FINAL PROJECT REPORT

"Effects of Land Processes on the Salinity of the Upper Colorado River Basin"

by

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between USDI, Bureau of Land Management

and

Utah State University

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From Section III: Surface Hydrology, Salt Pickup, Microchannel Erosion.

Summary.

Hydrology.

1. Runoff Curve Numbers: For the geologic conditions encountered, runoff curve numbers are presented which may be used in the calculation of rainstorm runoff from small areas. They are generally higher than handbook expectations, especially considering the dry antecedent conditions.
2. Infiltration Rates: Terminal infiltration rates calculated are presented, and may be used as representatives of small areas of the soil/geologic conditions encountered. They are generally higher than might be expected from either curve number analysis or soils descriptions.
3. Effects of Cover: For the extreme hydrologic situations encountered on Mancos Undivided sites, cover density had no effect in simulated rainstorm runoff.
4. Frequency Perspective: The applied synthetic rainstorms were extreme events when compared to natural rainfall intensity, frequency, and duration.
5. Variability: Hydrologic performance varied within and between plot groups, sites, and geologic types. The least variation is with the smallest areas. There are definite hydrologic differences between the various geologic types.

Overland Flow Salinity: Plots and Microwatersheds

1. Sources and Processes: Overland flow salinity pickup is apparently a thin surface phenomenon, being influenced by an active layer perhaps as small as 1/10 inch. There is an immediate washoff of easily available chemical material, and a base salinity level to which the concentrations recede. The base level is reached within about 20 minutes after the initiation of rainfall, and it may represent a raindrop impact associated soil erosion salt source.
2. Variability: Chemical runoff concentrations varied widely, and more so as sampling bounds expanded. As with hydrology, there is variation (both significant and insignification) between and within plot groups, sites, and geologic sites. There are, however, easily identifiable differences between the hydrochemical characteristics of some of the geologic types.
3. Salt and Sediment: The relationship between salinity and sediment was generally vague, although encouraging. Associations were variable, but somewhat indicative of geologic type.
4. Modeling Runoff Salinity: Physics-based salinity models were resoundingly unsuccessful. Although definitely in the realm of curve-fitting, empirically based regressions were found to more adequately describe the observed data.
5. Salinity Contributions: The overland flow originated salinity from the Mancos Shale lands in the Price basin contributes less than one percent of the total basin salt production.

General:

1. Variability: Unexpected variation in short distances over apparently homogeneous settings should be expected. Abrupt changes in soil chemistry alone could be responsible for heterogeneity in hydrology, overland flow chemistry, sediment, and channel flow salinity.
2. Similarities: Flow salinity from the overland flow plots, the microwatersheds, and the channels all behave similarly with time: an initial strong flush receding to a base level.
3. The geologic basis for classiciation of hydrologic and chemical responses to rainfall is of insufficient resolution and/or consistency to be broadly used.
4. The salt/soil ratio, "B", offers a promising perspective technology for design or environmental impact work with rainstorm runoff.

Microchannel Salinity Sources

1. Channel Flow Losses: Flow losses in the gullies are directly associated with the texture of the bottom. Usually the losses can be considered as zero.
2. Processes and Sources: As with the plot/microwatershed studies, salinity receded from an initial high value rapidly within about 20 minutes) to a pseudo stable level maintained by erosion of the channel by the flow. Salinity increases with distance downstream but also approaches an apparent upper limit, perhaps a reflection of gypsum particle dissolution with time.
3. Variability: Channel originated salinity varied also within and between channels, runs, sites, and geologic types, although not as widely as the variation witnessed in hydrology or overland flow salinity.
4. Salt and Sediment: Double summation of both salt and sediment flow masses demonstrates consistent and characteristic relationships. The characteristic salt/soil ratio "B" can be estimated with some confidence ($r^2 = 0.48$) for these areas by

$$B = -0.00143 + 10^{-7} (1.63 X_1X_2 + 7.12 X_2^3)$$

where X_1 and X_2 are measures of the soil 1:1 extract conductivity and clay content, respectively.
5. Basin Salinity: The relative contribution of rainstorm flow in the Mancos Shale microchannels to the total salt transport of the Price River is about 2-1/2 percent.

From Section IV: Impact of Native Vegetation As Source of Diffuse Salt

Summary.

1. Of 13 species tested, recent litter from mat saltbush (Atriplex corrugata), halogeton (Halogeton glomeratus), Gardner saltbush (Atriplex gardneri), salt cedar (Tamarix pentendra), shadscale (Atriplex confertifolia), greasewood (Sarcobatus vermiculatus), and four-wing saltbush (Atriplex canescens) have the highest potentials for releasing salt.

