydrologic condition is adversely affected by excessive soil compaction and removal of vegetation. The data also indicate that moderate grazing on lands with stable soils and adequate vegetative ground cover does not greatly reduce hydrologic condition as compared with ungrazed conditions.

An analysis of the available data led the authors to conclude that improvement in hydrologic conditions can be achieved, through livestock management, on all but the most saline arid lands. Grazing systems should include periodic rest of plants during important phenological stages, periodic rest during an entire year or more, and moderate use of grazed pastures. Busby (23) found that, on juniper-pinyon ranges, it was ". . . evident that one or more seasons of rest is not sufficient for full recovery of infiltration rates." It was suggested that a grazing system developed for the area should regulate grazing intensity in order to build up litter and reduce trampling.

The data concerning effects of trampling on compaction point to the importance of selecting the proper season of grazing for maintenance of good hydrologic condition. The proper season of grazing for erosion control may conflict with livestock production objectives. Fine-textured soils are easily compacted when wet, but are less affected by grazing when they are dry. Many ranching operations depend upon public lands in winter and spring. Some would be forced out of business if they were unable to find alternative feed sources, should these ranges be closed during critical seasons. In other cases, weight gains of animals would be lower if they were unable to use early green feed when plants are actively growing.

Stocking rates (the number of livestock allowed to graze) may need to be reduced on saline lands in order to reduce salt yields. In some cases, the original adjudicated grazing privileges allow too many livestock on the range. Some ranges have deteriorated due to drought or overgrazing. In other cases, updated suitability determinations are needed to identify portions of ranges which cannot be grazed (reached by livestock). Stocking rates may need to be reduced, where certain pastures are rested season or year long in accordance with a livestock grazing management system. This is to insure that the utilization of grazed pastures remains at a moderate level.

Removal of livestock should be considered on highly saline soils below 10 inches average annual precipitation. These soils, such as those derived from the Mancos Formation, are highly erosive and have a relatively low percent vegetative ground cover. Effects of trampling are damaging to infiltration. Figure V-7 shows how hoof prints of cattle compact soil when it is wet, thereby destroying the fluffy friable soil surface created by frost heaving. Grazing during late winter and spring when the area is normally used, because of open suitable weather, is most harmful according to Lusby (124). Figure V-8 shows rills and gullies forming on a Mancos hillside with a good cover of shadscale and Nuttall saltbush.

Step point transects (190) were made both inside and outside a long-standing 80 acre exclosure, designated as Cisco study area number 1 (191). The site is in the shadscale-galleta grass community on a gravel pediment remnant, as described by West and Ibrahim (216). The soil is a sandy loam; the slope is 1 percent. The area outside the exclosure is grazed each winter by sheep and cattle. The purpose of this study was to determine the effects of heavy winter-spring grazing on desert shrub vegetation. Data showed that sheep and cattle grazing has significantly changed the vegetation (see Table V-2). Grazing has reduced live vegetation and total ground cover (including litter) by 60 percent, as well as reduce the variety of plant species most useful for livestock and wildlife forage. Outside the exclosure, sheep feces made up a significant percent of the litter measured, one-third of the hits. Soil was much less compacted inside the exclosure than outside.

H. Summary

Projects designed to reduce erosion by eliminating native shrub and tree vegetation and introducing seeded grasses have not been shown to produce consistent positive results. Erosion control structures and land treatment projects can control erosion and salinity. Their use was not considered on nonsaline or slightly saline lands, where large quantities of water with relatively low salt concentrations would be retained. Erosion control structures and land treatments may produce potentially harmful side effects on environments with sparse vegetation and highly erosive soils. The useful life of projects on these soils is limited, requiring periodic replacement. Maintenance of structures could be a difficult task because of unstable soils.

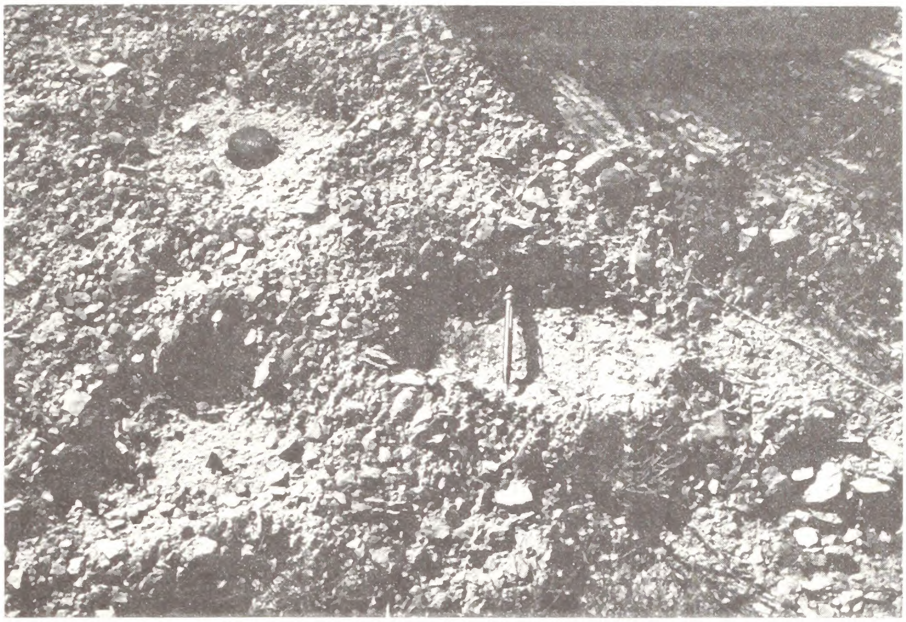

Figure V-7. Livestock Hoof Prints in Soil Derived from Mancos Shale.

Figure V-8. Rills and Gullies on a Mancos Hillside with Good Vegetative Cover.

Table V-2. Comparison of Grazed and Ungrazed Areas in the Shadscale Salt Desert Zone in Utah.

	Percent of Composition	
Species	Inside Exclosure	Grazed Area
<u>Shrubs</u>		
Atriplex confertifolia	3.7	6.0
Atriplex nuttallii	-0-	T
Artemisia spinescens	T *	T
Ceratoides lanata	1.3	T
Xanthrocephalum sarothrae	T	1.0
Opuntia spp.	0.3	2.3
<u>Forbs</u>		
Halogeton glomeratus	-0-	T
<u>Grasses</u>		
Bromus tectorum	3.7	1.7
Hilaria jamesii	9.3	0.7
Oryzopsis hymenoides	1.0	0.3
Sitanion hystrix	T	T
<u>Other</u>		
Litter	27.7	16.3
Small rock	2.7	2.7
Large rock	T	T
Bare ground	50.3	69.0
Total	100.0	100.0
Percent ground cover - live vegetation	19.3	12.0
Percent ground cover, including litter and rock	49.7	31.0

* Note: T = Trace.

The hazard of failure during extreme storm events is great. The disturbance of soil aggregates and plants, characteristic with onland facilities such as contour furrows, may result in serious deterioration of the natural environment on frail sites. Unstable soils and arid climate reduce the chances of reestablishing a protective soil covering after mechanical disturbance.

Grazing management on moderately saline lands should strive to improve infiltration, reduce erosion significantly, while still allowing the greatest volume of relatively controlled runoff. This is extremely important on nonsaline and slightly saline lands. The low salt concentration runoff yielded from these lands acts to reduce salt concentrations at Imperial Dam; therefore, runoff should be maximized as a salinity control objective. However, it must be remembered that runoff cannot be increased to the extent that erosion is harmful to the site or increased flood peaks cause damage to downstream areas. On the other hand, a grazing management system that increases the amount of water kept on-site may rightfully be charged with the cost of increased salinity downstream. Removal of livestock may be the only lasting solution to the salinity problem on highly saline lands.

Evapotranspiration is theorized to equal precipitation on areas receiving less than 16 inches of annual precipitation. Therefore, an increase of water kept on-site on highly and moderately saline lands should not add to salinity through interflow.

In order to have a viable salinity control program over the entire Upper Basin, grazing by all classes of animals on all lands will need to be properly managed. This includes wildlife and wild (feral) horses as well as domestic livestock. Wildlife and wild horse ranges can be depleted if animal numbers are not kept within limits of the available feed. Grazing should also be managed on private, state, and other federal lands. It is especially important when lands under various ownerships are intermingled. The responsibility for developing programs for these lands and to see they are carried out belongs to state and other federal agencies. Wild horse ranges may be difficult to manage because of public sentiment against trapping animals and possible shortage of homes for excess horses.

As outlined in sections IV.B.2. and 3., ORV use should be carefully controlled. Vehicles should be confined to established roads and trails, or special areas where the products of erosion can be impounded. Exploration for and extraction of minerals and fossil fuels should be carefully balanced, with salinity objectives made a definite part of the design and construction of facilities. It should be recognized that mining of areas with highly saline soils and geologic formations may potentially cause some increase of salt yields to waters downstream, no matter how much caution is exercised.

VI. PHYSICAL EFFECTS OF CONTROL MEASURES ON SAMPLE ALLOTMENTS

Six BLM grazing allotments, representative of lands and conditions contributing to salinity, were selected for study (see Figure VI-1). The Cisco, Utah area represents the most arid salt desert shrub site, on soils derived from the highly saline Mancos Formation. Annual precipitation here averages 7.66 inches. The Coal Creek and Soldier Creek allotments just east of Price, Utah represent the top of the arid salt desert shrub zone on marine soils and the lower reaches of the juniper-pinyon and big sagebrush types. Annual precipitation averages 9 to 12 inches. The Gypsum Valley allotments, south of Naturita, Colorado, are representative of juniper-pinyon breaks and badlands with interspersed broad alluvial valleys which support a mixture of short sod-forming grasses and shrubs. Annual precipitation averages about 16 inches and runoff is moderately saline. The Little Colorado allotment 25 miles north of Rock Springs, Wyoming is typical of a large area of the state which yields moderately saline runoff. The Stone Cabin allotment on the Book Cliffs northeast of Price, Utah, is typical of juniper-pinyon benches, big sagebrush valleys, high mountain grassland, mountain brush (deer browse), and aspen vegetation types. Annual precipitation ranges from 12 to 16 inches at the lower juniper-pinyon elevations up to 18 inches at the upper elevation mountain brush and aspen sites. This allotment represents nonsaline or slightly saline lands.

On each study site, vegetation was mapped and watershed condition characteristics determined (including evidence of present erosion, soil texture, amount of rock, percent ground cover, slope, etc.). A runoff factor was developed for each vegetative type on each allotment. This factor is a function of plant form, elevation, and precipitation. Factors were taken directly from Branson et al (14), where actual site conditions correlated closely with those listed in the handbook. Where site conditions (elevation, precipitation) on the allotments varied from those listed, the factor was changed to fit actual conditions. A factor for the concentration of salts in runoff water was developed for each major geologic formation (and related soils) on each allotment. Factors are related to water quality data collected during different seasons on or in the area of the study allotments.

A sediment yield factor was developed using the Pacific Southwest Inter-Agency Committee (PSIAC) (150) method for rating erosion potential, as modified by BLM, (26). A separate factor was developed for each vegetative community. A factor for the percent of salt in sediment was developed for each major geologic formation on each allotment studied. The weight of sediment per cubic foot was set at an average of 85 pounds (182).

The procedures followed in estimating annual runoff and sediment yields and accompanying salt load, from each allotment, are presented in the Soldier Creek example, Appendix XII-1. The basic data on runoff, sediment and salt yields for each allotment are presented in Appendix Table XII-1-1. The effects of proposed treatments to reduce these yields are presented in Appendix Table XII-1-2. A summary of the resulting data is shown in Table VI-1. Several proposed treatments were theoretically applied to each allotment.

Table VI-1. Summary of Existing Runoff, Sediment, and Salt Yields and Effects of Proposed Treatments on Reductions, by Allotments.

Yield/Year	Allotment Name					
	Cisco	Coal Creek	Soldier Creek	Gypsum Valley	Little Colorado	Stone Cabin
A. Existing Yields						
1. Total Runoff (ac-ft)	3,721	1,078	1,099	1,082	4,385	1,520
2. Total Sediment (tons)	509,461	39,725	49,121	59,753	504,577	42,821
3. Total Salt (tons)	19,480	1,540	1,597	1,178	6,867	600
a. From Runoff	6,088	999	1,008	530	3,923	449
b. From Sediment	13,392	541	589	648	2,944	151
B. Reduction in Yields by Treatments						
1. Removal of Livestock						
a. Runoff (ac-ft)	843	164	114	269	1,311	585
b. Sediment (tons)	208,128	9,862	8,755	19,308	159,918	14,658
c. Salt (tons)	7,524	372	314	403	2,143	208
2. Grazing Management						
a. Runoff (ac-ft)	511	118	83	184	861	348
b. Sediment (tons)	74,758	4,833	4,628	11,906	96,856	8,457
c. Salt (tons)	2,876	189	170	243	1,301	121
3. Contour Furrows and Trenches						
a. Runoff (ac-ft)	580	32		22	398	
b. Sediment (tons)	156,898	6,929		2,981	45,954	
c. Salt (tons)	6,284	294		68	627	
4. Detention Dams						
a. Runoff (ac-ft)	-0-	-0-	-0-	-0-	-0-	
b. Sediment (tons)	176,529	25,463	39,965	41,180	385,587	
c. Salt (tons)	3,664	142	419	473	2,244	
5. Retention Dams						
a. Runoff (ac-ft)	2,487	1,026	1,056	784	3,702	
b. Sediment (tons)	196,143	28,292	44,406	45,756	427,958	
c. Salt (tons)	6,970	1,054	1,404	920	5,805	

Selection of treatments for each of the allotments was based upon site factors expected to affect the technical feasibility of each treatment. For example, contour furrows were not proposed for sites with slopes above 15 percent and having shallow soils. However, contour trenches were proposed on slopes between 15 and 30 percent where soils are at least 2 feet deep. Table VI-1 also shows a summary of the expected results of each treatment theoretically applied to the study allotments. The data presented in this section and in Appendix XII-1 are used in the economic analysis outlined in section VII and Appendix XII-2.

Information gathered from the six sample allotments was extrapolated to all saline public lands in the Upper Basin. The acreage of all lands in each saline class (Table VI-2) was determined from the salinity classes of rocks (surficial geology) developed by Don Price and presented in Table IV-1. Acreages of all highly and moderately saline lands were determined by eliminating the lands in both categories receiving more than 16 inches of average annual precipitation (see Figure IV-1). This left only those lands not subject to heavy leaching. The acreage of public lands in each class was finally determined by applying a factor representing the percent of public lands in each of the states of Colorado, Utah, and Wyoming (see Table VI-2). The ratio of acreages in the sample allotments, to the total public lands in each salinity class, in each state, was used to extrapolate total runoff, sediment, and salt yielded and volumes of each that would be reduced by the treatments.

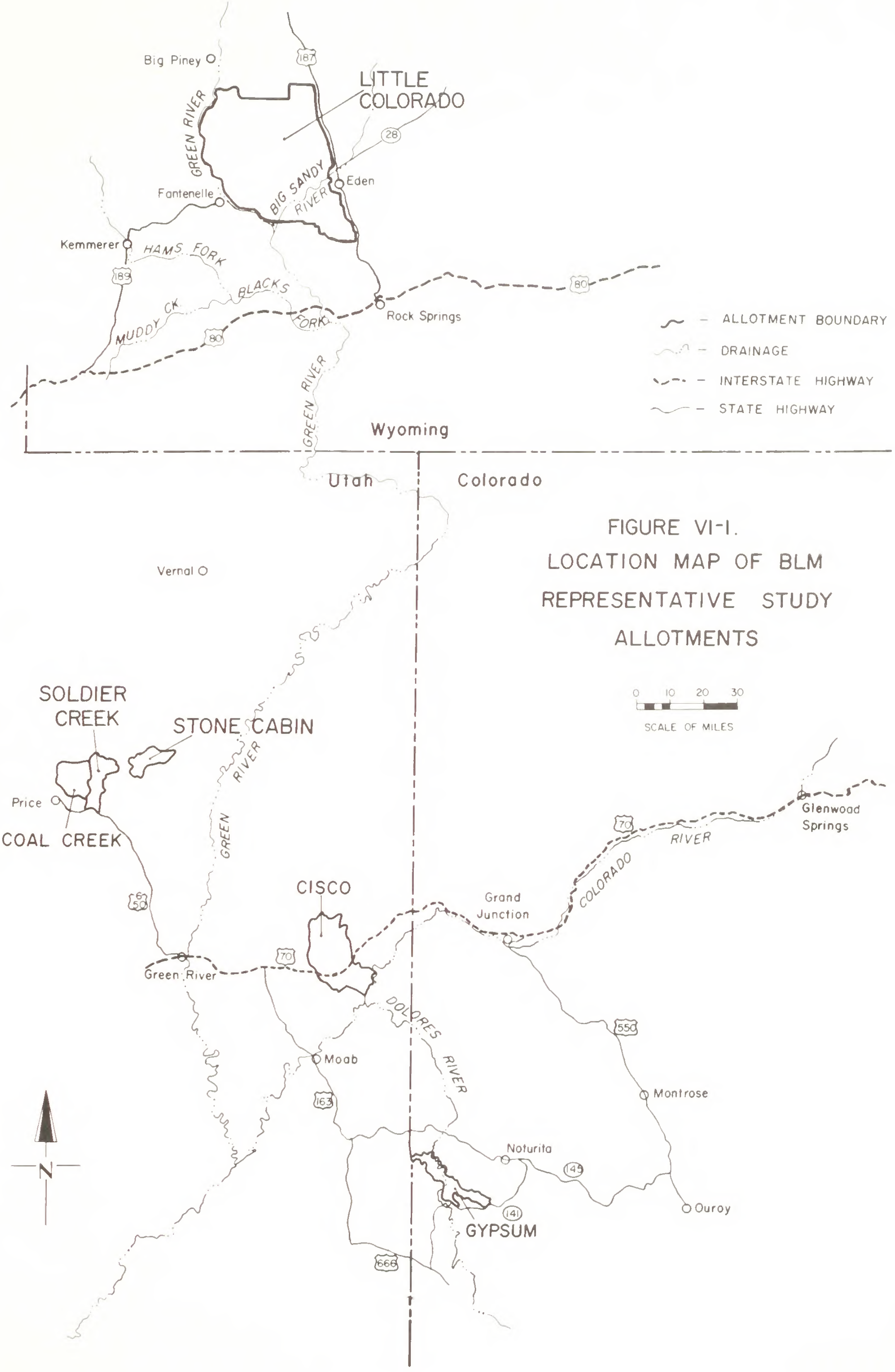

FIGURE VI-1. LOCATION MAP OF BLM REPRESENTATIVE STUDY ALLOTMENTS

Table VI-2. Saline Public Lands in the Upper Basin.

State	Non & Slightly Saline	Moderately Saline	Highly Saline
Colorado	5,657,070	713,448	469,482
Utah	8,765,609	1,605,498	2,284,893
Wyoming	3,952,122	3,473,510	435,368
TOTAL	18,374,801	5,792,456	3,189,740
Total Moderately and Highly Saline	8,982,196		
GRAND TOTAL	27,356,997		

VII. ECONOMIC FEASIBILITY OF SALINITY CONTROL

A. Relationship Between Resources & Economic Analysis

The following is a discussion of important items affecting the economic analysis of salinity control in the Colorado River. Benefits [1] occur through reduction of the average annual salt concentration and are a reflection of reduced costs to agricultural, municipal, and industrial water users. Section III describes the adverse effects of salinity (dollars per mg/l annually) to Lower Basin water users (Figure III-1). Appendix Tables XII-2-6A and 6B present the annual reductions in runoff, sediment, and salt and the net change in salt concentration at Imperial Dam, resulting from alternative treatments. These physical data provide the basis for direct quantification of benefits through salinity control. Appendix XII-2 describes the calculation procedure used.

An economic feasibility analysis requires the identification of the alternative that yields the greatest benefits for any given cost. No attempt was made to quantify all benefits or costs; for example, potential livestock production, wildlife, or recreation benefits. Some information was not available or would have been too costly to obtain, some was not applicable. Increases in forage quantity and improved quality (increase in desirable species) may occur. Because of uncertainties of future forage allocations, these potential benefits were excluded. Also it can be argued that future increases in vegetal cover would be reserved for watershed protection, especially on highly saline lands. If increased forage was allocated to livestock production, sediment and salt reductions would decrease. The value of salinity reductions may more than offset increases in livestock or wildlife benefits on highly and moderately saline lands. Other benefits accruing to livestock, wildlife, and recreation and resulting from improved management were not considered because they are not directly related to the salinity problem.

Figure VII-1 illustrates the problem of identifying total benefits of reducing salinity and sediment resulting from changes of intensity in livestock use. It can be seen that the amount of salt and sediment kept on-site decreases as the volume of forage consumed increases. Conversely, livestock production increases as forage consumption increases. The relationships shown in Figure VII-1 are only general in nature and can change with the percent of salt in the soil, steepness of slope, percent vegetative cover, and other variables relating to runoff and erosion.

Salinity control measures were found to be counter productive on nonsaline and slightly saline lands. The objective of each alternative salinity control measure, considered during the BLM study, was to reduce salinity damages resulting from use of Colorado River water in the Lower Basin. The control measures will retain sediment and salt on slightly saline lands, but they also retain significant quantities of relatively salt-free water. Because the salt concentration of this runoff is lower than water measured at Imperial Dam, it reduces the concentration of salts by dilution. Keeping this water on-site, then, would cause an increase in salinity concentrations at Imperial Dam and potential salinity damages to Lower Basin water users. Therefore, no further economic analysis was made on nonsaline and slightly saline lands.

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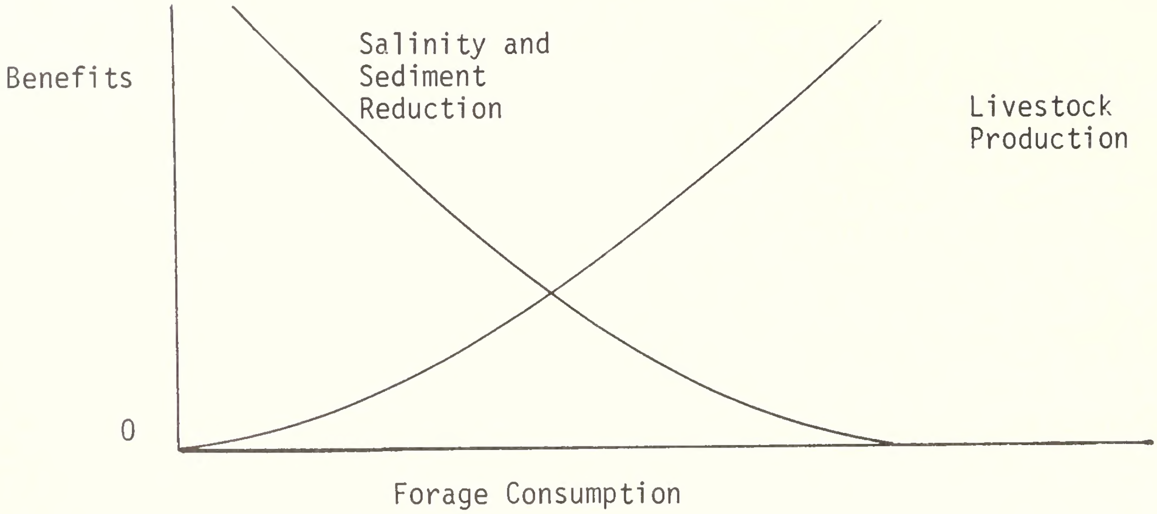
[1] Benefit is the value (in monetary terms) of products or services resulting from some activity for which associated costs would be incurred.

Figure VII-1. Trade-off Relationship Between Salinity and Sediment Reduction Benefits and Livestock Production Benefits at Various Levels of Forage Consumption on Saline Lands.



B. Benefit-Cost Analysis

Information derived from five of the six allotments described in Section VI was used to develop the data required for an economic analysis of all highly and moderately saline public lands in the Upper Basin. This information includes the total amount of runoff, sediment and salt from the allotments; amounts of each reduced by the several control measures; and number of facilities and treatments needed to accomplish the controls. Table VII-1 outlines the required facilities. Table VI-2 lists the acres of each class of saline lands by state.

Three alternative practices were considered to be potentially useful for controlling salinity, based on the analyses portrayed in Section V. These are:

1. Grazing management

2. Removal of domestic livestock

3. Structures and land treatments, i.e., detention dams, retention dams, and contour furrows-trenches.

Table VII-2 summarizes the effects of each salinity control measure on both highly and moderately saline lands in the Upper Basin. Structures (detention and retention dams) and land treatments (contour furrows) are not economically feasible on moderately saline lands with benefit-cost ratios of approximately 0.3 to 1. However, retention dams and contour furrows on highly saline lands are economically feasible with a benefit-cost ratio of 1.01 to 1. Grazing management on highly saline lands is marginal, with a benefit-cost ratio of 0.90 to 1, and not feasible on moderately saline lands (0.37 to 1). Removal of livestock grazing from both the highly and moderately saline lands is the most economically efficient practice, with benefit-cost ratios of 4.63 to 1 and 1.48 to 1, respectively.

Table VII-1 Number of Range Improvements, Structures, and Land Treatments Needed for Each Salinity Control Alternative

Alternatives and Facilities	Highly Saline Lands		Moderately Saline Lands		
	New Control Measure(s)	Existing Control Measure(s)	New Control Measure(s)	Existing Control Measure(s)	Average Cost($)
Grazing Management					
Fence	239	621	874	1,855	2,300/mile
Cattleguard	33	75	80	228	1,700/each
Water Catchment	370	0	1,020	0	12,000/each
Spring	0	88	0	60	2,300/each
Pipeline	0	17	0	200	2,500/mile
Water Trough	0	21	0	133	200/each
Reservoir (small)				229	13,900/each
Well	0	0	156	372	20,500/each
Removal of Grazing					
Fence		610	0	823	2,300/mile
Cattleguard		54	0	52	1,700/each
Structures & Land Treatment					
Detention Dam					
Large	480	0	1,445	0	68,700/each
Small	119	54	0	0	17,100/each
Small (Conversion from Retention Dam	108	0	0	0	5,000/each
Contour Furrows (acres)	1,142,814	98,224	555,626	0	14/acres
Retention Dam					
Large	480	0	1,445	0	63,600/each
Small	119	108			13,900/each
Small (Conversion from Detention Dam)	54	0	0	0	5,000/each
Contour Furrows		98,224	555,626	0	14/acres

Table VII-2. Summary of the Effects on Salinty of Control Measures on Highly and Moderately Saline Lands in the Upper Basin.

Alternatives	Water Retained acre-feet	Sediment Reduced tons/yr	Salt Reduced tons/yr	Salt Concentration Change mg/liter/yr	Forage Reduced AUMs/yr	Present Value Benefits $1,000	Present Value Costs $1,000	Net Benefits $1,000	Benefit Cost Ratio
GRAZING MANAGEMENT									
Highly Saline (3 million acres)	7,752	917,011	35,911	- 2.43	20,500	19,700	21,900	- 2,100	0.90:1
Moderately Saline (6 million acres)	13,984	1,101,378	19,303	- 0.39	3,057	11,300	30,500	- 19,200	0.37:1
LIVESTOCK REMOVAL									
Highly Saline	12,206	2,468,598	89,437	- 6.86	95,024	54,700	11,800	+ 42,900	4.63:1
Moderately Saline	20,693	1,799,653	31,855	- 0.88	322,566	19,700	13,300	+ 6,419	1.48:1
STRUCTURES & LAND TREATMENTS									
Highly Saline									
Detention Dams & Contour Furrows	6,663	4,474,037	119,110	-10.08	0	87,600	90,000	- 2,402	0.97:1
Retention Dams & Contour Furrows	56,412	4,733,554	175,185	-10.32	0	91,000	90,100	+ 904	1.01:1
Moderately Saline									
Detention Dams & Contour Furrows	3,081	4,425,203	44,084	- 3.67	0	55,800	176,100	-119,300	0.32:1
Retention Dams & Contour Furrows	41,579	4,874,732	85,055	- 3.64	0	59,500	181,900	-122,400	0.33:1

Net benefits of salt and sediment reductions are highest through removal of livestock on highly and moderately saline lands ($43 million and $6 million, respectively). Only one other alternative--retention dams with contour furrows on highly saline lands--had positive net benefits (Table VII-2). On highly saline lands, it is interesting to note that while detention dams and contour furrows had a higher benefit-cost ratio than grazing management, the loss of net benefits was higher for detention dams and contour furrows ($2.1 million as compared to $2.4 million). This is a reflection of the higher facility costs associated with detention dams and contour furrows versus grazing management. Therefore, grazing management on highly saline lands could conceivably be the more attractive alternative.

From a strict economic efficiency standpoint, salinity control through removal of livestock grazing is the most feasible practice. However, it is unlikely that livestock would be removed from moderately saline lands solely for salinity control. Unlike the highly saline lands, these lands are generally good producers of perennial livestock forage. It must be remembered that the economic analysis, which resulted in a benefit-cost ratio of 0.37 to 1 for grazing management, included all costs of reducing salinity through control of livestock grazing. However, benefits of this single purpose analysis of grazing management include only those accruing to salinity. Those benefits not relating to salinity, i.e., increased livestock production, improved wildlife habitat, recreation, etc., were not considered. Benefits to these activities would be important to an economic analysis of an overall resource management program, and when considered, could significantly increase the benefit-cost ratio.

An argument may also be made for salinity control through grazing management on moderately saline lands versus control through detention-retention dams and contour furrows, when the net benefits of these two alternatives are compared. The loss of net benefits is much less with grazing management (-$19,200,000) than with dams and furrows (-$120,000,000). Grazing management on moderately saline lands (6 million acres), can become a cost effective control measure, when combined with elimination of grazing on the highly saline lands (3 million acres). The overall benefit-cost ratio of the combined alternatives is favorable at 1.56 to 1.

Salinity control measures applied to nonsaline and slightly saline lands would result in increased salt concentrations at Imperial Dam, as shown in Table VII-3. These increases explain why no control measures were proposed for such lands. Such practices as grazing management could be charged with a cost of increasing salinity if significant quantities of water are kept on-site.

Removal of livestock grazing may occur on certain highly saline public lands through means other than a formal salinity control program. New soil and vegetation inventories are planned by BLM as a means of gathering information for grazing environmental statements. This information will ultimately lead to new range use suitability classifications. Lands with highly saline soils, low vegetative cover, low forage production (present and potential), and highly erosive soils will be identified. They will most probably be classified as either unsuited for continuation of grazing, or for reductions in stocking rates and/or change in season of grazing, to achieve watershed (salinity) objectives. In these instances, salinity reductions would be achieved with little or no costs.

Table VII-3. Effects of Salinity Control Measures Applied to Nonsaline and Slightly Saline Lands

Alternatives	Water Retained (ac-ft/yr)	Sediment Reduced (tons/yr)	Salt Reduced (tons/yr)	Change in Concentration (± mg/l)
1. Grazing Management 1/				
Colorado	66,009	1,599,527	22,886	+ 4.4
Utah	102,280	2,478,460	35,461	+ 6.8
Wyoming	46,115	1,117,456	15,988	+ 3.1
TOTAL	214,404	4,195,443	74,335	+14.3
2. Grazing Removal (Livestock) 2/				
Colorado	110,645	2,772,360	39,340	+ 7.3
Utah	171,444	4,295,760	60,958	+11.3
Wyoming	77,298	1,936,820	27,484	+ 5.1
TOTAL	359,387	9,004,940	127,782	+23.7

1/ AUMs shown are usable AUMs under proposed grazing management systems.

2/ AUMs shown would be lost by removal of livestock grazing and are based on the present licensed use. The impact is based on the assumption that wildlife grazing would be controlled at the present level.

VIII. REGIONAL ECONOMIC EFFECTS OF SALINITY CONTROL

A. Procedures Used for Regional Analysis

Two regions have been delineated for the purpose of analyzing the likely effects of salinity control upon related economies. The Upper Basin region is defined by the county boundaries most closely conforming to the hydrologic region (see Figure III-1). The Lower Basin agriculture economic region made up of Imperial County, California and Yuma County, Arizona has also been defined to assess downstream agricultural impacts.1/

While beneficial impacts can be expected in the municipal and industrial (M&I) economic region (as described in Section III.B.), such impacts are not further analyzed here, because they accrue only to the household sector of the economy. Households typically spend a fixed proportion of income for consumption items. Improved water quality would allow households to shift "cost" expenditures to more desired items, but would not affect the total flow of income of the regional economy. These benefits were included, however, in the analysis of the previous section. Industrial impacts (see Section III.C.) are considered to be too small to analyze.

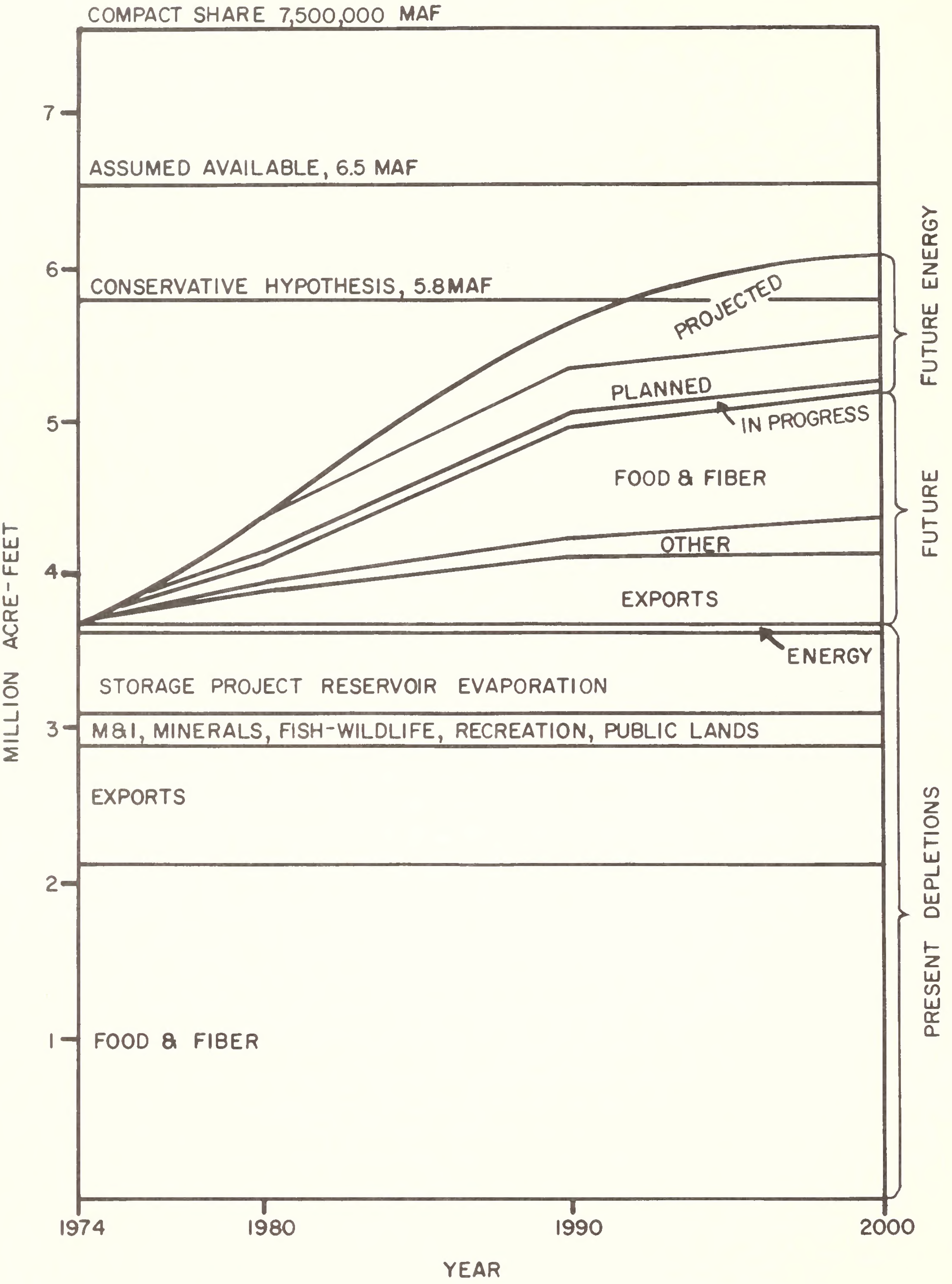
The basic approach used in the measurement of regional economic impacts is to compute the estimated change in annual flow of industry earnings, which are expected to result from the construction activity, salt reduction, and other effects of a control program (see Appendix XII-3.B. for rationale). All economic measures have been adjusted to a 1980 base year. (See Appendix XII-3.A. for a detailed explanation of methodology). Adjustment to a 1980 base year and the use of industry earnings rather than output prices, preclude a one-to-one relationship to data presented in Section VII. However, the analyses of Sections VII and VIII are based on identical data regarding the effects of salinity control actions.

Upper Basin impacts result from construction activity, the effect (if any) on the quantity of agricultural water available for use in the three Upper Basin states, and the reduction of forage use by domestic livestock. Construction costs used in Section VII (updated to a 1980 base) are assumed to be expended in the Upper Basin during the period 1980 to 1985. Costs (gross receipts to the construction industry) are converted to industry earnings based on output-earnings ratios of the 1971 national input-output (I-O) tables (see Appendix XII-3.B.).

Figure VIII-1 displays Upper Basin water use from 1974 to 2000 as compared to three possible levels of water availability. Table VIII-1 shows the state component breakdown. From these data it is assumed that water retained on-site by control measures would not cause a reduction in acreage of irrigated agriculture in the Upper Basin until the year 2000. However, beginning in 1990, it is assumed that diminishing supples of surplus water will cause an annual cost increase to agriculture in Colorado and Utah. This cost is estimated as being a time function approaching the projected value of an acre-foot of water, at the point where irrigated land may go out of production. (See Appendix XII-3.C. for computations.)

1/ Impact is the ultimate change from a baseline condition of a cause-effect sequence.

Figure VIII-1. Upper Colorado River Basin Water, 1974 to 2000



Source: Report on Water for Energy in the Upper Colorado River Basin, Bureau of Reclamation, July 1974 (32).

Table VIII-1. Upper Basin Water Use in 1974 and Projected to 2000, Related to Share at Three Levels of Availability (Millions of Acre-feet)

State	Use Level		State Share		
	1974	2000	7.5 MAF	6.5 MAF	5.8 MAF
Colorado	2.2	3.2	3.8	3.3	3.0
Utah	0.8	1.4	1.7	1.5	1.3
Wyoming	0.4	0.7	1.0	0.9	0.8

Effects on the livestock industry in the Upper Basin are computed by relating earnings of the industry, to feed consumption measured in animal unit months (AUMs).[2] Average earnings per AUM are estimated to be $8.20 (1980 dollars). This figure is used to assess changes in forage availability to domestic livestock.

Impacts on Lower Basin agriculture result from a reduction of salt concentration in irrigation water. The net return data (Section III.A.), adjusted to 1980 dollars ($35,400 per mg/l; see Appendix XII-3.A.) is directly applied to salt concentration data for an estimate of changes in agricultural earnings.

B. Direct Impacts of Control Measures

As developed in Section V, salinity control could take a variety of forms (removal of livestock, grazing management, retention or detention dams combined with contour furrows), and can be applied to saline lands in various combinations. Each control option would have a different effect upon physical relationships (as described in Section V) depending upon the type of action and the degree of salinity associated with the treated land. Consequently, each option would have a different impact on the earnings (personal income) flow of related regional economies.

Table VIII-2A displays the direct effects and related impacts on industry earnings for each control option as applied to highly saline public lands (approximately 3 million acres). Table VIII-2B displays the same type of information for moderately saline public lands (approximately 6 million acres). The annual impacts on industry earnings shown in the tables are not necessarily juxtaposed in time, i.e.:

- New construction impacts would be present for a period of time (1980 to 1985) and then decrease to maintenance levels;
- Livestock impacts would be subsequent to construction, but maintain the level shown indefinitely;

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[2] Animal Unit Month (AUM) is defined as the forage required to support one mature cow for 1 month.

Table VIII-2A. Upper Basin Direct Effects of Salinity Control on Highly Saline Public Lands and Related Primary Impacts on Economic Sectors, in 1980 Dollars.

				Construction Costs		Related Annual Impacts on Industry Earnings ($1,000)				
						Upper Basin				Lower Basin
Control Option	Reduction in Livestock Use (AUM)	Reduction in Salt (mg/liter)	Water Retained (acre-ft)	New ($1,000)	Annual Maintenance ($1,000)	New Const.	Maint. Const.	Live-stock	Other Agr.	Agri-culture
Grazing Mgmt. (total)	20,500	2.43	7,800	5,100	100	500	small	- 200	- 100	100
Colorado	3,000	0.36	1,100	800	small 1/					
Utah	14,700	1.73	5,600	3,600	small					
Wyoming	2,800	0.34	1,100	700	small					
Removal of Livestock (total)	95,100	6.86	12,200	0	small	0	small	- 800	- 100	200
Colorado	14,000	1.01	1,800							
Utah	68,100	4.91	8,700							
Wyoming	13,000	0.94	1,700							
Detention Dams (total)	0	10.08	6,700	55,600	1,500	5,500	700	0	-small	400
Colorado		1.47	1,000	8,200	200					
Utah		7.24	4,800	39,800	1,100					
Wyoming		1.37	900	7,600	200					
Retention Dams (total)	0	10.32	56,400	52,200	1,500	5,100	700	0	- 400	400
Colorado		1.51	8,300	7,700	200					
Utah		7.40	40,400	37,400	1,100					
Wyoming		1.41	7,700	7,100	200					

1/ Small indicates estimates are too small to measure.

Table VIII-2B. Upper Basin Direct Effects of Salinity Control on Moderately Saline Public Lands and Related Primary Impacts on Economic Sectors, in 1980 Dollars.

Control Option	Reduction in Livestock Use (AUM)	Reduction in Salt (mg/liter)	Water Retained (acre-ft)	Construction Costs		Related Annual Impacts on Industry Earnings ($1,000)				
				New ($1,000)	Annual Maintenance ($1,000)	Upper Basin				Lower Basin Agri-culture
						New Const.	Maint. Const.	Live-stock	Other Agr.	
Grazing Mgmt. (total)	3,000	0.39	13,900	18,900	500	1,900	200	- small	- 100	small 1/
Colorado	900	0.07	3,000	2,300	100					
Utah	2,100	0.16	6,800	5,200	100					
Wyoming	0	0.16	4,100	11,400	300					
Removal of Livestock (total)	322,700	0.88	20,700	0	small	0	small	- 2,600	- 100	small
Colorado	34,700	0.18	4,400							
Utah	78,000	0.38	10,000							
Wyoming	210,000	0.32	6,300							
Detention Dams (total)	0	3.67	3,100	115,300	2,900	11,300	1,400	0	-small	100
Colorado		0.76	400	14,200	400					
Utah		1.70	800	32,000	800					
Wyoming		1.21	1,900	69,100	1,700					
Retention Dams (total)	0	3.64	41,600	107,400	2,900	10,500	1,400	0	- 300	100
Colorado		0.81	6,800	13,200	400					
Utah		1.80	15,200	29,800	800					
Wyoming		1.03	19,600	64,400	1,700					

1/ Small indicates estimates are too small to measure.

- Upper Basin agriculture impacts would not reach the level shown until the decade of the 1990s; and

- Lower Basin impacts would follow construction in the Upper Basin and continue indefinitely.

Grazing management, for example, when applied to highly saline lands, would cost (in 1980 dollars) about 5.1 million dollars, for construction, and require a reduction of about 20,500 AUMs of livestock use. Construction expenditure, spread over the period 1980-84, would increase annual earnings in the construction industry of the Upper Basin by about a half million dollars during the period. Construction activity would drop to maintenance levels by 1985, while the reduction in livestock would cause livestock industry earnings to decline by about 200,000 dollars per year. The salt reduction would allow agricultural earnings in the Lower Basin to increase about 100,000 dollars annually. However, agricultural earnings in the Upper Basin would decline by about 100,000 dollars each year, during the decade of the 1990s, because of the water retained on-site.

The types of impacts described above result directly from salinity control actions; secondary (or indirect) impacts can be estimated from linked impacts, which come about from the interdependency of industries within an economy. In the following paragraphs, secondary impacts are estimated for three combinations of control measures. Earnings multipliers were developed for 20 industries in each of the two regions based on a model which estimates net trade flows of a region (see Appendix XII-3.D. for reference). Sectoral impacts are estimated from both "backward linkage" and "comparative advantage" components of the model.

C. Total Regional Impacts of Selected Alternatives

Each control measure applied to highly saline lands can be combined with any one of the control measures on moderately saline lands; there are, therefore, 16 possible combinations or salinity control alternatives. Using the feasability analysis of Section VII, three alternatives have been selected for further analysis regarding their possible total impact on the regional economies of the Upper and Lower Basins. In each case, base year earnings data are presented for 1980 and projected to 1985 and 1995 without salinity control action (based on OBERS projections, see Appendix XII-3.A.). Both direct and indirect changes in earnings are then estimated for control alternatives as they might occur in each period. Impacts are then "netted out" for 1995 for the purpose of comparison.

1. Alternative One: Removal of Livestock from all Saline Lands (approximately 9 million acres)

This alternative has the highest benefit-cost ratio because of the relatively low cost of implimentation. However, its adverse impacts on the Upper Basin are rather substantial, as can be seen from Table VIII-3A.

Table VIII-3A. Upper Basin Primary and Secondary Annual Economic Impacts, 1980-1995--Alternative 1. 2/
(1980 dollars)

Sector/Industry	Base Year: 1980		Impacts: 1980-84 Earnings ($1,000)	1985 Earnings Without Action ($1,000)	Impacts: 1985-94 Earnings ($1,000)	1995 Earnings Without Action ($1,000)	1995 Earnings With Action ($1,000)
	Earnings ($1,000)	Employment (Number)					
AGRICULTURE							
Livestock	88,300	6,500	-4,060	95,400	small 1/	112,300	108,200
Other agriculture	47,000	4,900	-1,380	50,800	- 200	59,800	58,200
MINING							
Metal mining	40,400	2,400		40,400		41,600	41,600
Coal mining	30,300	1,800		34,200		43,300	43,300
Oil & gas extraction	34,000	1,100		34,000		34,000	34,000
Other mining	4,700	300		4,700		4,700	4,700
CONSTRUCTION	101,600	7,500		115,800	- small	151,800	151,800
MANUFACTURING							
Food & kindred prods.	10,600	800	- 360	11,500		13,800	13,400
Lumber & related prods.	20,100	1,000		22,700		29,300	29,300
Paper & allied prods.	0	0		0		0	0
Petroleum refining	6,800	600		7,800	- small	9,800	9,800
Primary metals	2,800	200		3,100		4,000	4,000
All other mfg.	52,900	4,800	- 210	63,000	- small	89,300	89,100
TRANS. and COMM.	84,400	6,700	- 200	99,600	- small	139,800	139,600
PUBLIC UTILITIES	54,000	3,100		64,300	- small	91,000	91,000
WHOLS. & RETL. TRADE	208,600	21,800	- 330	237,800	- small	309,100	308,800
FIN., INS. & R.E.	47,600	4,400	- 70	58,100	- small	86,500	86,400
SERVICES	267,400	24,800	- 90	328,900	- small	497,700	497,600
FEDERAL GOV'T.	95,500	6,800		111,700		152,900	152,900
STATE & LOCAL GOV'T.	195,300	9,700		236,300		345,900	345,900
TOTAL 3/	1,392,300	109,300	-6,700	1,620,100	- 200	2,216,600	2,209,700

1/ Small indicates estimates are too small to measure.
2/ Removal of livestock from all saline lands (approximately 9 million acres).
3/ May not add due to rounding.

The annual flow of Upper Basin earnings (personal income) would be reduced about 6.7 million dollars beginning in the early 1980s with an additional reduction in the 1990s of slightly over 200,000 dollars. Therefore, income by 1995 would be approximately 7 million dollars a year less than it otherwise would be without the salinity control alternative. Table VIII-3A also indicates which economic sectors would be most affected. About 575 people would lose their jobs with slight chance of reemployment within the region. An estimated 1,000 persons would probably emigrate from the region, as the head of household seeks employment in areas of lower unemployment.

The Lower Basin economy would experience less than a half million dollar per year increase in personal income; the majority would be derived from the agricultural sector. Essentially the same Lower Basin impacts can be expected from Alternative Two (see Table VIII-4).

2. Alternative Two: Removal of Livestock from Highly Saline Lands (3 million acres) and Grazing Management on Moderately Saline Lands (6 million acres)

This alternative maintains positive impacts on the Lower Basin, while greatly reducing adverse impacts on the Upper Basin, by substituting the grazing management alternative for the removal of livestock on moderately saline lands. The grazing management control measure, however, does not have a favorable benefit-cost ratio based on salinity objectives alone (see Section VII), although the alternative as a whole would be economically feasible. Grazing management on moderately saline lands was selected instead of detention-retention dams and contour furrows, on the basis of net benefits, as shown in Table VII-2.

Table VIII-3B displays the impacts of this alternative on the Upper Basin. Construction expenditures during the period 1980-84, associated with the grazing management control measure more than offset the loss of income caused by the removal and reduction of livestock; of course different sectors of the economy would be affected differently as shown in the table. The net effect for the period would be a temporary 1.2 million dollar increase in the region's annual flow of personal income.

In the following period (1985-94) when construction activity is reduced, the Upper Basin's economy would contract by 2.7 million dollars in earnings. Therefore, 1995 earnings (personal income) would be 1.5 million dollars less than it would be without implementation of the alternative.

3. Alternative Three: Detention Dams on Highly Saline Lands (3 million acres) and Grazing Management on Moderately Saline Lands (6 million acres)

Detention dams were selected for analysis even though retention dams showed a higher benefit-cost ratio (see Table VII-2). The effects of both kinds of dams on reductions of salt concentration at Imperial Dam are essentially the same (see Table VIII-2A). However, the amount of water retained is significantly less with detention dams. Adverse impacts on Upper Basin agriculture are less when water is allowed to flow to the Lower Basin, thus satisfying demand for water identified in the Colorado River Compact of 1922.

Table VIII-3B. Upper Basin Primary and Secondary Annual Economic Impacts, 1980-1995--Alternative 2. 4/
(1980 Dollars)

Sector/Industry	Base Year: 1980 Earnings ($1,000)	Base Year: 1980 Employment (Number)	Impacts: 1980-84 Earnings ($1,000)	1985 Earnings Without Action ($1,000)	Impacts: 1985-94 Earnings ($1,000)	1995 Earnings Without Action ($1,000)	1995 Earnings With Action ($1,000)
AGRICULTURE							
Livestock	88,300	6,500	- 920	95,400	- small	112,300	111,400
Other agriculture	47,000	4,900	- 310	50,800	- 200	59,800	59,300
MINING							
Metal mining	40,400	2,400	small 1/	40,400		41,600	41,600
Coal mining	30,300	1,800	small	34,200		43,300	43,300
Oil & gas extraction	34,000	1,100	small	34,000		34,000	34,000
Other mining	4,700	300	small	4,700	- small	4,700	4,700
CONSTRUCTION	101,600	7,500	1,940	115,800	- 1,700	151,800	152,000
MANUFACTURING							
Food & kindred prods.	10,600	800	- 80	11,500		13,800	13,700
Lumber & related prods.	20,100	1,000	small	22,700	- 70	29,300	29,200
Paper & allied prods.	0	0		0		0	0
Petroleum refining	6,800	600	small	7,800	- small	9,800	9,800
Primary metals	2,800	200		3,100	- small	4,000	4,000
All other mfg.	52,900	4,800	-small	63,000	- 310	89,300	89,000
TRANS. and COMM.	84,400	6,700	small	99,600	- 60	139,800	139,700
PUBLIC UTILITIES	54,000	3,100	small	64,300		91,000	91,000
WHOLS. & RETL. TRADE	208,600	21,800	70	237,800	- 197	309,100	309,000
FIN., INS. & R.E.	47,600	4,400	small	58,100	- small	86,500	86,500
SERVICES	267,400	24,800	180	328,900	- 110	497,700	497,800
FEDERAL GOV'T.	95,500	6,800	small	111,700		152,900	152,900
STATE & LOCAL GOV'T.	195,300	9,700	160	236,300		345,900	346,100
TOTAL 3/	1,392,300	109,300	1,200	1,620,100	- 2,700	2,216,600	2,215,100

1/ Small indicates estimates are too small to measure.
3/ May not add due to rounding.
4/ Removal of livestock from highly saline lands (3 million acres) and grazing management on moderately saline lands (6 million acres).

This alternative nearly doubles favorable impacts in the Lower Basin (see Table VIII-4). The increased construction activity and minimum reduction in livestock use in the Upper Basin would result in an increase of 1.5 million dollars in annual earnings by 1995 (see Table VIII-3C). However, both options of this alternative are not economically feasible based on the analysis in Section VII.

The apparent anomaly of infeasible actions resulting in favorable impacts reflects the role played by construction costs in the two types of economic analysis. In short, construction expenditures would create income and employment in the Upper Basin, but the benefits derived from the constructed projects would not be sufficient to cover their costs. Therefore, Alternative Three, if implemented, would represent a net transfer from the rest of the nation to the Colorado River regions.

Figure VIII-2 provides a visual summary of the regional economic impacts which could occur from implementing any of three possible salinity control alternatives. Other combinations of control options can be analyzed from the data in Tables VIII-2A and 2B and the industry multipliers shown in Appendix XII-3.D.

Table VIII-3C. Upper Basin Primary and Secondary Annual Economic Impacts, 1980-1995--Alternative 3. 5/
(1980 Dollars)

Sector/Industry	Base Year: 1980 Earnings ($1,000)	Base Year: 1980 Employment (Number)	Impacts: 1980-84 Earnings ($1,000)	1985 Earnings Without Action ($1,000)	Impacts: 1985-94 Earnings ($1,000)	1995 Earnings Without Action ($1,000)	1995 Earnings With Action ($1,000)
AGRICULTURE							
Livestock	88,300	6,500	150	95,400	- small	112,300	112,500
Other agriculture	47,000	4,900	50	50,800	- 100	59,800	59,700
MINING							
Metal mining	40,400	2,400	80	40,400		41,600	41,700
Coal mining	30,300	1,800	60	34,200		43,300	43,400
Oil & gas extraction	34,000	1,100	130	34,000		34,000	34,100
Other mining	4,700	300	small 1/	4,700	- 50	4,700	4,600
CONSTRUCTION	101,600	7,500	7,600	115,800	- 6,500	151,800	152,900
MANUFACTURING							
Food & kindred prods.	10,600	800	small	11,500		13,800	13,800
Lumber & related prods.	20,100	1,000	120	22,700	- 290	29,300	29,100
Paper & allied prods.	0	0		0		0	0
Petroleum refining	6,800	600	small	7,800	- 50	9,800	9,700
Primary metals	2,800	200	small	3,100	- 140	4,000	3,900
All other mfg.	52,900	4,800	170	63,000	- 1,160	89,300	88,300
TRANS. and COMM.	84,400	6,700	310	99,600	- 230	139,800	139,900
PUBLIC UTILITIES	54,000	3,100	120	64,300		91,000	91,100
WHOLS. & RETL. TRADE	208,600	21,800	590	237,800	- 740	309,100	309,000
FIN., INS. & R.E.	47,600	4,400	120	58,100	- 50	86,500	86,600
SERVICES	267,400	24,800	830	328,900	- 420	497,700	498,100
FEDERAL GOV'T.	95,500	6,800	170	111,700		152,900	153,100
STATE & LOCAL GOV'T.	195,300	9,700	670	236,300		345,900	346,600
TOTAL 3/	1,392,300	109,300	11,200	1,620,100	- 9,700	2,216,600	2,218,100

1/ Small indicates estimates are too small to measure.

3/ May not add due to rounding.

5/ Detention dams on highly saline lands (3 million acres) and grazing management on moderately saline lands (6 million acres).

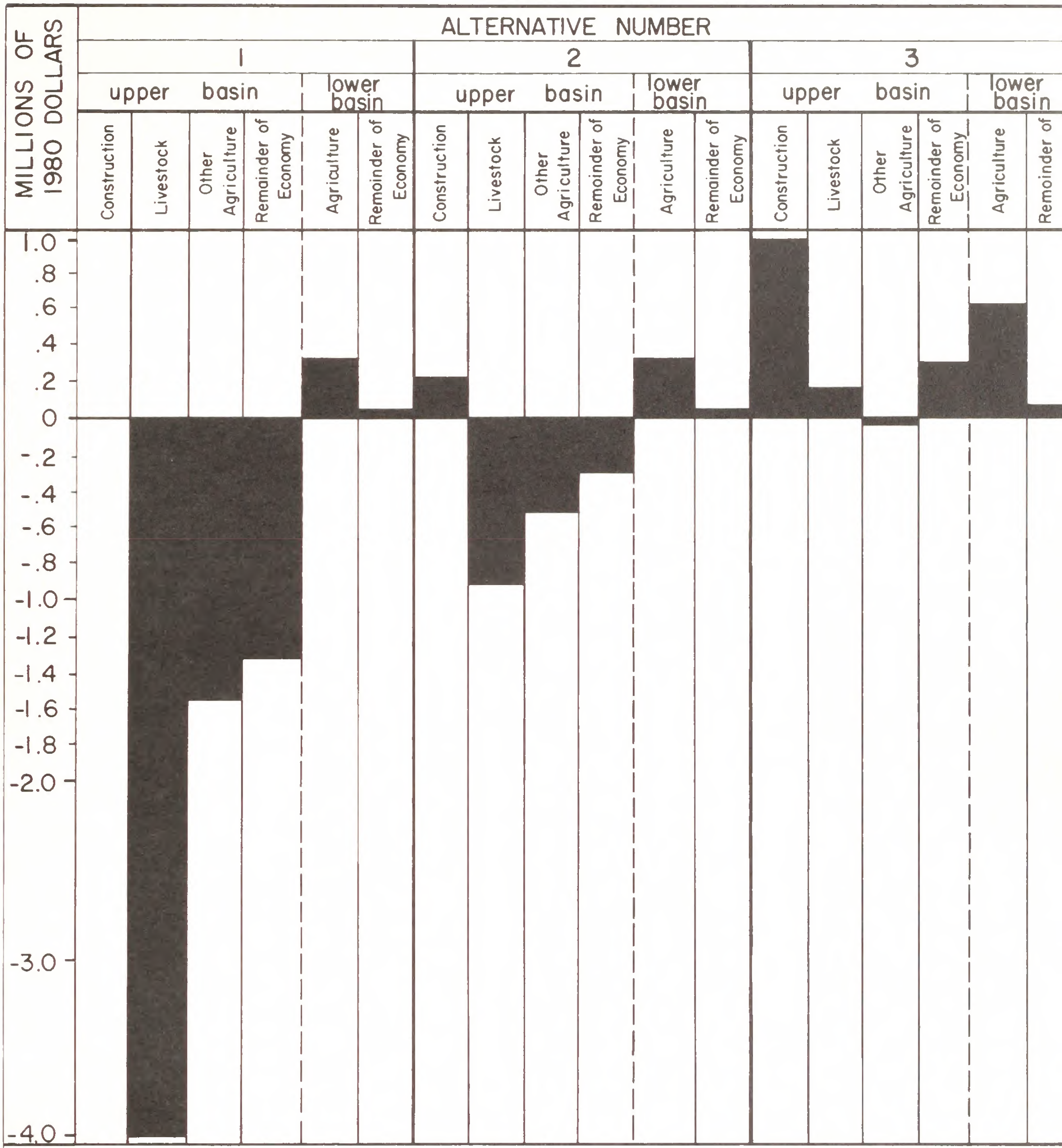
Table VIII-4. Lower Basin Prmary and Secondary Annual Economic Impacts (1980-1985) of Selected Salinity Control Alternatives (in 1980 Dollars).

Economic Sector	Base Year: 1980 Earnings ($1,000)	Earnings Impacts 1980-84		1985 Earnings Without Action ($1,000)
		Alternative 1&2 ($1,000)	Alternative 3 ($1,000)	
Agriculture	230,000	300	640	244,600
Mining	3,900			3,900
Construction	49,100	small 1/	small	53,500
Manufacturing	40,700	small	small	44,400
Trans., Comm. & Pub. Util.	54,800	small	small	64,700
Whols. & Ret. Trade	129,000	small	small	148,400
Fin., Ins. & R.E.	28,900	small	small	35,600
Services	109,500	small	small	121,600
Government	174,400	small	small	211,700
TOTAL 3/	821,000	400	700	928,400

1/ Small Indicates estimates are too small to measure.

3/ May not add due to rounding.

FIGURE VIII-2. ANNUAL LONG-TERM IMPACTS ON INDUSTRY EARNINGS OF SELECTED SALINITY CONTROL ALTERNATIVES



ALTERNATIVES

1. Removal of livestock on nine million acres.
2. Removal of livestock on three million acres and grazing management on six million acres.
3. Detention dams and contour furrows on three million acres and grazing management on six million acres.

IX. FUTURE WATER QUALITY WITHOUT SALINITY CONTROL MEASURES

Future conditions in the Colorado River Basin based on present and future water use are expected to increase the concentration and total salt loading throughout the Basin. As each of the Upper Basin states continue to develop their individual water allocations, they will reduce the supply of water available for dilution of water delivered to the Lower Basin states and add to the salt load through irrigation return flow (surface and subsurface), M & I, and energy development. Table IX-1 contains future estimates of salinity, based on the results of studies by BR, EPA, Colorado River Board of California (CRBC), Water Resources Council (WRC).

Table IX-1. Projected Salinity Concentrations at Imperial Dam, Assuming A No-Action Program (130)

	Milligrams Per Liter by Year				
Agency	1980	2000	2010	2020	2030
EPA	1060	--	1220	--	--
CRBC	1070	1340	--	--	1390
WRC	1260	1290	--	1350	--
BR	1000	1250	--	--	--

These projections represent conditions expected to occur without a salinity control program.

The proposed development of additional transmountain or out of Basin diversions (above 5,000 feet elevation) to the east slope of the Rocky Mountains in Colorado would remove very high quality water (less than 100 mg/l) from the Colorado River system. This water would normally have diluted lower quality water contributed from saline watersheds at lower elevations. EPA (53) estimates these diversions will contribute 7 percent of the predicted 2010 year salinity concentration at Hoover Dam, Arizona-Nevada. Projected increases in municipal water use would remove relatively good quality water, result in a small loss of water through consumptive use, and an increased salt load returned to the river system. This addition is a relatively small amount (4 percent at Hoover Dam based on year 2010 conditions) as predicted by EPA (53).

The increased demand for energy production in the Upper Basin will require the consumption of additional water. Use of water for energy can have several effects on concentration of salts in the Colorado River. The processed water, a return flow into the river system, may carry an increased salt load because of the addition of salts leached from materials used in the treatment of water. On the other hand, environmental constraints will probably require no discharge of process water. This would have a detrimental effect where the relatively good quality water originally withdrawn had a dilution effect on downstream water. Most of the coal, oil, gas, oil shale, and other energy producing minerals are located in watersheds that produce good to high quality water.

Present activities on public lands would not significantly contribute to the increased salt loading shown in Table IX-1. However, management practices effective in reducing salinity from public lands would have a significant effect in holding salinity at Imperial Dam below predicted levels. The goal of accepted standards set for the Colorado River by the Basin States is to hold salinity at the present level (1972 concentrations) while the Basin States continue to develop their compact apportioned water.

X. SUMMARY

Increased salt concentrations in Colorado River water have adversely affected agricultural, municipal, and industrial water users in the Lower Basin. The technical and economic feasibility of reducing salt yields from the public lands of the Upper Basin has been investigated. Studies were made to determine the mechanisms involved in the pickup and transport of salts. The following is a summary of findings:

A. Technical

1. Geologic formations and soils containing some level of salt are common to public lands. The standard agronomic soil salinity classification is not responsive to salt yielded in surface runoff. Some soils classed as nonsaline were found to yield significant amounts of salt. The development of a new soil classification system related to salt in runoff would be beneficial.

2. Disturbance of soils, including upland and channel erosion, is considered to be the major source of salt from overland runoff. Accelerated erosion is the result of soil compaction, removal of vegetative cover and litter, and excessive runoff. Upland erosion removes the leached surface soils, exposing salts in more saline subsurface soils to further leaching and transport in runoff. Channel erosion results in mass wasting of saline soils from gully walls.

3. Salts in water and soils, kept on-site, will remain in place and will contribute little to groundwater salinity from the general land surface. Evapotranspiration will generally equal precipitation in areas receiving less than 16 inches of annual precipitation.

4. Any use of the land which disturbs salt-bearing soils will contribute to the salinity problem. The most important uses--because of their potential to cause soil disturbance and widespread occurrence--are grazing, ORV, and mineral and energy exploration and development.

5. Commonly used structures, land treatment practices and use (grazing, ORV, energy) management techniques for controlling erosion were investigated with regard to salinity, because of the conclusion that erosion and sedimentation are related to salt yields.

6. Structures and land treatments can control salt in runoff and sediment when water and soils are kept on-site, or impounded before reaching perennial streams. However, such projects may create potential environmental hazards when located on highly erosive soils.

7. Grazing management is a technically and environmentally feasible means of controlling runoff, erosion, and salinity on moderately saline soils. The removal of livestock from highly saline soils can be an effective means of reducing salt yields.

8. Water from surface runoff containing salts in concentration below that measured at Imperial Dam will dilute water in the Lower Basin. Salinity control measures were not considered for nonsaline and slightly saline lands. Practices, such as grazing management, should strive to

produce a maximum volume of runoff from these lands, while keeping erosion and peak floods at a minimum.

B. Economic

1. Benefit-Cost Analysis

a. Removal of livestock grazing, management of livestock grazing, and detention-retention dams and contour furrows are three alternative salinity control measures considered for use on highly and moderately saline lands.

b. Detention-retention dams and contour furrows on moderately saline lands are not economically feasible with benefit-cost ratios of approximately 0.3 to 1. However, the benefit-cost ratios of detention-retention dams and contour furrows on highly saline lands are much improved with 0.97 to 1 and 1.01 to 1, respectively. Grazing management on highly saline lands is marginal, with a benefit-cost ratio of 0.91 to 1, and not feasible on moderately saline lands (0.37 to 1). However, grazing mangement on moderately saline lands can become a cost effective control measure, when combined with elimination of grazing on highly saline lands. The combined benefit-cost ratio is 1.56 to 1. Removal of livestock is the most economically efficient with benefit-cost ratios of 4.63 to 1 (highly saline) and 1.48 to 1 (moderately saline).

c. No analysis was made of salinity control measures on non-saline and slightly saline lands, as control would be counter productive on these lands.

2. Regional Economic Impacts

a. Three salinity control measures applied on the 2 classes of saline lands (highly and moderately) could produce a total of 16 possible options for implementation. Three representative options were selected for a regional economic analysis.

b. Removal of livestock from all saline lands, while having the highest benefit-cost ratio, would result in only a $1/2 million annual increase of personal income in the Lower Basin. At the same time, the annual loss of earnings in the Upper Basin would be approximately $7 million.

c. The removal of livestock from only the highly saline lands and management of livestock grazing on the moderately saline lands would also result in an annual increase of $1/2 million of personal income in the Lower Basin. However, annual loss of earnings in the Upper Basin would be cut to $1.5 million by 1995.

d. Detention dams and contour furrows applied to the highly saline lands and grazing management on the moderately saline lands would result in $700,000 of annual earnings to the Lower Basin. Annual earnings in the Upper Basin would be increased by $1.5 million by 1995.

XI. BIBLIOGRAPHY

1. Albertson, F.W., G.W. Tomanek, and A. Riegel. 1957. Ecology of drought cycles and grazing intensity on grasslands of central Great Plains. Ecological Monographs. 27(1): 27-44.

2. Aldon, E.F. 1966. Deferred grazing and soil ripping improves forage on New Mexico's Rio Puerco drainage. N.M. Stockman. 31(11): 44-46.

3. Aldon, E.F. and G. Garcia. 1973. Seventeen-year sediment production from a semiarid watershed in the Southwest. U.S.D.A., Forest Service Res. Note, RM-248. 4p.

4. Allis, J.A. and A.R. Kuhlman. 1962. Runoff and sediment yield studies on rangeland watersheds. J. Soil and Water Conserv. 17: 68-71.

5. Anderson, J.C. and A.P. Kleinman. Salinity management options for the Colorado River. Consortium of Western Water Research Institutes and Centers. Utah State Univ., Logan. (In Press).

6. Aro, R.S. 1971. Evaluation of pinyon-juniper conversion to grassland. J. Range Manage. 24: 188-197.

7. Barnes, O.K., D. Anderson, and A. Heerwagon. 1958. Pitting for range improvement in the Great Plains and the Southwest desert regions. U.S.D.A., Production Research Report 23. 17 p.

8. Baxter, C. 1977. A comparison between grazed and ungrazed juniper woodland. p. 25-27. _in_ Proc., Ecology, Uses, and Management of Pinyon-Juniper Woodlands (Workshop). U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Gen. Tech. Report RM-39. 48 p.

9. Beetle, A.A., and M. May. 1971. Grasses of Wyoming. University of Wyoming Research Journal 39. 151 p.

10. Betton, H.B. 1972. Pinyon-juniper type species; ecology, biology, and management research evaluation. Denver Service Center, BLM publication. 74 p.

11. Blackburn, W.H., and C.M. Skau. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. J. Range Manage. 27: 476-480.

12. Bleak, A.T., N.C. Frischknecht, A.P. Plummer, and R.E. Eckert, Jr. 1965. Problems in artificial and natural revegetation of the arid shadscale vegetation zone of Utah and Nevada. J. Range Manage. 18: 59-65.

13. Branson, F.A. 1975. Natural and modified plant communities as related to runoff and sediment yields. Ecological Studies 10, Coupling of Land and Water Systems. A.D. Hasler, Editor. p. 157-171.

14. Branson, F.A., G.F. Gifford, and J.R. Owen, 1972. Rangeland hydrology. Society for Range Management. Denver. Range Sci. Ser. No. 1. 84 p.

15. Branson, F.A., R.F. Miller, and I.S. McQueen. 1966. Contour furrowing pitting, and ripping on rangelands of the western United States. J. Range Manage. 19: 182-190.

16. Branson, F.A., R.F. Miller, and I.S. McQueen. 1967. Geographic distribution and factors affecting the distribution of salt desert shrubs in the United States. J. Range Manage. 20: 287-296.

17. Branson, F.A., R.F. Miller, and I.S. McQueen. 1976. Moisture relationships in twelve northern desert shrub communities near Grand Junction, Colorado. Ecology. 57: 1104-1124.

18. Branson, F.A., and J.B. Owen. 1970. Plant cover, runoff, and sediment yield relationship on Mancos Shale in western Colorado. Water Resources Res. 6: 783-790.

19. Brown, G.W. 1962. Piping erosion in Colorado. J. Soil and Water Conserv. 17: 220-222.

20. Brown, H.E. 1971. Evaluating watershed management alternatives. American Soc. Civil Eng., J. Irrigation Drainage Div. 97: 93-108.

21. Buckhouse, J.C. and G.B. Coltharp. 1976. Soil moisture response to several levels of foliage removal on two Utah ranges. J. Range Manage. 29: 313-315.

22. Buckhouse, J.C. and G.F. Gifford. 1976. Sediment production and infiltration rates as affected by grazing and debris burning on chained and seeded pinyon-juniper. J. Range Manage. 29: 83-85.

23. Busby, F.E. 1977. Effects of livestock grazing on infiltration and erosion rates measured on chained and unchained pinyon-juniper sites in southeastern Utah. Ph.D. Dissertation. Utah State Univ., Logan. 130 p.

24. Bureau of Land Management. 1965. Handbook - range seeding equipment. U.S.D.I., BLM Manual 7410.5, Release 7-15, 1/23/69. 150 p.

25. Bureau of Land Management. 1968. Watershed tillage. U.S.D.I., BLM Manual 7412, Release 7-12.

26. Bureau of Land Management. 1971. Erosion. U.S.D.I., BLM Manual 7317.33B, Release 7-43.

27. Bureau of Land Management. 1972. Socio-economic data system. U.S.D.I., Denver Service Center. Computer Data System.

28. Bureau of Land Management. 1975. Proposed domestic livestock grazing program for the Uncompahgre Basin Resource Area. U.S.D.I., Draft, unpublished.

29. Bureau of Land Management. 1975. Range Condition Report. Prepared for the Senate Committee on Appropriations. U.S.D.I., January.

30. Bureau of Economic Analysis. 1977. Survey of current business. U.S. Dept. of Commerce. May. 64 p.

31. Bureau of Reclamation. 1972. Colorado River water quality improvement program. U.S.D.I. 88 p.

32. Bureau of Reclamation. 1974. Report on water for energy in the upper Colorado River Basin. U.S.D.I. Upper Colorado Region. Salt Lake City. 71 p.

33. Bureau of Reclamation. 1975. Progress reports on Colorado River Basin Salinity Control Act - Title II, and Colorado River water Quality Improvement Program. U.S.D.I. p. PV1-PV5.

34. Bureau of Reclamation. 1975. Salinity and Sediment Study, Upper Colorado River Basin, Utah, Colorado, Wyoming. U.S.D.I. Upper Colorado Region, Salt Lake City. 80 p.

35. Chapline, W.R. 1948. Grazing on range lands. U.S.D.A. Yearbook of Agriculture, Yearbook Separate No. 2019. p. 212-216.

36. Clary, W.P. 1975. Present and future multiple use demands on the pinyon-juniper type. p. 19-26. in Proc., The Pinyon-Juniper Ecosystem--A Symposium. Utah State Univ., Agric. Exp. Sta., Logan. 194 p.

37. Clary, W.P., M.B. Baker, Jr., P.F. O'Connell, T.J. Johnsen, Jr., and R.E. Campbell. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-128. 28 p.

38. Collings, M.R. and R.M. Myrick. 1966. Effects of juniper and pinyon eradication on streamflow from Corduroy Creek Basin, Arizona. U.S.D.I., Geol. Survey, Prof. Paper 491-B. B12 p.

39. Coltharp, G.B. 1967. How effective are gully plugs and contour furrows on frail lands in Utah? in Soil and America's Future, Proc. of the 22nd Annual Meeting, Soil Conserv. Soc. of Amer. August 13-16. Des Moines. p. 82-89.

40. Cook, C.W., R.M. Hyde, and P.L. Sims. 1974. Revegetation guidelines for surface mined areas. Colorado State Univ., Range Sci. Series No. 16. 70 p.

41. Currie, P.O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper RM-159. 24 p.

42. Dee, R.F., T.W. Box, and E. Robertson, Jr. 1966. Influence of grass vegetation on water intake of Pullman silty clay loam. J. Range Manage. 19: 77-79.

43. Dickerman, A.R. 1975. Estimating regional net trade flows and income multipliers from secondary data: an application of Keynesian Theory. in The Annals of Regional Sci., Western Reg. Sci. Assoc., 9(3): 44-50.

44. Dortignac, E.J. and W.C. Hickey, Jr. 1963. Surface runoff and erosion as affected by soil ripping. in Proc. of the Federal Interagency Sedimentation Conference. U.S.D.A., Agric. Res. Serv., Misc. Publ. No. 970. p. 156-165.

45. Dregne, H.E. 1975. Salinity aspects of the Colorado River Agreement. Nat. Res. J., Univ. of New Mexico, School of Law, Albuquerque. 15: 43-53.

46. Eckert, R.E., F.F. Peterson, M.K. Wood, W.H. Blackburn. 1977. Properties, occurrence and management of soils with vesicular surface horizons. Nevada Agric. Exp. Sta., Reno. Final Report to BLM, Contract No. 52500-CT5(N). 116 p.

47. Economic Research Service. 1977. Fair market value analysis of grazing fees on national resource lands. U.S.D.A., Farm Real Estate Bulletin. July.

48. Elkin, A.D. 1976. Grand Valley Salinity study, investigations of sediment and salt yields in diffuse source areas, Mesa County, Colorado. U.S.D.A., Soil Conserv. Serv., Internal Report. 8 p.

49. Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26: 1-78.

50. Evans, R.A., R.E. Eckert, J.A. Young. 1975. The role of herbicides in management of pinyon-juniper woodlands. p. 83-90. in Proc., The Pinyon-Juniper Ecosystem -- A Symposium. Utah State Univ., Agric. Exp. Sta., Logan. 194 p.

51. Environmental Protection Agency. 1971. The mineral quality problem in the Colorado River Basin - appendix A - natural and man-made conditions affecting mineral quality. Regions VIII and IX. 168 p.

52. Environmental Protection Agency. 1971. The mineral quality problem in the Colorado River Basin - appendix B - physical and economic impacts. Regions VIII and IX. 166 p.

53. Environmental Protection Agency. 1971. The mineral qualtiy problem in the Colorado River Basin. Summary Report. Regions VIII and IX. 65 p.

54. Eubanks, L., and R.C. d'Arge. 1976. Water quality damage functions: a statistical analysis of residences in Los Angeles. Department of Economics, University of Wyoming. Unpublished Contract Report. 9 p.

55. Federal Register. 1977. 42(24) February 4.

56. Fletcher, J.E. and P.H. Carroll. 1948. Some properties of soils associated with piping in southern Arizona. in Proc. Soil Sci. of Amer. 13: 545-547.

57. Forest Service. 1964. 1963 Annual Report. U.S.D.A., Rocky Mtn. For. and Range Exp. Sta.

58. Fowells, H.A. 1965. Silvics of forest trees of the United States. U.S.D.A., Forest Service, Agricultural Handbook No. 271. 762 p.

59. Frevert, R.K., G.O. Schwab, T.W. Edminster and K.K. Barnes. 1955. Soil and Water Conserv. Eng. John Wiley and Sons, New York. 479 p.

60. Frickel, D.G., L.M. Shown, and P.C. Patton. 1975. An evaluation of hillslope and channel erosion related to oil-shale development in the Piceance Basin, northwestern Colorado. Colorado Water Resources Circular No. 30, Colorado Dept. of Nat. Res., Denver. 37 p.

61. Gardner, J.L. 1950. Effects of thirty years of protection from grazing on desert grassland. Ecology. 31: 44-50.

62. Gates, D.H., L.A. Stoddart, and C.W. Cook. 1956. Soil as a factor influencing plant distribution on salt-deserts of Utah. Ecol. Monographs. 26: 155-175.

63. Geological Survey. 1970. National atlas of the United States of America. U.S.D.I. 417 p.

64. Gifford, G.F. 1970. Some water movement patterns over and through pinyon-juniper litter. J. Range Manage. 23: 365-366.

65. Gifford, G.F. 1972. Infiltration rate and sediment production trends on a plowed big sagebrush site. J. Range Manage. 25: 53-55.

66. Gifford, G.F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. J. Range Manage. 26: 440-443.

67. Gifford, G.F. 1975. Approximate annual water budgets of two chained pinyon-juniper sites. J. Range Manage. 28: 73-74.

68. Gifford, G.F. 1975. Beneficial and detrimental effects of range improvement practices on runoff and erosion. p. 216-248. in Proc. Watershed Management Symposium, Amer. Soc. of Civil Eng. 781 p.

69. Gifford, G.F. 1975. Impacts of pinyon-juniper manipulation on watershed values. p. 127-141. in Proc., The Pinyon-Juniper Ecosystem -- A Symposium. Utah State Univ., Logan. 194 p.

70. Gifford, G.F., and F.E. Busby. 1974. Intensive infiltrometer studies on a plowed big sagebrush site. J. of Hydrology. 21: 81-90.

71. Gifford, G.F., and R.H. Hawkins. 1976. Grazing systems and watershed management: a look at the record. J. Soil and Water Conserv. 31: 281-283.

72. Gifford, G.F., and C.B. Shaw. 1973. Soil moisture patterns on two chained pinyon-juniper sites in Utah. J. Range Manage. 26: 436-440.

73. Gifford, G.F., and R.K. Tew. 1969. Influence of pinyon-juniper conversions and water quality on permeability of surface soils. Water Resources Res. 5: 895-899.

74. Gifford, G.F., D.B. Thomas, and G.B. Coltharp. 1977. Effects of gully plugs and contour furrows on erosion and sedimentation in Cisco Basin, Utah. J. Range Manage. 30: 290-292.

75. 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: 402-406.

76. Gleason, H.A., and A. Cronquist. 1964. The natural geography of plants. Columbia Univ. Press. New York. 420 p.

77. Goodin, J.R. 1975. Salinity relations in shrubs. in Proc. Symposium and Workshop on Wildland Shrubs. U.S.D.A., Forest Service, Shrub Sci. Lab., Provo. p. 1-31.

78. Hadley, R.F. 1965. Characteristics of sediment deposits above channel structures in Polacca Wash, Arizona. U.S.D.A., Misc. Publ. 970, Paper 80. p. 806-810.

79. Hancock, V.B. 1969. Effects of certain soil surface treatments on the soil moisture regime in the Cisco Basin, Utah. M.S. Thesis, Utah State Univ., Logan. 87 p.

80. Harper, K.T. 1959. Vegetational changes in a shadscale-winterfat plant association during twenty-three years of controlled grazing. M.S. Thesis. Brigham Young Univ., Provo.

81. Harrington, H.D. 1954. Manual of the plants of Colorado. Sage Books, Denver. 666 p.

82. Hastings, J.R., and R.M. Turner. 1965. The changing mile. Univ. of Arizona Press. Tucson. 317 p.

83. Heady, H.F. 1975. Rangeland Management. McGraw-Hill Book Co., New York. 460 p.

84. Heede, B.H. 1971. Characteristics and processes of soil piping in gullies. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Paper, RM-68. 15 p.

85. Heede, B.H. 1975. Stages of development of gullies in the West. in Present and Prospective Technology for Predicting Sediment Yields and Sources. U.S.D.A., Agric. Res. Serv., ARS-S-40. p. 155-161.

86. Heede, B.H. 1976. Gully development and control. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-169. 42 p.

87. Heede, B.H. 1977. Case study of a watershed rehabilitation project: Alkali Creek, Colorado. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-189. 18 p.

88. Heerman, D.F., M.D. Finkner, and E.A. Hiler. 1971. Probability of sequences of wet and dry days for eleven western states and Texas. Tech. Bull. 117. Colorado State Univ., Fort Collins. 303 p.

89. Heidmann, L.J., and D.D. Thorud. 1975. Effect of bulk density on frost heaving of six soils in Arizona. U.S.D.A., Forest Service Research Note, RM-293. 4 p.

90. Heil, R.D., D.S. Romine, D.C. Moreland, R.K. Dansdill, R.H. Montgomery, and J.E. Cipra. 1977. Soils of Colorado. Colo. State Univ. Exp. Sta. Bull. 566S. Fort Collins. 39 p.

91. Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural water. Second edition. U.S.D.I., Geol. Survey, Water-supply Paper 1473. 363 p.

92. Hibbert, A.R., E.A. Davis, and D.G. Scholl. 1974. Chaparral conversion potential in Arizona - part I: water yield response and effects on other resources. U.S.D.A, Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-126. 36 p.

93. Hickey, W.C., Jr. 1969. A discussion of grazing management systems and some pertinent literature (abstracts and excerpts); 1895-1966. U.S.D.A., Forest Service, Rocky Mtn. Region, Denver. Unnumbered publ.

94. Hickey, W.C., Jr., and G. Garcia. 1964. Changes in perennial grass cover following conversion from yearlong to summer-deferred grazing in west central New Mexico. U.S.D.A., Forest Service, Research Note, RM-33. 3 p.

95. Hickey, W.C. JR., and E.J. Dortignac. 1965. An evaluation of soil ripping and soil pitting on runoff and erosion in the semiarid Southwest. Extract of Publ. No. 65 of the I.A.S.H. Land Erosion, Precipitation, Hydrometry, Soil Moisture. p. 22-33.

96. Holmgren, R.C., and S.S. Hutchens. 1972. Salt desert shrub response to grazing use. in Proc. Wildland Shrubs - Their Biology and Utilization, 1971. p. 153-165. Utah State Univ., Logan. U.S.D.A., Forest Service Gen. Tech. Report INT-1.

97. Hormay, A.L., and M.W. Talbot. 1961. Rest-rotation grazing . . . a new management system for perennial bunchgrass ranges. U.S.D.A., Forest Service, Prod. Res. Report No. 51. 43 p.

98. Hutchings, S.S. 1954. Managing winter sheep range for greater profit. U.S.D.A. Farmer's Bull. 2067. 46 p.

99. Hutchings, S.S. and G. Stewart. 1953. Increasing forage yields and sheep production on Intermountain winter ranges. U.S.D.A. Circular 925. 63 p.

100. Ibrahim, K.M. 1963. Ecological factors influencing plant distribution in the shadscale zone of southeastern Utah. Ph.D. Dissertation. Utah State Univ., Logan. 120 p.

101. International Boundary and Water Commission, United States and New Mexico. 1975. Minute 242, permanent and definitive solution to the International problem of the salinity of the Colorado River. August 30, 1973. Nat. Res. J., Univ. of New Mexico, Albuquerque. 15: 2-9.

102. Iorns, W.V., C.H. Hembree, D.A. Phoenix, and G.L. Oakland. 1964. Water resources of the Upper Colorado River Basin - basic data. U.S.D.I., Geol. Survey, Prof. Paper 442. 1036 p.

103. Iorns, W.V., C.H. Hembree, and G.L. Oakland. 1965. Water resources of the Upper Colorado River Basin - technical report. U.S.D.I., Geol. Survey, Prof. Paper 441. 370 p.

104. Jager, D.J. 1972. The influence of cultural practices and seeded species on overland flow and sediment production from the big sage cover type and East Gate Basin. Nevada Agric. Exp. Sta., Univ. of Nevada, Reno. Final report to BLM, Contract No. 14-11-0001-3815. 182 p.

105. Jensen, C.L. 1964. A preliminary study and report on frail watershed lands. U.S.D.I., Bur. of Land Manage., Salt Lake City. 67 p.

106. Johnson, C.W., and C.L. Hanson. 1976. Sediment sources and yields from sagebrush rangeland watersheds. in Proc., Interagency Sedimentation Conference. Water Resources Council. p. 1-71 to 1-80.

107. Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15: 79-82.

108. Judd, I. and L.W. Judd. 1976. Plant survival in the arid Southwest 30 years after seeding. J. Range Manage. 29: 248-251.

109. Jurinak, J.J., J.C. Whitmore, and R.J. Wagenet. 1977. Kinetics of salt release from a saline soil. J. Soil Sci. Soc. of Amer. 41: 721-724.

110. Kincaid, D.R., J.L. Gardner, and H.A. Schreiber. 1964. Soil and vegetation parameters affecting infiltration under semi-arid conditions. Intern. Assoc. Sci. Hydrol., Publ. 65. p. 440-453.

111. King, N.J. Undated. Erosion control on arid and semiarid rangelands. U.S.D.I., Geol. Survey, Denver. Unpublished report to BLM. 247 p.

112. King, N.J. 1966. Erosion-characteristics of salt desert shrub areas. p. 69-87. in Proc. Salt Desert Shrub Symposium. U.S.D.I., Bur. of Land Manage., Cedar City. 292 p.

113. Kleinman, A.P. and F.B. Brown. 1977. Analysis of farmer response to saline irrigation water in the Colorado River Basin. Western J. of Agric. Economics. 1: 145-151.

114. Kleinman, A.P., G.J. Barney, and S.G. Titmus. 1974. Economic impacts of changes in salinity levels of the Colorado River. U.S.D.I., Bur. of Recl., Denver. 41 p.

115. Knoll, G., and H.H. Hopkins. 1959. The effects of grazing and trampling upon certain soil properties. in Trans. Kansas Acad. Sci. 62: 221-231.

116. Kothmann, M.M. 1974. A glossary of terms used in range management. Compiled and Edited by Range Term Glossary Committee, Society for Range Manage., Denver. 36 p.

117. Laronne, J.B. 1977. Dissolution potential of surficial Mancos Shale and alluvium. Ph.D. Dissertation, Colorado State Univ., Fort Collins. 128 p.

118. Leopold, L.B., W.M. Emmett, and R.M. Myrick. 1966. Channel and hillslope processes in a semiarid area New Mexico. U.S.D.I., Geol. Survey, Prof. Paper 352-G. p. 193-253.

119. Leopold, L.B., and T. Maddock, Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S.D.I., Geol. Survey, Prof. Paper 252. 57 p.

120. Leopold, L.B., and J.P. Miller. 1956. Ephemeral streams-hydraulic factors and their relation to the drainage net. U.S.D.I., Geol. Survey, Prof. Paper 282-A. 37 p.

121. Loope, W.L., and G.F. Gifford. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southern Utah. J. Soil and Water Conserv. 27: 164-167.

122. Lull, H.W. 1959. Soil compaction on forest and rangelands. in U.S.D.A., Misc. Publ. 768. p. 1-32.

123. Lusby, G.C. 1965. Causes of variations in runoff and sediment yield from small drainage basins in western Colorado. U.S.D.A., Misc. Publ. 970. Paper 14. p. 94-98.

124. Lusby, G.C. 1970. Hydrologic and biotic effects of grazing versus nongrazing near Grand Junction, Colorado. J. Range Manage. 23: 256-260.

125. Lusby, G.C., and R.F. Hadley. 1967. Deposition behind low dams and barriers in the southwestern United States. J. of Hydrol. (New Zealand). 6: 89-105.

126. Lusby, G.C., V.H. Reid, and O.D. Knipe. 1971. Effects of grazing on the hydrology and biology of the Badger Wash Basin in western Colorado, 1953-66. U.S.D.I., Geol. Survey, Water-Supply Paper 1532-D. D90 p.

127. Lusby, G.C., and T.J. Toy. 1976. An evaluation of surface-mine spoils area restoration in Wyoming using rainfall simulation. Earth Surface Processes. 1: 375-386.

128. Lusby, G.C., G.T. Turner, J.R. Thompson, and V.H. Reid. 1963. Hydrologic and biotic characteristics of grazed and ungrazed watersheds of the Badger Wash Basin in western Colorado, 1953-58. U.S.D.I., Geol. Survey, Water-Supply Paper 1532-B. B73 p.

129. Malekuti, A.A. 1975. Salt leaching from plants as one source of diffuse salt movement from rangelands. M.S. Thesis, Utah State Univ., Logan. 107 p.

130. Maletic, J.T. 1972. Colorado River water quality improvement program. U.S.D.I., Bur. of Recl., Paper presented at Wyoming Interdepartment Water Conference, Cheyenne.

131. Marquiss, R., and R. Lang. 1959. Vegetational composition and ground cover of two natural relict areas and their associated grazed areas in the Red Desert of Wyoming. J. Range Manage. 12: 104-109.

132. Marston, R.B. 1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. J. Forestry. 50: 303-307.

133. Martin, S.C. 1975. Ecology and management of southwestern semiarid grass-shrub ranges. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper RM-156. 39 p.

134. McWhorter, D.B. 1977. Potential of interflow as a salt transport mechanism in the Colorado River Basin. Progress Report to BLM. Colo. State Univ., Ft. Collins.

135. McWhorter, D.B., and J.W. Rowe. 1976. Inorganic water quality in a surface mined watershed. in Symp., Amer. Geophysical Union-Methodologies for Environ. Assess. in Energy Devel. Regions, San Francisco, December 8. 27 p.

136. McWhorter, D.B., R.K. Skogerboe, and G.V. Skogerboe. 1975. Water quality control in mine spoils, Upper Colorado River Basin. Environ. Prot. Tech. Ser., EPA-670/2-75-048. Nat. Environ. Res. Center, Cincinnati. 100 p.

137. Meeuwig, R.O. 1960. Watersheds A and B - a study of surface runoff and erosion in the subalpine zone of central Utah. J. Forestry. 58: 556-560.

138. Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23: 185-188.

139. Meeuwig, R.O., and P.E. Packer. 1975. Erosion and runoff on forest and rangelands. p. 105-116. in Proc., Watershed Management on Range and Forest Lands. Utah State Univ., Water Res. Lab., Logan. June 15-22. 222 p.

140. 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: 246-257.

141. Mitchell, J.E., N.E. West, and R.W. Miller. 1966. Soil physical properties in relation to plant community patterns in the shadscale zone of northwestern Utah. Ecology. 47: 627-630.

142. Mundorff, J.C. 1972. Reconnaissance of chemical quality of surface water and fluvial sediment in the Price River Basin, Utah. Utah Dept. of Nat. Res. Tech. Publ. 39. 55 p.

143. Nelson, R.A. 1970. Plants of Rocky Mountain National Park. Rocky Mtn. Nature Assoc. 168 p.

144. Nichols, J.T. 1969. Range improvement practices on deteriorated dense clay wheatgrass range in western North Dakota. Agric. Exp. Sta., South Dakota State Univ., Brookings. Bull. 552. 23 p.

145. Orr, H.K. 1960. Soil porosity and bulk density on grazed and protected Kentucky bluegrass range in the Black Hills. J. Range Manage. 13: 80-86.

146. Packer, P.E. 1951. An approach to watershed protection criteria. J. Forestry. 49: 639-644.

147. Packer, P.E. 1953. Effects of trampling disturbance on watershed conditions, runoff, and erosion. J. Forestry. 51: 28-31.

148. Packer, P.E. 1961. The effects of grazing on soil erosion, water quality and sedimentation. in Proc., Watershed Management Study Conference, McCall. September 11-14. p. 1-24.

149. Packer, P.E. 1963. Soil stability requirements for the Gallatin elk winter range. J. Wildlife Manage. 27: 401-410.

150. Pacific Southwest Inter-Agency Committee. 1968. Factors affecting sediment yield in the Pacific Southwest area. Water Manage. Subcommittee Sedimentation Task Force. 13 p.

151. Paulsen, H.A., Jr. 1975. Range management in the central and southern Rocky Mountains. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-154. 34 p.

152. Pechanec, J.F., G. Stewart, and J.P. Blaisdell. 1954. Sagebrush burning good and bad. U.S.D.A., Farmer's Bull. 1948. 34 p.

153. Peterson, H.V., and F.A. Branson. 1962. Effects of land treatments on erosion and vegetation on range lands in parts of Arizona and New Mexico. J. Range Manage. 15: 220-226.

154. Ponce, S.L., II. 1975. Examination of a non-point source loading function for the Mancos Shale wildlands of the Price River Basin, Utah. Ph.D. Dissertation, Utah State Univ., Logan. 177 p.

155. Potter, L.D., and J.C. Krenetsky. 1967. Plant succession with released grazing on New Mexico range lands. J. Range Manage. 20: 145-151.

156. Preston, R.J. 1948. North American trees. Iowa State College Press, Ames. 426 p.

157. Price, D., and T. Arnow. 1974. Summary appraisals of the nation's groundwater resources - Upper Colorado River Basin. U.S.D.I., Geol. Survey, Prof. Paper 813-C. 40 p.

158. Price, D., and L.L. Miller. 1975. Hydrologic reconnaissance of the southern Uinta Basin, Utah and Colorado. Utah Dept. of Nat. Res. Tech. Publ. 49. 66 p.

159. Rauzi, F. 1960. Water intake studies on range soils at three locations in the Northern Plains. J. Range Manage. 13: 179-184.

160. Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangeland. J. Soil and Water Conserv. 18: 114-116.

161. Rauzi, F., C.L. Fly, and E.J. Dyksterhuis. 1968. Water intake on midcontinental rangelands as influenced by soil and plant cover. U.S.D.A., Agric. Res. Serv. and Soil Conserv. Serv., Tech. Bull. 1390. 58 p.

162. Rauzi, F., R.L. Land, and C.F. Becker. 1962. Mechanical treatment on shortgrass rangeland. Agric. Exp. Sta., Univ. of Wyoming, Laramie. Bull. 396.

163. Rauzi, F., and F.M. Smith. 1973. Infiltration rates: three soils with three grazing levels in northeastern Colorado. J. Range Manage. 26: 126-129.

164. Read, R.A. 1957. Effect of livestock concentration on surface-soil porosity within shelterbelts. J. of Forestry. 55: 529-530.

165. Renard, K.G. 1972. Sediment problems in the arid and semiarid southwest. in Proc. of the 27th Annual Meeting of the Soil Conserv. Soc. of Amer., August 6-9, Portland. p. 225-232.

166. Reynolds, H.G., and P.E. Packer. 1963. Effects of trampling on soils and vegetation. p. 116-122. in Range Research Methods: A Symposium. 1962. Denver. U.S.D.A., Misc. Publ. 940. 172 p.

167. Rhodes, E.D., L.F. Loche, H.M. Taylor, and E.H. McIlvain. 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. J. Range Manage. 17: 185-190.

168. Rich, L.R., and G.J. Gottfried. 1976. Water yields resulting from treatments on the Workman Creek experimental watersheds in central Arizona. Water Resources Res. 12: 1053-1060.

169. Rich, L.R., and H.G. Reynolds. 1963. Grazing in relation to runoff and erosion on some chaparral watersheds of central Arizona. J. Range Manage. 16: 322-326.

170. Rosa, J.M., and M.H. Tigerman. 1951. Some methods for relating sediment production to watershed conditions. U.S.D.A., Forest Service. Intermountain For. and Range Exp. Sta., Res. Paper 26. 19 p.

171. Schumm, S.A. 1960. The shape of alluvial channels in relation to sediment type. U.S.D.I., Geol. Survey, Prof. Paper 352-B. p. 16-30.

172. Schumm, S.A., and R.F. Hadley. 1957. Arroyos and the semiarid cycle of erosion. Amer. J. of Sci. 255: 161-174.

173. Schumm, S.A., and G.C. Lusby. 1963. Seasonal variation of infiltration capacity and runoff on hillslopes in western Colorado. J. Geophy. Res. 68: 3655-3666.

174. Sharma, M.L., and D.J. Tongway. 1973. Plant induced soil salinity patterns in two saltbush communities. J. Range Manage. 26: 121-125.

175. Sharp, A.L., J.J. Bond, J.W. Neuberger, A.R. Kuhlman, J.K. Lewis. 1964. Runoff as affected by intensity of grazing on rangeland. J. Soil and Water Conserv. 19: 103-106.

176. Shown, L.M. 1971. Sediment yield as related to vegetation on semiarid watersheds. Third International Seminar for Hydrology Professors. Purdue Univ. p. 347-354.

177. Shown, L.M., G.C. Lusby, and F.A. Branson. 1972. Soil-moisture effects of conversion of sagebrush cover to bunchgrass cover. Water Res. Bull., Amer. Water Res. Assoc. 8: 1265-1272.

178. Skau, C.M. 1964. Interception, throughfall, and stemflow in Utah and alligator juniper types in northern Arizona. Forest Sci. 10: 283-287.

179. Smeins, F.E. 1975. Effects of livestock grazing on runoff and erosion. p. 267-274. in Proc. of Watershed Management Symposium, Amer. Soc. of Civil Eng. 781 p.

180. Smith, J.G. 1895. Forage conditions of the Prairie Region. U.S.D.A., Yearbook of Agriculture - 1895. p. 309-324.

181. Snyder, C.T., D.G. Frickel, R.F. Hadley, and R.F. Miller. 1976. Effects of off-road vehicle use on the hydrology and landscape of arid environments in central and southern California. U.S.D.I., Geol. Survey, Water Res. Invest. 76-99. 45 p.

182. Soil Conservation Service. 1975. Erosion, sediment and related salt problems and treatment opportunities, U.S.D.A., Special Proj. Div. 152 p.

183. Soil Conservation Service. 1975. Soil taxonomy-a basic system of soil classification for making and interpreting soil surveys. U.S.D.A., Agric. Handbook No. 436. 754 p.

184. Springfield, H.W. 1976. Characteristics and management of southwestern pinyon-juniper ranges. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-160. 32 p.

185. Stoddard, L.A., and A.D. Smith. 1955. Range Management. McGraw-Hill Book Company. New York. 433 p.

186. Stoddard, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. McGraw-Hill Book Company. New York. 532 p.

187. Sturges, D.L. 1975. Hydrologic relations on undisturbed and converted big sagebrush lands. U.S.D.A., Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-140. 23 p.

188. Sturges, D.L. 1975. Sediment transport from big sagebrush watersheds. p. 728-739. in Proc., Watershed Management Symposium, Amer. Soc. of Civil Eng. 781 p.

189. Sturges, D.L. 1977. Soil moisture response to spraying big sagebrush: a seven-year study and literature interpretation. U.S.D.A, Forest Service, Rocky Mtn. For. and Range Exp. Sta., Res. Paper, RM-188. 12 p.

190. Subcommittee on Range Research Methods. 1962. Basic problems and techniques in range research. Report of a joint committee of the Amer. Soc. of Range Manage. and The Agric. Board of the Nat. Academy of Sci. Nat. Res. Council, Publ. No. 890. 341 p.

191. Thomas, D.B. 1975. The effects of gully plugs and contour furrows on erosion and sedimentation in Cisco Basin, Utah. M.S. Thesis, Utah State Univ., Logan. 54 p.

192. Thorud, D.B., and S.S. Frissell, Jr. 1969. Soil rejuvenation following artificial compaction in a Minnesota oak stand. Univ. of Minnesota, St. Paul, Minnesota For. Res. Note No. 208. 4 p.

193. Thorud, D.B., and S.S. Frissell. 1976. Time changes in soil density following compaction under an oak forest. Univ. of Minnesota, St. Paul, Minnesota For. Res. Note No. 257. 4 p.

194. Tromble, J.M. 1976. Semiarid rangeland treatment and surface runoff. J. Range Manage. 29: 251-254.

195. Turcott, G.L. 1966. Cover for frail lands. U.S.D.I., Bur. of Land Manage. Our Public Lands. 15(3): 20-21.

196. Turcott, G.L., C.V. McVee, and K.F. Hansen. 1966. Gone with the water. U.S.D.I., Bur. of Land Manage. Our Public Lands. 15(5): 12-15.

197. Turner, G.T. 1971. Soil and grazing influences on a salt-desert shrub range in western Colorado. J. Range Manage. 24: 31-37.

198. United States 70 Congressional Record. 1928. Colorado River Compact.

199. U.S.D.I. 1977. Quality of water, Colorado River Basin--progress report number 8. Bur. of Reclamation. January. 195 p.

200. U.S.D.I. 1977. Oil and gas: surface operating standards for oil and gas exploration and development. Bur. of Land Mgt. and Geol. Survey. Cheyenne. 47 p.

201. Utah State University. 1975. Colorado River regional assessment study, part I. Prepared for Nat. Commission on Water Qual. Water Res. Lab. 239 p.

202. Valentine, V.E. 1974. Impacts of Colorado River salinity. American Soc. of Civil Eng. J. Irrigation and Drainage, 100(IRA): 495-510.

203. Vaughn Hanson Associates. 1976. Unpublished data collected in Price and San Rafael River Basins. Salt Lake City, Utah.

204. Water Resources Council. 1971. Upper Colorado Region - comprehensive framework study - appendix V - water resources. Pacific Southwest Inter-Agency Committee. 66 p.

205. Water Resources Council. 1971. Upper Colorado Region - comprehensive framework study - appendix VI - land resources and use. Pacific Southwest Inter-Agency Committee. 142 p.

206. Water Resources Council. 1971. Upper Colorado Region - comprehensive framework study - appendix XV - Water Quality, Pollution Control and Health Factors. Pacific Southwest Inter-Agency Committee. 219 p.

207. Water Resources Council. 1972. OBERS projections, regional economic activity in the U.S., series E. population. U. S. Government, Vol. 2. 178 p.

208. Water Resources Council. 1977. Guideline 5, regional multipliers. U.S. Government, January. 135 p.

209. Weatherford, G.D., and G.C. Jacoby. 1975. Impact of energy development on the law of the Colorado River. Nat. Res. J., Univ. of New Mexico, School of Law, Albuquerque. 15: 170-213.

210. Weeks, J.B., G.H. Leavesley, F.A. Welder, and G.J. Saulnier, Jr. 1974. Simulated effects of oil-shale development on the hydrology of Piceance Basin, Colorado. U.S.D.I., Geol. Survey, Prof. Paper 908. 84 p.

211. Wein, R.W. 1970. Microenvironmental effects of erosion control treatments on seedling survival in a southeastern Utah salt desert area. Ph.D. Dissertation, Utah State Univ., Logan. 181 p.

212. Wein, R.W., and N.E. West. 1971. Phenology of salt desert plants near contour furrows. J. Range Manage. 24: 299-304.

213. Wein, R.W., and N.E. West. 1971. Seedling survival on erosion control treatments in a salt desert area. J. Range Manage. 24: 352-357.

214. Wein, R.W., and N.E. West. 1973. Soil changes caused by erosion control treatments on a salt desert area. in Proc., Soil Sci. Soc. of Amer. 37: 98-103.

215. West, N.E. and G.F. Gifford. 1976. Rainfall interception by cool-desert shrubs. J. Range Manage. 29: 171-172.

216. West, N.E., and K.I. Ibrahim. 1968. Soil-vegetation relationships in the shadscale zone of southeastern Utah. Ecology. 49: 445-456.

217. White, R.B. 1977. Salt production from microchannels in the Price River Basin, Utah. M.S. Thesis, Utah State Univ., Logan. 121 p.

218. Whitemore, J.C. 1976. Some aspects of the salinity of Mancos Shale and Mancos derived soils. M.S. Thesis, Utah State Univ., Logan. 69 p.

219. Wight, J.R. 1976. Land surface modifications and their effects on range and forest watersheds. p. 155-174. in Proc. of the Fifth Workshop of the U.S./Australia Rangelands Panel, June 15-22, 1975. Watershed Management on Range and Forest Lands, Boise. Published by Utah Water Res. Lab., Utah State Univ., Logan. March, 1976. 222 p.

220. Wight, J.R., and F.M. Siddoway. 1972. Improving precipitation-use efficiency on rangeland by surface modification. J. Soil and Water Conserv. 27: 170-174.

221. 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: 201-205.

222. Wilson, L., M.E. Olsen, T.B. Hutchings, A.R. Southard, and A.J. Erickson. 1975. Soils of Utah. Agric. Exp. Sta. Bull. 492, Utah State Univ., Logan. 94 p.

223. Workman, J., and J. Keith. 1975. Economics of soil treatments in the upper Colorado. p. 591-596. in Proc. of Watershed Management Symposium, Amer. Soc. of Civil Eng. 781 p.

224. Wright, H.A., F.M. Churchill, W.C. Stevens. 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in central Texas. J. Range Manage. 29: 294-298.

225. Young, J.F. and P.C. Singleton. 1977. Wyoming General Soils Map. Agric. Exp. Sta., Res. Journal 117, Univ. of Wyoming, Laramie. 41 p.

226. Zander, A.D. 1967. Some effects of juniper-grass vegetation on soil characteristics and soil-water relationships in east-central Arizona. M.S. Thesis. Univ. of Arizona, Tucson. 93 p.

APPENDIX

Soldier Creek Hydrologic Determinations for Runoff, Sediment, and Salt Yields

The Soldier Creek allotment, as shown in Figure XII-1-1, contains 23,120 acres. An additional 20,326 acres of juniper-pinyon and big sagebrush covered hills and canyons lying to the north, contribute runoff to perennial and ephemeral streams traversing the allotment. The major portion of runoff from within the allotment drains into the Soldier and Dugout Creeks. However, a big sagebrush watershed 1,370 acres in size, in the northwest corner of the allotment, drains into Coal Creek. Another area, 1,537 acres in size and supporting shadscale and greasewood, along the west border of the allotment, drains into Coal Creek through a diffuse network of small channels. A strip of land several miles long in the southeast corner, drains to the east. It contains 218 acres of big sagebrush, 560 acres of black sagebrush, and 458 acres of juniper-pinyon.

A. Basic Information

The following allotment resource information and derived factors were used to develop runoff, sediment, and salt yields for the Soldier Creek allotment. The basic data for all six allotments, including the data used for Soldier Creek, is shown in Table XII-1-1. The effects of treatments on reductions of runoff, sediment and salt, for all six allotments, is shown in Table XII-1-2.

1. Acreage within the allotment by vegetative type and range condition are:

Vegetative Type	Acres	Range Condition
juniper-pinyon	11,512	Poor
big sagebrush	3,547	Poor
black sagebrush	3,432	Fair
greasewood	1,671	Poor
shadscale	2,958	Fair

2. Annual Precipitation

juniper-pinyon woodland and big sagebrush = 12 inches

black sagebrush, greasewood, and shadscale = 9 inches

FIGURE XII-1-1. SOLDIER CREEK ALLOTMENT

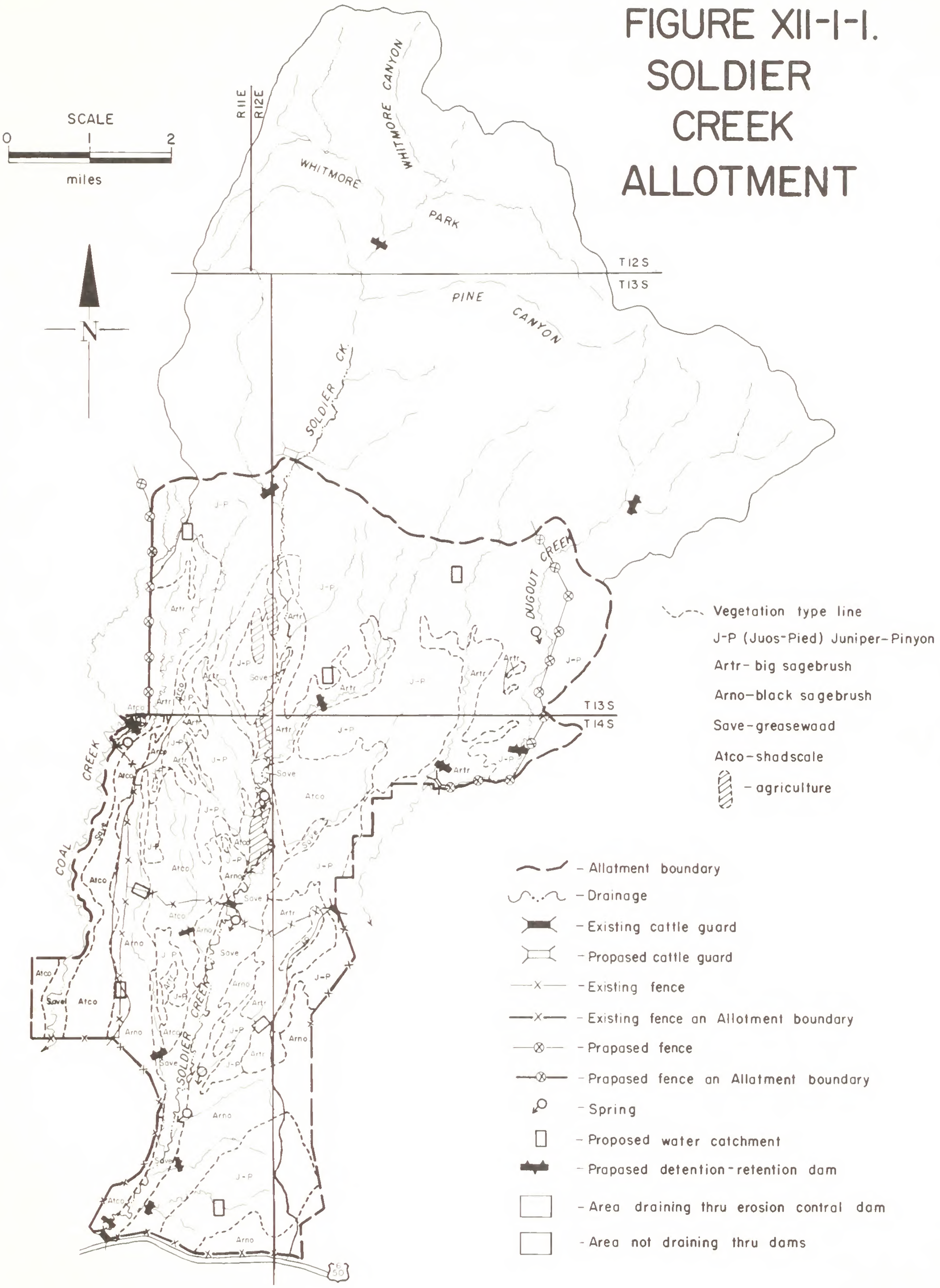


Table XII-1-1. Basic Information on Existing Runoff, Sediment, and Salt Yields by Allotment and Vegetative Type

Allotment Name	Vegetative Type	Type No.	Annual Precipitation (inches)	Runoff Factor (% of ppt.)	Concentration TDS (Mg/L)	Sediment Yield Factor (Tons/Ac/Yr)	Percent of Salt in Sediment	Total Yield/Year 1/ Runoff (Ac-Ft)	Total Yield/Year 1/ Sediment (Tons)	Salt From: (Tons) Runoff	Salt From: (Tons) Sediment	Salt From: (Tons) Total
Cisco	juniper-pinyon (outside allotment)	1A	12	2.8	600	1.00	0.5	310	11,074	253	55	308
	juniper-pinyon (within allotment)	1B	12	2.8	600	1.00	0.5	1,808	64,582	1,475	323	1,798
	salt desert shrub	1C	7.6	1.4	2,000	2.40	3.0	1,603	433,805	4,360	13,014	17,374
Coal Creek	juniper-pinyon and big sagebrush (outside allotment)	2A	12	3.9	600	1.00	0.5	293	7,504	239	38	277
	juniper-pinyon and big sagebrush (within allotment)	2B	12	3.9	600	1.00	0.5	723	18,550	590	93	683
	salt desert shrub	2C	9	1.4	2,000	2.30	3.0	62	13,671	170	410	580
Soldier Creek	juniper-pinyon (outside allotment)	3A	12	2.8	600	1.00	0.5	569	20,326	464	102	566
	juniper-pinyon (within allotment)	3B	12	2.8	600	1.00	0.5	322	11,512	263	57	320
	big sagebrush	3C	12	3.5	600	1.00	0.5	124	3,547	101	18	119
	black sagebrush	3D	9	1.4	1,000	0.90	3.0	36	3,089	49	93	142
	shadscale and greasewood	3E	9	1.4	2,000	2.30	3.0	48	10,647	131	319	450
Gypsum Valley	juniper-pinyon	4A	16	2.8	300	1.30	0.5	871	30,325	355	152	507
	grassland (slightly saline soils)	4B	16	0.8	300	1.40	0.5	117	15,437	48	77	125
	grassland (saline soils)	4C	16	0.8	1,000	2.30	3.0	94	13,991	127	419	546
Little Colorado	sagebrush-grass	5A	7	1.5	600	0.75-1.24	0.5	3,972	407,198	3,241	2,036	5,277
	saltbush-winterfat	5B	7	1.2	1,500	2.08	1.0	166	49,380	339	494	833
	greasewood	5C	7	1.2	1,500	2.08	1.0	121	35,954	247	360	607
	grass	5D	7	0.8	300	0.65	0.3	41	5,666	17	17	34
	meadow	5E	7	0.8	1,000	0.65	1.0	18	2,442	24	25	49
	conifer	5F	8	2.0	600	0.78	0.3	67	3,937	55	12	67
Stone Cabin	juniper-pinyon	6A	12	2.8	300	1.30	0.5	517	23,988	211	120	331
	chained and seeded juniper-pinyon	6B	12	2.8	300	1.30	0.5	64	2,954	26	15	41
	big sagebrush	6C	18	5.3	200	1.90	0.1	538	12,855	146	13	159
	grassland (native)	6D	18	5.0	200	1.30	0.1	90	1,560	24	2	26
	mountain brush and aspen	6E	18	17.0	100	1.20	0.1	311	1,464	42	1	43

1/ Total yields for the Little Colorado allotment are less 29.5%, or the area draining into closed basins (not a potential contributor to the Colorado River through surface runoff).

Table XII-1-2. Effects of Proposed Treatments on Reductions of Runoff, Sediment, and Salt by Allotment and Vegetative Type

Type No. 1/	Acres	Total Amount of Runoff, Sediment, and Salt Reduced Each Year by Allotment, Vegetative Type, and Treatment															
		Removal of Livestock			Grazing Management			Contour Furrows and Trenches			Acres	Detention Dams			Retention Dams		
		Runoff (ac-ft)	Sediment (tons)	Salt (tons)	Runoff (ac-ft)	Sediment (tons)	Salt (tons)	Runoff (ac-ft)	Sediment (tons)	Salt (tons)		Runoff (ac-ft)	Sediment (tons)	Salt (tons)	Runoff (ac-ft)	Sediment (tons)	Salt (tons)
1A											11,074	-0-	9,967	50	310	11,074	308
18	64,582	362	12,916	360	271	9,687	270				61,421	-0-	55,279	276	1,720	61,421	1,710
1C	180,752	481	195,212	7,164	240	65,071	2,606	580	156,898	6,284	51,520	-0-	111,283	3,338	457	123,648	4,952
Total	245,334	843	208,128	7,524	511	74,758	2,876	580	156,898	6,284	124,015	-0-	176,529	3,664	2,487	196,143	6,970
2A											7,504	-0-	6,754	34	293	7,504	277
28	18,550	145	3,710	137	109	2,782	102				18,550	-0-	16,695	84	723	18,550	683
2C	5,994	19	6,152	235	9	2,051	87	32	6,929	294	973	-0-	2,014	24	10	2,238	94
Total	24,494	164	9,862	372	118	4,833	189	32	6,929	294	27,027	-0-	25,463	142	1,026	28,292	1,054
3A											20,326	-0-	18,293	92	569	20,326	566
38	11,512	64	2,303	64	48	1,727	48				11,054	-0-	9,949	50	309	11,054	307
3C	3,547	25	709	24	19	532	18				3,329	-0-	2,996	15	116	3,329	112
30	3,432	11	952	43	9	772	36				2,872	-0-	2,326	70	30	2,585	119
3E	4,629	14	4,791	183	7	1,597	68				3,092	-0-	6,401	192	32	7,112	300
Total	23,120	114	8,755	314	83	4,628	170				40,673	-0-	39,965	419	1,056	44,406	1,404
4A	23,327	174	6,065	101	131	4,549	76				16,329	-0-	19,105	95	610	21,228	355
48	11,027	53	6,947	56	29	3,859	31	12	1,564	13	9,027	-0-	11,373	57	96	12,637	102
4C	8,883	42	6,296	246	24	3,498	136	10	1,417	55	7,383	-0-	10,702	321	78	11,891	463
Total	43,237	269	19,308	403	184	11,906	243	22	2,981	68	32,739	-0-	41,180	473	784	45,756	920
5A	453,956	1,192	122,159	1,583	794	81,440	1,055	371	37,992	492	383,338	-0-	309,894	1,547	3,354	343,854	4,456
58	23,740	50	19,752	300	25	7,407	125	16	4,607	78	20,047	-0-	37,528	375	140	41,698	703
5C	17,286	36	14,382	218	18	5,393	91	11	3,355	57	14,597	-0-	27,325	274	102	30,361	512
50	8,716	14	1,983	12	10	1,416	8				8,716	-0-	5,099	15	35	5,666	31
5E	3,758	6	855	17	4	610	12				3,758	-0-	2,198	22	15	2,442	45
5F	5,048	13	787	13	10	590	10				5,048	-0-	3,543	11	56	3,937	58
Total	512,504	1,311	159,918	2,143	861	96,856	1,301	398	45,954	627	435,504	-0-	385,587	2,244	3,702	427,958	5,805
6A	18,452	155	7,196	99	78	3,598	50										
68	2,272	19	886	12	16	738	10										
6C	6,766	215	5,142	63	134	3,214	40										
6D	1,200	40	702	12	27	468	8										
6E	1,220	156	732	22	93	439	13										
Total	29,910	585	14,658	208	348	8,457	121										

1/ The Type number corresponds to vegetation types shown in Table XII-1-1.

3. Runoff Factors (see Rangeland Hydrology, SRM, 1972, p. 34 (14))

shadscale and greasewood	1.4% of ppt.
juniper-pinyon woodland	2.8% of ppt.
big sagebrush	3.5% of ppt.[1]
black sagebrush	1.4% of ppt.[2]

4. Concentration of Salt in Water

Runoff from Mancos-derived soils, shadscale and greasewood = 2,000 mg/l

Runoff from black sagebrush areas, leached Mancos-derived soils = 1,000 mg/l

Runoff from juniper-pinyon and big sagebrush areas = 600 mg/l

5. Sediment Yield Factors [3] (see BLM Manual 7317.33B (26))

Mancos-derived soils, shadscale and greasewood = 2.3 tons/acre/year

black sagebrush = 0.9 tons/acre/year

juniper-pinyon and big sagebrush = 1.0 tons/acre/year

6. Percent of Salt in Sediment

Sediment from Mancos-derived soils, shadscale, greasewood, black sagebrush areas = 3.0%

Sediment from other soils, juniper-pinyon and big sagebrush areas = 0.5%

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[1] It is assumed that the high value of 5.3 percent for the sagebrush runoff factor, shown in the Rangeland Hydrology handbook is reflecting an open stand of brush with little understory vegetation. Precipitation listed is also higher than the 12 inches found on the Soldier Creek area. Sagebrush stands on the Soldier Creek allotment have a greater percent of grass.

[2] Black sagebrush soils have a relatively high percentage of gravel, and have a fair understory of protective sodforming grass.

[3] A factor of 85 lbs./cu.ft. was used as the weight of sediment (182).

B. Determination of Runoff and Sediment Yields and Associated Salt Yield

1. By Vegetative Type

a. Juniper-Pinyon Area Within Allotment (Flowing Through Dams)

(1) Salt from Runoff

$$\frac{2.8\%\ \text{runoff} \times 12\ \text{inches ppt.} \times 11{,}054\ \text{acres}}{12} = 309\ \text{acre-feet of runoff/year}$$

0.00136 x 309 ac-ft x 600 mg/l = 252 tons of salt/year

(2) Salt from Sediment

1.0 tons of sediment/acre/year x 11,054 acres = 11,054 tons of sediment/year
11,054 tons x 0.5% salt = 55 tons of salt/year

b. Juniper-Pinyon Area Within Allotment (Flowing Outside)

(1) Salt from Runoff

$$\frac{2.8\% \times 12\ \text{inches ppt.} \times 458\ \text{acres}}{12} = 13\ \text{acre-feet of runoff/year}$$

0.00136 x 13 x 600 mg/l = 11 tons of salt/year

(2) Salt from Sediment

1.0 tons of sediment/acre/year x 458 acres = 458 tons of sediment/year
458 tons x 0.5% salt = 2 tons of salt/year

c. Juniper-Pinyon and Big Sagebrush Area Outside Allotment (Runoff Flowing through Allotment)

(1) Salt from Runoff

$$\frac{2.8\% \times 12\ \text{inches ppt.} \times 20{,}326\ \text{acres}}{12} = 569\ \text{acre-feet of runoff/year}$$

0.00136 x 569 x 600 mg/l = 464 tons of salt/year

(2) Salt from Sediment

1.0 tons of sediment/acre/year x 20,326 acres = 20,326 tons of sediment/year
20,326 tons x 0.5% salt = 102 tons of salt/year

d. Salt and Sediment Yield from Big Sagebrush

(1) Area Flowing through Dams

(a) Salt from Runoff

$$\frac{3.5\% \times 12 \text{ inches ppt.} \times 3{,}329 \text{ acres}}{12} = 116 \text{ acre-feet of runoff/year}$$

0.00136 x 116 x 600 mg/l = 95 tons of salt/year

(b) Salt from Sediment

1.0 tons of sediment/acre/year x 3.329 acres = 3,329 tons of sediment/year
3,329 tons x 0.5% salt = 17 tons of salt/year

(2) Area Flowing Outside the Allotment

(a) Salt from Runoff

$$\frac{3.5\% \times 12 \text{ inches ppt} \times 218 \text{ acres}}{12} = 8 \text{ acre-feet of runoff/year}$$

0.00136 x 8 x 600 mg/l = 6 tons of salt/year

(b) Salt from Sediment

1.0 tons of sediment/acre/year x 218 acres = 218 tons of sediment/year
218 tons x 0.5% salt = 1 ton of salt/year

e. Salt and Sediment Yield from Black Sagebrush

(1) Area Flowing through Dams

(a) Salt from Runoff

$$\frac{1.4\% \times 9 \text{ inches ppt.} \times 2{,}872 \text{ acres}}{12} = 30 \text{ acre-feet of runoff/year}$$

0.00136 x 30 x 1,000 mg/l = 41 tons of salt/year

(b) Salt from Sediment

0.9 tons of sediment/acre/year x 2,872 acres = 2,585 tons of sediment/year
2,585 tons x 3% salt = 78 tons of salt/year

(2) Area Flowing Outside the Allotment

(a) Salt from Runoff

$$\frac{1.4\% \text{ x } 9 \text{ inches ppt. x } 560 \text{ acres}}{12} = 6 \text{ acre-feet of runoff/year}$$

0.00136 x 6 x 1,000 mg/l = 8 tons of salt/year

(b) Salt from Sediment

0.9 tons of sediment/acre/year x 560 acres = 504 tons of sediment/year
504 tons x 3% salt = 15 tons of salt/year

f. Salt and Sediment Yield from Shadscale and Greasewood

(1) Area Flowing through Dams

(a) Salt from Runoff

$$\frac{1.4\% \text{ x } 9 \text{ inches ppt. x } 3{,}092 \text{ acres}}{12} = 32 \text{ acre-feet of runoff/year}$$

0.00136 x 32 x 2,000 mg/l = 87 tons of salt/year

(b) Salt from Sediment

2.3 tons of sediment/acre/year x 3,092 acres = 7,112 tons of sediment/year
7,112 tons x 3% salt = 213 tons of salt/year

(2) Area Flowing Outside the Allotment

(a) Salt from Runoff

$$\frac{1.4\% \text{ x } 9 \text{ inches ppt. x } 1{,}537 \text{ acres}}{12} = 16 \text{ acre-feet of runoff/year}$$

0.00136 x 16 x 2,000 mg/l = 44 tons of salt/year

(b) Salt from Sediment

2.3 tons of sediment/acre/year x 1,537 acres = 3,535 tons of sediment/year
3,535 tons x 3% salt = 106 tons of salt/year

2. Total Runoff, Sediment and Salt Yields/Year

a. Within Allotment (Flowing through Dams)

Vegetation Type	Runoff (ac-ft)	Sediment (tons)	Salt (tons)		
			Sediment	Runoff	Total
juniper-pinyon	309	11,054	55	252	307
big sagebrush	116	3,329	17	95	112
black sagebrush	30	2,585	78	41	119
shadscale and greasewood	32	7,112	213	87	300

b. Within Allotment (Flowing Outside)

Vegetation Type	Runoff (ac-ft)	Sediment (tons)	Salt (tons)		
			Sediment	Runoff	Total
juniper-pinyon	13	458	2	11	13
big sagebrush	8	218	1	6	7
black sagebrush	6	504	15	8	23
shadscale and greasewood	16	3,535	106	44	150

c. Area Outside the Allotment (Runoff Flowing through Allotment)

Vegetation Type	Runoff (ac-ft)	Sediment (tons)	Salt (tons)		
			Sediment	Runoff	Total
juniper-pinyon and big sagebrush	569	20,326	102	464	566

C. Reductions of Salt and Sediment from Alternative Means of Salinity Control

1. Removal of Livestock

Total Salt and Sediment Yield before treatment:

Vegetative Type	Runoff (ac-ft)	Salt (tons)	Sediment (tons)
juniper-pinyon and big sagebrush	446	439	15,059
black sagebrush	36	142	3,089
shadscale and greasewood	48	319 (from sediment) 131 (from runoff)	10,647

Total removal of livestock will result in the following:

45 percent reduction in sediment and 30 percent reduction in runoff from shadscale and greasewood areas after 3 years (124, 126).
20 percent reduction in sediment and runoff from juniper-pinyon and big sagebrush areas after 3 years.
30 percent reduction in sediment and runoff from black sagebrush areas after 5 years.

a. Runoff Reduction (acre-feet/year)

juniper-pinyon and big sagebrush	446 x 20% = 89
black sagebrush, shadscale and greasewood	84 x 30% = 25
Total	=114

b. Sediment Reduction (tons/year)

juniper-pinyon and big sagebrush	15,059 x 20% = 3,012
black sagebrush	3,089 x 30% = 952
shadscale and greasewood	10,647 x 45% = 4,791
Total	= 8,755

c. Salt Reduction (tons/year)

juniper-pinyon and big sagebrush	439 x 20% = 88	
black sagebrush	142 x 30% = 43	
shadscale and greasewood	319 x 45% = 144	(from sediment)
	131 x 30% = 39	(from runoff)
Total	314	

2. Management of Livestock
a. Grazing Use (past and present)

Licensed use prior to 1978	835 AUMs
Present licensed activity use (1977)	625 AUMs
Administratively suspended nonuse	1,859 AUMs
Total adjudicated privileges	2,484 AUMs

The Allotment Management Plan (AMP) states that the major objective is to improve watershed condition while producing enough forage to satisfy the qualified demand of 1,650 AUMs. This is in error since the adjudicated privileges are 2,484 AUMs.

Objectives of reducing salinity and sediment loss, from this semiarid allotment, cannot be achieved without adequate ground cover, maintenance of aerial plant parts (canopy), and keeping effects of livestock trampling to a minimum. The following grazing capacities can be tolerated under grazing management and still achieve the same reduction in salinity. Much of the juniper-pinyon area is unusable because of steep topography and dense trees and rock.

Vegetative Type	Acreage (60% usable)	Grazing Capacity Ac/AUM	Usable AUMs
juniper-pinyon	6,907	40	173
big sagebrush	3,547	20	177
black sagebrush	3,452	15	229
shadscale and greaswood	4,629	50	92
			671

The difference between 625 and 671 AUMs equals a 7 percent increase. This increase in AUMs is possible under management because of the large reduction in livestock use made in 1977.

Grazing management will result in the following:

15 percent reduction in runoff, sediment, and salt from juniper-pinyon, big sagebrush, and shadscale and greasewood areas after 15 years.

25 percent reduction in runoff, sediment and salt from the black sagebrush area after 15 years.

b. Runoff Reduction (acre-feet/year)

juniper-pinyon	322 x 15% = 48
big sagebrush	124 x 15% = 19
black sagebrush	36 x 25% = 9
shadscale and greasewood	48 x 15% = 7
	Total = 83

c. Sediment Reduction (tons/year)

juniper-pinyon	11,512 x 15% = 1,727
big sagebrush	3,547 x 15% = 532
black sagebrush	3,089 x 25% = 772
shadscale and greasewood	10,647 x 15% = 1,597
	Total = 4,628

d. Salt Reduction (tons/year)

juniper-pinyon	320 x 15% = 48
big sagebrush	119 x 15% = 18
black sagebrush	142 x 25% = 36
shadscale and greasewood	450 x 15% = 68
	Total = 170

3. Detention Dams

Detention dams will result in 90 percent reduction in sediment and no reduction in runoff, from affected areas (not including areas draining runoff outside the influence of dams).

a. Runoff Reduction = 0

b. Sediment and Salt Reduction (tons/year)

Vegetative Type	Sediment	Salt
juniper-pinyon and big sagebrush (from outside the allotment)	20,326	102
juniper-pinyon (within the allotment)	11,054	55
big sagebrush (within the allotment)	3,329	17
black sagebrush	2,585	78
shadscale and greasewood	7,112	213
Totals	44,406 (39,965)	465 (419)

44,406 tons less 10% loss of suspended sediment through the outlet pipe = 39,965 tons sediment; 465 tons less 10% loss = 419 tons salt.

4. Retention Dams

Retention Dams will result in 100% reduction in sediment and runoff, from affected areas.

a. Runoff, Sediment and Salt Reduction

Vegetative Type	Runoff (ac-ft/year)	Sediment (tons/year)	Salt (tons/year)
juniper-pinyon and big sagebrush (from outside the allotment)	569	20,326	566
juniper-pinyon (within the allotment)	309	11,054	307
big sagebrush (within the allotment)	116	3,329	112
black sagebrush	30	2,585	119
shadscale and greasewood	32	7,112	300
Totals	1,056	44,406	1,404

Appendix XII-2

Calculation Procedures for Benefit-Cost Analysis of Salinity Reductions on Sample Allotments

The following procedures are used to calculate the present value of benefits and costs of several salinity control measures on sample allotments.

Typical benefit-cost analysis requires the measurement of new benefits and costs from an existing, or base level. The sum of the existing plus new benefits or costs, resulting from the alternatives considered establish the "with project" level. Net benefits, and costs are derived through the following methodology:

Direct Costs

Existing (Without) + New = With

With - Without = Net due to the "with project".

This study uses net benefits accruing from tons of sediment reduced, net change (+ or -) in salinity concentration, and increases in AUMs of forage.

Salinity control benefits for each alternative are derived by multiplying the estimated reduction in salinity concentration at Imperial Dam by the dollar value per mg/l of salinity damages at Imperial Dam. Sediment reduction benefits are derived by multiplying the estimated tons of sediment reduced by the dollar value per ton of sediment damages at Lake Powell.

The present value (P.V.) of costs equals the sum of direct costs, maintenance and operation costs, replacement costs, and the costs associated with the direct livestock related income effects.

The direct costs include only the sum of new construction and treatment costs and the loss of the BLM grazing fee. The procedure for computing direct construction costs of existing measures is outlined in the following display. Similar methodology applies to the determination of benefits.

Methodology for Benefit-Cost Analysis

	Existing and/or Without Project (w/o)		New Investments in Improvements and Treatments		With Project Σ Existing + New
Construction of Improvements and Land Treatments	1/2 Replacement [1] Costs	+	New Costs	=	Σ Row
Operation and Maintenance	Present Value of Costs	+	Present Value of Costs	=	Σ Row
Replacement of Improvements and Treatments	Present Value of Future Costs	+	Present Value of Future Costs	=	Σ Row
	Σ of Column		Σ of Column		Σ of Rows

Total Costs = Σ of Rows + Opportunity Costs (Water Retained On-site, Direct Income Effects, Loss of Grazing Fees, etc.)

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[1] Assumes that, on the average, all existing improvements and treatments are half worn out, or that only one-half of their economic life remains.

Direct livestock related income effects of each alternative are a function of the number of AUMs eliminated (if any), the range livestock related income, and a buildup factor (present value factor).

A sample procedure for calculation of the benefit-cost analysis for one alternative is presented on the following pages. The physical data used in the calculations for economic efficiency of the sample allotments on highly saline and moderately saline lands are found in Tables XII-2-6A and -6B.

A. Present Value of Benefits from Removal of Livestock on Highly Saline Lands

	Net Benefits ($)
1. Salinity Reduction (Change in concentration level ±) milligram/liter x $330,800 2/ x Buildup Factor 3/ 6.86 mg/l x $330,800 x 14.77 = $33,517,383	33,518,000
2. Tons of Sediment Reduced x $0.58 4/ x Buildup Factor 3/ 2,468,598 x $.58 x 14.77 = $21,147,491	21,148,000
3. Increase in AUMs 5/: AUM Increase x $6.48 6/ x Buildup Factor 3/ = 0 x $6.48 x 14.77 = $ 0	0
	55,666,000

2/ Dollar per mg/l in salinity concentration at Imperial Dam (from Table XII-2-1) = $330,800.

3/ Buildup factor from Table XII-2.

4/ Dollars per ton of sediment reduced at Lake Powell.

$$\frac{\$54,774,410}{93,979,000 \text{ tons/yr}} = \$0.58/\text{ton}$$

$54,774,410 (1977 dollars) = $48,749,030 (1975 dollars) @ 6% annual inflation. Taken from Workman and Keith "Economics of Soil Treatments in the Upper Colorado" 1975 (223).
93,979,000 tons/yr. Taken from Upper Colorado Region State - Federal Interagency Group "Upper Colorado Region", June 1971, Table 3 p. 35. Average annual tons of suspended sediment discharge in the Upper Colorado River Region 1965 (204).

5/ Occurs with livestock only.

6/ A combined value of range livestock related income ($4.97) and BLM grazing fee ($1.51). This value compares with the commercial values of AUMs ($7.20), taken from Economic Research Service, U.S.D.A., Fair Market Value Analysis of Grazing Fees on National Resource Lands, Farm Real Estate Bulletin, July 1977 (47).

B. Present Values of Costs from Removal of Livestock on Highly Saline Lands

	With Project ($)	Without Project ($)
1. Direct Costs:		
a. (With) Σ(New Construction and Treatment Costs) 7/ + 1/2 Replacement Costs of Existing Improvements and Treatments) 8/		
(0) + (747,000) = $747,400	747,400	
a1. (Without) Existing Costs = 1/2 Replacement ($747,400) =		747,400
+		
b. Loss of BLM Grazing Fees (AUMs x $1.51 9/ x Buildup Factor) 10/ (95,024) x $1.51 x 14.77 = $2,119,291	2,120,000	0
2. Maintenance and Operation 11/		
a. (With) Σ(New Construction and Treatment Costs x Yearly Maintenance Charge 11/ x Buildup Factor 3/ + (P.V. of Existing Maint. and Oper.) =		
($ 0) + ($233,218) =	233,218	

7/ New construction and treatment costs based on Table XII-2-5 (costs of improvements by geographic area for calendar year 1976).

8/ Accounts for depreciation; assumes that the average existing structure or treatment is half depreciated.

9/ Current BLM Grazing Fee. Taken from Table 3 Federal Register Feb. 4, 1977, Vol. 42, No. 24, page 6989 (55).

10/ Occurs only with the removal of domestic livestock grazing.

11/ Yearly maintenance charge taken from Table XII-2-3.

B. Present Value of Costs (cont.)

	With Project ($)	Without Project ($)
b. (Without) P.V. of Existing Maint. and Oper. Costs) ($233,218) =		233,218
+		
c. Water Retained x $15.00 [12] x Buildup Factor (12,206) x $15.00 x 14.77 = $2,704,239	2,704,200	0
3. Replacement Costs [13] (New Const. and Treatments x Replacement Factor [13]) + (Existing Improvements & Treatments x Replacement Factor [13]) ($ 0) + ($33,048) =	33,048	33,048
+		
4. Direct Livestock Related Income Effect: [14] No. AUMs eliminated x $4.97 [15] x Buildup Factor (95,024 AUMs) x $4.97 x 14.77 = $6,975,417	6,975,400	0
Total Costs	$12,813,266	$1,013,666

Net Costs = With Project - Without
($12,813,266) - ($1,013,666) = $11,799,600

C. Benefit Cost Ratio

$$\frac{\text{Present Value Benefits (A)}}{\text{Present Value Costs (B)}} = \frac{\$54,660,000}{\$11,799,600} = 4.63:1$$

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[12] Taken from personal conversation with John Keith, Assist. Prof. of Economics, Utah State Univ., May 1977 pertaining to USU watershed salinity control studies.

[13] Replacement factor from Table XII-2-4.

[14] Occurs only with the elimination of domestic livestock grazing.

[15] Range livestock related income. Taken from "Draft of the Environmental Statement. Proposed Domestic Livestock Grazing Program for the Uncompahgre Basin Resource Area." Unpublished document (28).

1970 dollars = $2.90
1977 dollars = $4.97 @ 8% inflationary rate among livestock receipts from 1967-1977 (survey of current business BEA p. S-3 May 1977) (30).
index = 100 1967
index = 180 1977
80% increase

D. Net Benefits (A-B) = $42,900,000

E. Costs - Construction, Maintenance, Operation and Replacement for Removal of Livestock on Highly Saline Lands.

Alternative: Removal of Livestock Highly Saline Lands

Range Improvements Land Treatments	No.	Existing and/or W/O Project	No.	Investments	With Project (W/)
Fence miles @ $2,300	610	1,403,000	610	0	
Cattleguards each @ $1,700	54	91,800	54	0	
Sub Total		1,494,800		0	747,400 16/

Operation and Maint.	Buildup Factor	W/O Annual Cost	Present Value	W/Project Annual Cost	Present Value
Fence miles @ $25	14.77	15,250	225,242	15,250	225,242
Cattleguards each @ $10	14.77	540	7,976	540	7,976
Sub Total			233,218		233,218

Replacements	Year	Replacement Factor	W/O Project		With Project	
			Cost	Present Value	Cost	Present Value
Fence miles @ $2,300	50	-0-	-0-	-0-	-0-	-0-
Cattleguards each @ $1,700	20	.36	91,800	33,048	91,800	33,048
Sub Total				33,048		33,048

16/ Equals 1/2 the Replacement Cost of Existing Improvements.

Table XII-2-1. Agricultural, Municipal, and Industrial Salinity Damages.

Agricultural, municipal and industrial damages from salinity in the Lower Basin are based on studies conducted for the Consortium of Western Water Research Institutes and Centers (5).

Agricultural Damages	Estimated Average $/mg/l	1977 Estimated Damage @ 6.7% Inflation Rate $/mg/l
USBR (1974 Dollars)	$ 33,168	$ 40,000
Municipal (Household) Damages (USBR 1974 Dollars)		
Metropolitan Water District	$187,000	
Central Arizona Service Area	26,300	
Lower Main Stem	27,200	
	$240,500	$289,000
Industrial		
USBR (1974 Dollars)	$ 1,500	$ 1,800
Average agriculture, municipal and industrial damages estimated from salinity		$330,800

Damage assessments by Kleinman et al (113), Valentine (202), Utah Water Research Laboratory, Utah State University (201), and Eubanks and d'Arge (54) were reviewed to confirm the Bureau of Reclamation estimates, and also to establish the range of damages in dollars per mg/l annually.

Table XII-2-2. Buildup Factors - Benefit Factors for Various Buildup Periods @ 6-5/8 Percent Discount Rate (50-year lifetime)[17]

Methodology: Present Worth (P.W.) of 1 Factor (50 years - life of project) x Buildup Factor/Year of Project.

Buildup Years	Factor	Buildup Years	Factor
1	14.77 [17]	14	9.97
2	14.31	15	9.70
3	13.85	16	9.42
4	13.44	17	9.17
5	13.02	18	8.92
6	12.63	19	8.68
7	12.24	20	8.45
8	11.89	25	7.68
9	11.54	30	7.41
10	11.20	35	6.56
11	10.87	40	5.20
12	10.56	45	4.68
13	10.26	50	4.22

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[17] P.W. of 1 - 50 year factor.

Table XII-2-3. Yearly Maintenance and Operation Charges.

Item	Yearly Charge Per Item	
Detention Dam		
Small	11,900 yds x	$0.05
Large	34,600 yds x	$0.05
Retention Dam		
Small	13,900 yds x	$0.05
Large	40,600 yds x	$0.05
Fence	1 mile	$ 25.00
Cattleguard	1 each	$ 10.00
Water Catchment	1 each	$100.00
Spring	1 each	$ 50.00
Pipeline	1 mile	$ 25.00
Trough	1 each	$ 20.00
Contour Furrow	1 acre	$ 0.25

Table XII-2-4. Replacement Factors.

Methodology: Sinking Fund Factor (SFF) SFF x P.W. of 1 Factor @ Life of Project (50 years).

Replacement Year	Factor	Replacement Year	Factor
1	14.77 [18/]	11	.95
2	7.15	12	.84
3	4.61	13	.75
4	3.34	14	.67
5	2.58	15	.60
6	2.08	20	.36
7	1.73	25	.25
8	1.46	30	.17
9	1.25	35	.12
10	1.09	40	.08

[18/] P.W. of 1 - 50 year factor.

Table XII-2-5. Costs of Improvements by Geographic Area.[19/]

Improvement Type	Montana	Idaho	Eastern Oregon	Arizona	Utah	Colorado	Expected Life (years)	Maintenance Cost/Year
Fencing								
4-wire								
Standard	$1,800/mi	$1,200/mi	$1,850/mi		$2,050	$3,000/mi	25	$25
Cattleguard		$1,325/ea	$1,800/ea			$1,700 ea	20	$10
Spring Development	$1,200/ea	$2,300/ea	$2,000/ea				--	$50
Reservoir								
<20,000/cu yds	$0.32-$0.42/cu yd	$1.25/cu yd	$0.68/cu yd		$0.70-$0.86/cu yd	$0.50-$0.60/cu yd	25	$0.05
>20,000/cu yds	$0.34-$0.37/cu yd	$1.10/cu yd	$0.74/cu yd				25	$0.05
Well								$200
Drill and Casing			$30/ft				7	
Rigging			$5,000/ea				25	
Storage Tanks			$300/M.gal.				25	
Trough			$200/ea					$20
Pipeline			$3,000/mi			$2,500/mi		$100
Water Catchments	$8,000		$17,000		$12,000		20	$100
Contour Furrowing	$14/acre						15-20	$0.25
Dikes		$1.10/cu yd	$0.74/cu yd				25	$0.05
Detention Dams							25-30	$0.05
<20,000/cu yds								
>Excavation for Core Trench				$0.75-$1.10/cu yd	-0-	$0.52-$0.75/cu yd		
Compacted Fill		$1.10/cu yd		$0.80-$1.40/cu yd	$0.87-$1.15/cu yd	$0.74-$1.60/cu yd		
Pipe Outlet				$4,500-$10,000	$10,000-$11,000	-0-		
Spillway				$2,775-$3,975	$4,900-$5,600	-0-		
Equip. Rental				$40-$50/hr	$47-$55/hr	$35-$40/hr		
>20,000/cu yds								
Excavation for Core Trench					-0-			
Compacted Fill					$0.77-$1.21/cu yd			
Pipe Outlet					$14,000-$17,000			
Spillway					$13,000-$18,200			
Equip. Rental					$47-$77/hr			

[19/] Material and Labor Cost from BLM job documentation reports for range land treatment and improvements for fiscal year 1976-1977.

Table XII-2-6A. Reductions of Water, Sediment, and Salt Resulting from Selected Treatments Applied to Highly Saline Lands in the Upper Basin.

Control Measure	Water Retained (ac-ft)	Sediment Reduced (tons)	Salt Reduced (tons)	Change in Concentration (± mg/1)	AUMs Reduced Per Year
1. Grazing Management					
Colorado	1,141	134,942	5,178	- 0.36	3,016
Utah	5,554	656,999	25,213	- 1.73	14,686
Wyoming	1,057	125,070	4,800	- 0.34	2,796
Total	7,752	917,011	35,191	- 2.43	20,498
2. Removal of Livestock					
Colorado	1,796	363,264	13,161	- 1.01	13,983
Utah	8,745	1,768,647	64,078	- 4.91	68,081
Wyoming	1,665	336,687	12,198	- 0.94	12,960
Total	12,206	2,468,598	89,437	- 6.86	95,024
3. Structures and Land Treatments					
a. Colorado					
(1) Detention Dams	-0-	387,682	6,769	- 0.61	
Contour Furrows	980	262,496	10,540	- 0.86	
(2) Retention Dams	7,321	430,758	15,107	- 0.65	
Contour Furrows	980	262,496	10,540	- 0.86	
b. Utah					
(1) Detention Dams	-0-	1,920,736	33,539	- 3.01	
Contour Furrows	4,774	1,300,514	52,219	- 4.23	
(2) Retention Dams	35,643	2,097,253	73,549	- 3.17	
Contour Furrows	4,774	1,300,514	52,219	- 4.23	
c. Wyoming					
(1) Detention Dams	-0-	359,318	6,274	- 0.57	
Contour Furrows	909	243,291	9,769	- 0.80	
(2) Retention Dams	6,785	399,242	14,001	- 0.61	
Contour Furrows	909	243,291	9,769	- 0.80	
Total (1)	6,663	4,474,037	119,110	-10.08	-0-
Total (2)	56,412	4,733,554	175,185	-10.32	-0-

Table XII-2-6B. Reductions of Water, Sediment, and Salt Resulting from Selected Treatments Applied to Moderately Saline Lands in the Upper Basin.

Control Measure	Water Retained (ac-ft)	Sediment Reduced (tons)	Salt Reduced (tons)	Change in Concentration (± mg/l)	AUMs Reduced Per Year
1. Grazing Management					
Colorado	3,037	196,469	4,026	- 0.07	941
Utah	6,833	442,148	9,061	- 0.16	2,116
Wyoming	4,114	462,761	6,216	- 0.16	-0-
Total	13,984	1,101,378	19,303	- 0.39	3,057
2. Removal of Livestock					
Colorado	4,439	318,597	6,650	- 0.18	34,653
Utah	9,990	716,996	14,966	- 0.38	77,987
Wyoming	6,264	764,060	10,239	- 0.32	209,926
Total	20,693	1,799,653	31,855	- 0.88	322,566
3. Structures and Land Treatments					
a. Colorado					
(1) Detention Dams	-0-	678,520	7,699	- 0.69	
Contour Furrows	363	49,191	1,122	- 0.07	
(2) Retention Dams	6,402	753,911	15,066	- 0.74	
Contour Furrows	363	49,191	1,122	- 0.07	
b. Utah					
(1) Detention Dams	-0-	1,526,992	17,313	- 1.55	
Contour Furrows	817	110,704	2,525	- 0.15	
(2) Retention Dams	14,409	1,696,659	33,905	- 1.65	
Contour Furrows	817	110,704	2,525	- 0.15	
c. Wyoming					
(1) Detention Dams	-0-	1,840,236	10,724	- 0.97	
Contour Furrows	1,901	219,560	4,701	- 0.24	
(2) Retention Dams	17,687	2,044,707	27,736	- 0.79	
Contour Furrows	1,901	219,560	4,701	- 0.24	
Total (1)	3,081	4,425,203	44,084	- 3.67	
Total (2)	41,579	4,874,732	85,055	- 3.64	

Appendix XII-3. Methodology Employed in Section VIII

A. Up-dating to 1980 Dollar Base

1. Industry earnings for an initial year (1972) were established for each of the regions by aggregating county data. The regional aggregates were projected to 1980 using growth rates for each industry, computed from OBERS Projections in BEA economic areas containing the subject counties (207). The 1980 regional data were adjusted for price by projecting the GNP price deflation index (1972 = 100) using quarterly data for 1975 and 1976 from Survey of Current Business, May 1977 (30). The regression equation of $Y = a+bX$ was computed as $I = 122.96 + 1.67\ X$ ($r^2 = .99$). It yielded a 1980 index of 156.36 (or an annual average price increase of 6.7% from 1977 through 1979).

2. Construction costs used in Chapter VII were adjusted to a 1980 price base by projecting the Department of Commerce construction cost index, i.e., an annual increase of 7.7 percent from 1977 through 1979 (30).

B. Relationship of Industry Output (receipts) to Earnings

From Water Resources Council, Guideline 5, "The measurement of impact, in terms of earnings (defined as wage and salary payments, other labor income, and proprietor's income) and employment, is much more meaningful for assessing implications of a given regional change than is the I-O concept of gross output. This follows, because gross-output changes are compounded by varying amounts of double counting . . ." (208).

The following table provides coefficients relating earnings to output as contained in the earnings model used in this study.

Table XII-3-1 Earnings as Related to Output

Industry	Earnings-Output Coefficient
Livestock	3.608
Other Agr.	2.106
Metal Mining	2.847
Coal Mining	1.411
Oil & Gas Extraction	1.901
Other Mining	1.870
Construction	2.037
Food & Kindred Prods.	3.709
Lumber & Related Prods.	2.456
Paper & Allied Prods.	2.936
Petroleum Refining	5.173
Primary Metals	2.978
Other Mfg. (general)	2.586
Trans. & Comm.	1.600
Public Utilities	2.207
Whols. & Retail Trade	1.383
Fin., Ins. & R.E.	1.470

Earnings may be converted to an estimate of output by multiplying by the appropriate coefficient above; output can be converted to earnings by division. For example, the 1980 up-dated construction costs (gross receipts to industry) were divided by 2.037 to arrive at earnings impacts.

C. Estimating Upper Basin Agriculture Cost Adjustment Factor

The following assumptions and computations were made:

1. Surplus water exists until total use reaches at least 5.8 MAF.
2. Redistribution among users would occur when total use reaches 6.5 MAF.
3. At 6.5 MAF, agricultural rights would be purchased by competing users.
4. At 1980 prices, earnings per acre-foot of water in agriculture is estimated to be $21.84.
5. As surplus water supplies dwindle, between 5.8 MAF and 6.5 MAF, efficiency in agriculture could be purchased through cost increases up to the earnings value of an acre-foot of water.
6. By the year 1995 (midway in the decade when projected water use exceeds 5.8 MAF) the ratio of water use to earnings value in agriculture would indicate that $6.55 of additional cost could be incurred per acre-foot used in agriculture.
7. It was assumed that, during the 1990s, earnings in the upper basin agriculture industry would be reduced by $6.55 per acre-foot of water retained for salinity control action.

D. Estimating Secondary Impacts

Industry earnings multipliers were estimated for each region based on an eighteen sector net-trade-flow model which uses regional industry earnings as input. Multipliers are based on regionally computed marginal propensities to consume and import. The model is described in "Estimating Regional Net Trade Flows and Income Multipliers from Secondary Data: An Application of Keynesian Theory," The Annals of Regional Science, November 1975 (43).

Table XII-3-2 Multipliers Used in This Study

Industry/Sector	Upper Basin	Lower Basin-Agr.
Livestock	1.970	1.912
Other Agr.	1.196	1.812
Metal Mining	2.123	2.086
Coal Mining	2.038	1.013
Oil & Gas Extraction	1.779	1.020
Other Mining	2.020	2.056
Construction	1.472	1.317
Food & Kindred Prod.	1.292	1.283
Lumber & Related Prod.	1.690	1.034
Paper & Allied Prod.	1.024	1.021
Petroleum Refining	1.004	1.073
Primary Metals	1.053	1.046
Other Mfg. (General)	1.898	1.713
Trans. & Comm.	1.275	1.019
Public Utilities	1.526	1.217
Whols. & Retail Trade	1.086	1.059
Fin., Ins. & R.E.	1.020	1.020
Services	1.583	1.238

FIGURE VIII

VEGETATION OF

8bb

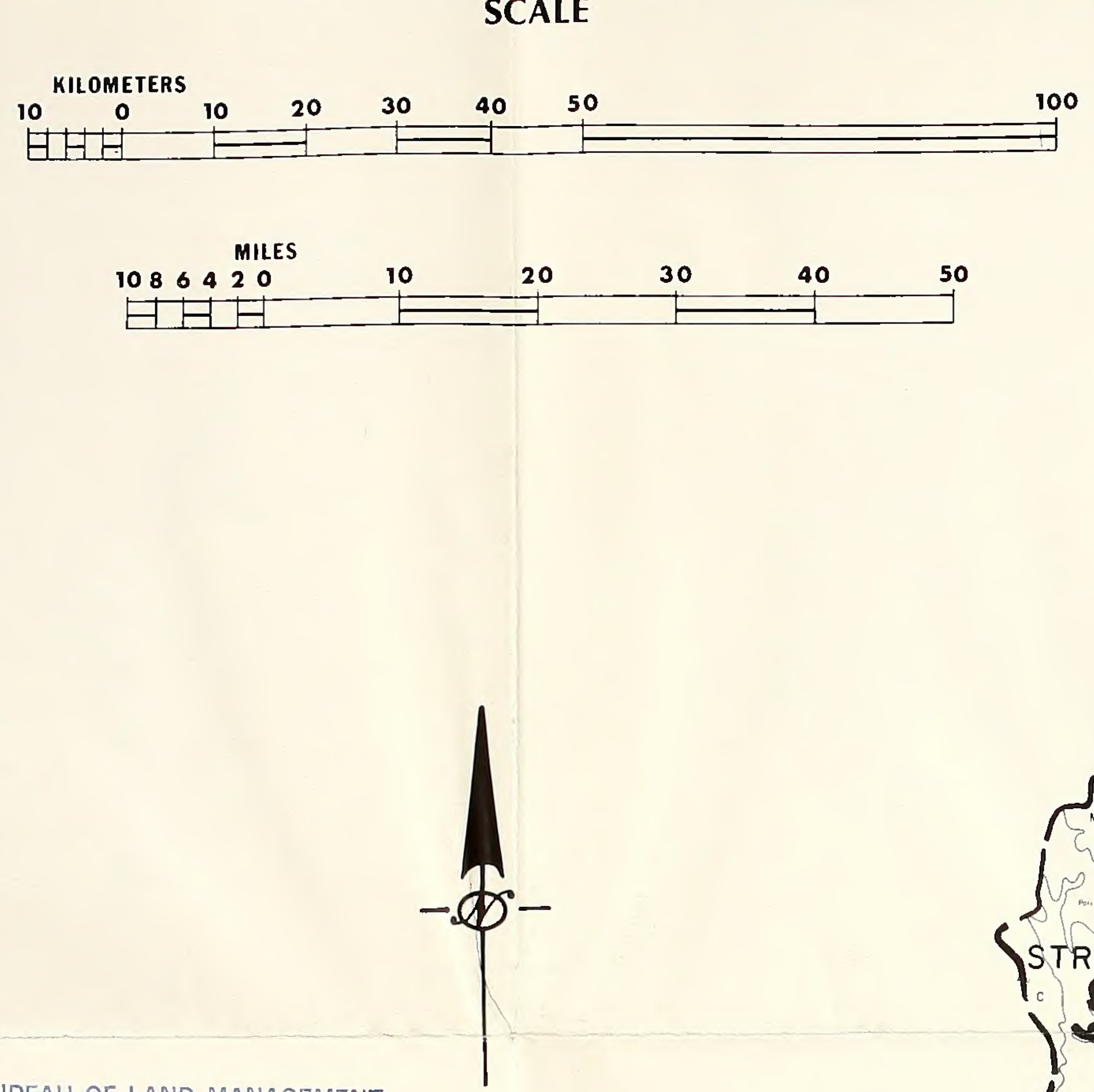


FIGURE IV-8bb
VEGETATION OF UTAH

A	AGRICULTURAL
W	WATER
GW	GREASEWOOD
DS	DESERT SHRUB
SB	SALTBUSH
G	GRASSLAND

DS	DESERT SHRUB
SB	SALTBUSH
G	GRASSLAND
S	SAGEBRUSH
PJ	PINYON-JUNIPER
MS	MOUNTAIN SHRUB
M	MEADOW
C	CONIFER & ASPEN
B	BARREN
R	RIPARIAN

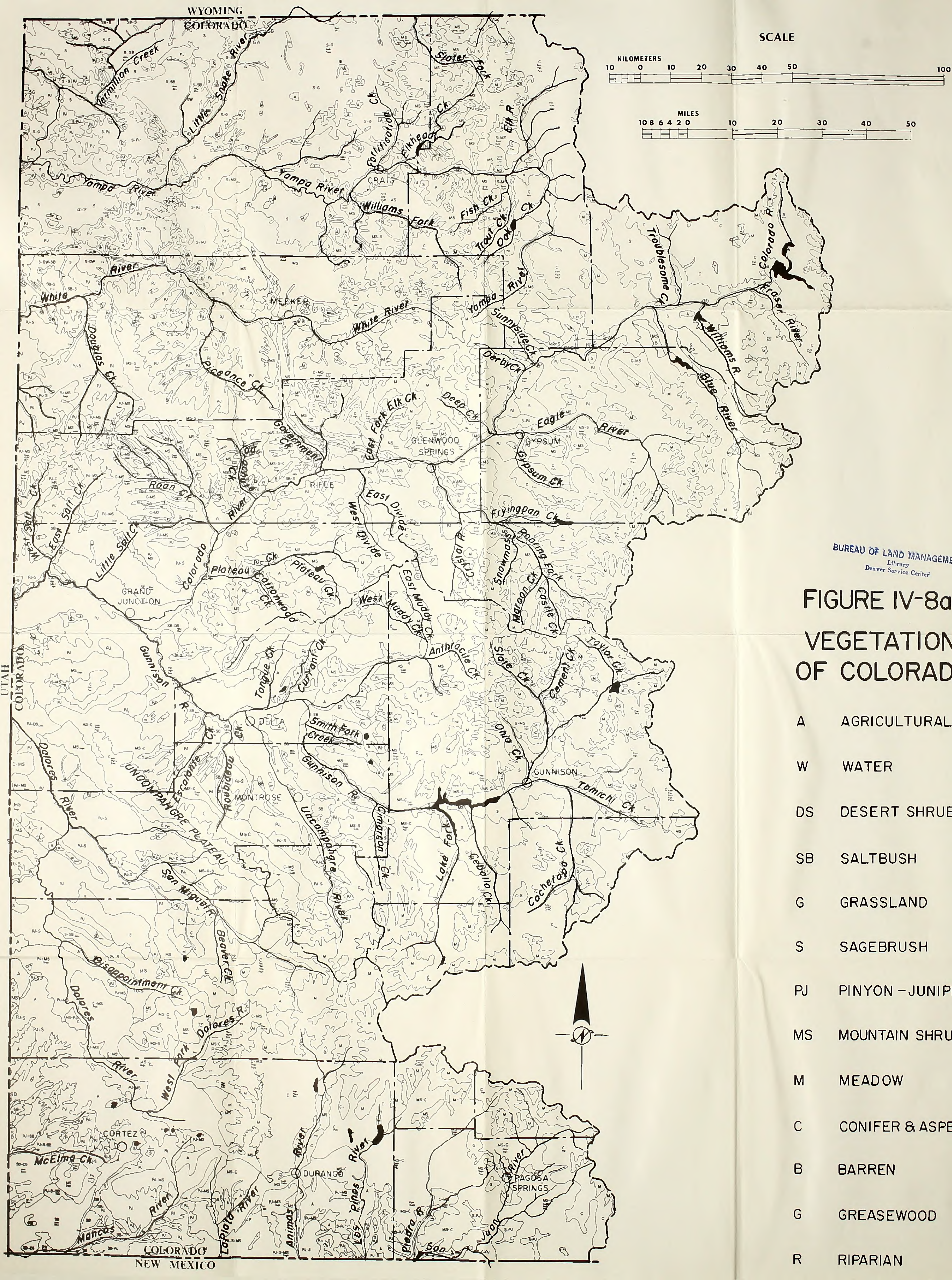
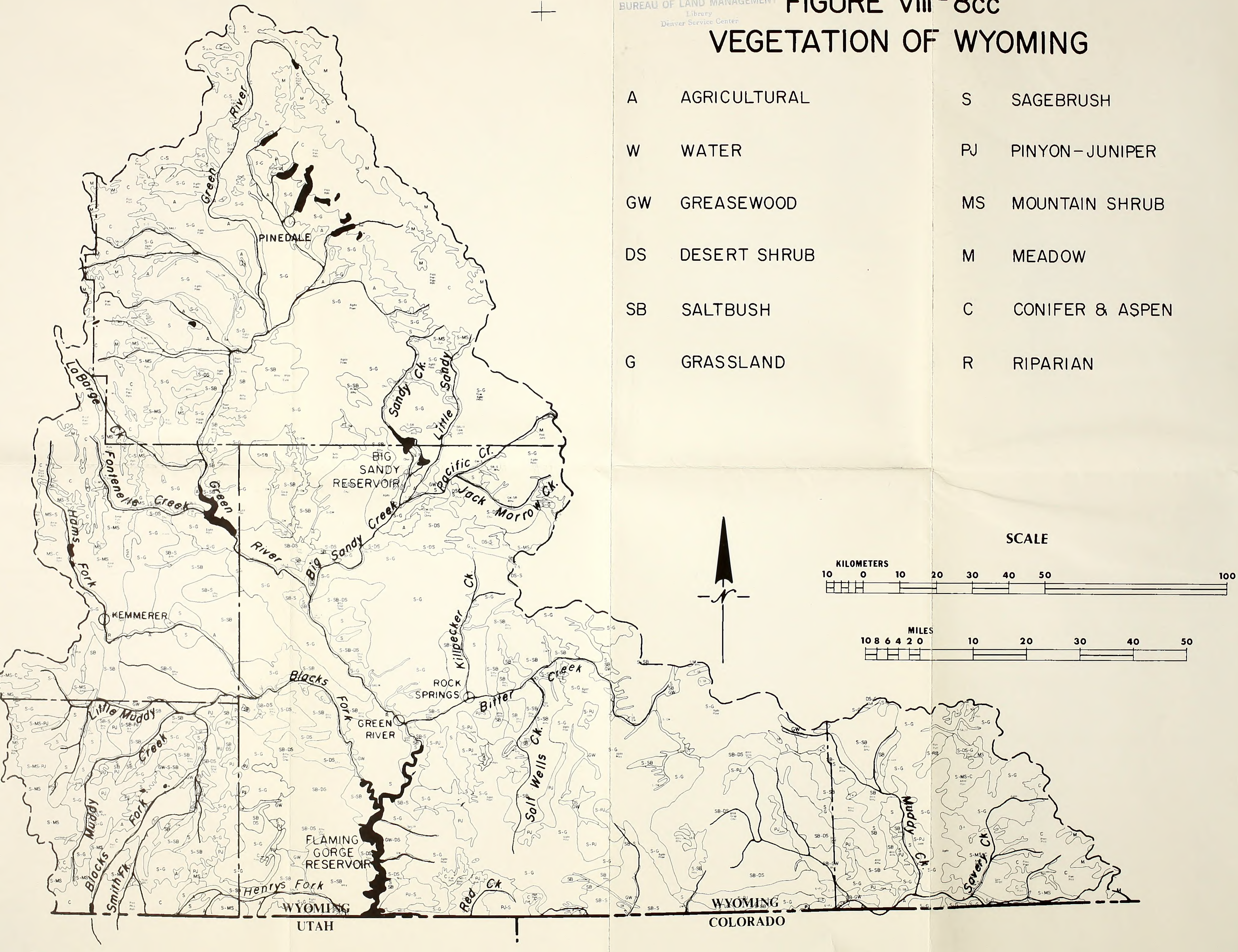


FIGURE IV-8aa VEGETATION OF COLORADO

A	AGRICULTURAL
W	WATER
DS	DESERT SHRUB
SB	SALTBUSH
G	GRASSLAND
S	SAGEBRUSH
PJ	PINYON - JUNIPER
MS	MOUNTAIN SHRUB
M	MEADOW
C	CONIFER & ASPEN
B	BARREN
G	GREASEWOOD
R	RIPARIAN

FIGURE VIII-8cc
VEGETATION OF WYOMING

A	AGRICULTURAL	S	SAGEBRUSH
W	WATER	PJ	PINYON-JUNIPER
GW	GREASEWOOD	MS	MOUNTAIN SHRUB
DS	DESERT SHRUB	M	MEADOW
SB	SALTBUSH	C	CONIFER & ASPEN
G	GRASSLAND	R	RIPARIAN

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