2. Under high intensity simulated rainfall (7.6 cm/hr, 1-hour duration) the percent of total salt which was leached from litter of various species varied from a high of 78 percent in greasewood litter down to 2 percent in juniper (Juniperus osteosperma) litter. Only about 45 percent of the species tested showed significant differences in salt concentrations in litter leachate as a function of high and low intensity (3.8 cm/hr, 2-hour duration) simulated rainfall.

3. Results of foliage leaching tests (13 species) in the field indicate that the greatest quantities of salt per gram dry weight of foliage (including stems) were delivered by mat saltbush, Gardner saltbush, halogeton, and shadscale. The least amount of salt came from foliage of pinyon (Pinus edulis) and juniper trees.

4. Based on characteristics of two range sites whose present condition is typical of the lower portion of the Price River drainage it was calculated that plants contribute between .01 and .02 percent or less of the total annual salt load to the Price River.

From Section V: Soil Chemistry Studies

Summary.

This study uses a unique method to estimate the salt producing potential of a saline surface soil. The calculated 2 percent salt in the sample studied is a realistic approximation of the salt loading potential of this surface soil. Since the salinity of Mancos derived soil areas usually increase with depth the value of 2 percent represents the readily available salinity which can be released during a surface erosion event. Large amounts of salt can be expected to be released upon contact with the subsoil or consolidated shale. Extrapolating a sample value to a watershed is not without hazard, but it can serve as a management guideline if a representative sample is obtained. Using larger amounts of sample in the column proved to require an inordinately long time to obtain the salt release curve since a slow flow rate is essential to obtain valid data.

From Section VI: Impact of Various Range Improvement Practices on Annual Production, Cover, and Soil Profile Salt Concentrations.

Summary.

1. Salt accumulations in the soil profile were significantly different among sampling positions on three out of six gully plug treatments. However, the significant differences showed no consistent trend. Likewise, significant differences in salt concentrations as a function of soil depth were never consistent among the gully plug treatments.

2. On contour furrowing treatments salt concentrations on three out of 11 sites were significantly different among sampling locations.

Two treatments had significantly higher salt concentrations inside the furrow while one treatment had significantly higher salt concentrations outside the furrow.

3. The only consistent pattern on pinyon-juniper chainings and the various sagebrush treatments was the general lack of difference in salt concentrations between treated and untreated sites. In general the measured salt concentrations in surface soils of either pinyon-juniper or sagebrush sites present a problem of little concern as related to salt production within major river basins.

4. About one-third of the contour-furrowed sites indicated increased annual production. Best responses were found on loam and clay loam soils while soils of sandy loam or clay texture indicated a poor response to treatment. Soils classified as typic ustifluvents and ustollic haplargids were most favorable in terms of increased production.

5. Annual production on pinyon-juniper chainings was significantly increased across a variety of soil types (growth of trees excluded on both treated and untreated sites). The greatest increases in production were measured on sites with loam soils classified as typic haplustolls.

6. Neither of the two pitting treatments (on clay and sandy clay loam soils) indicated increased annual production at time of sampling. The pitting treatment on clay soils actually indicated a significant reduction in annual production.

7. Less than half of the various sagebrush treatments indicated increased annual production. There appears to be a general trend for sagebrush treatments to be most successful on loam soils, though significant

decreases in production were noted for three treatments on loam soils. Plowing was the least successful sagebrush treatment studied.

8. Cover on 7 of 11 contour furrowing treatments increased across a broad spectrum of soil textures and soil types. Cover increases were greatest on sandy clay loam and loam textured soils and on typic torriorthent and ustic torriorthent soil types.

9. Though cover increases due to chaining were noted on 8 of 14 pinyon-juniper sites on a variety of soil textures and soil types, the increases were uniformly small (tree cover included on both treated and untreated sites). No clear pattern emerged with either soil texture or soil type.

10. Pitting had no impact on cover.

11. Only about 20 percent of the various sagebrush treatments indicated increased cover. Ten percent indicated decreased cover. There was no impact on cover on the remaining 70 percent of treatments.

12. Age of treatment made little difference as to whether there was a significant increase or decrease in either production or cover on contour furrowed sites.

13. Cover data from pinyon-juniper treatments indicate either that significant increases in cover (where they occur) are slightly more dramatic on more recent treatments or that treatments which are approximately 11 years old represent conditions most ideal for enhanced cover (assuming again that an increase in cover occurs). The former interpretation is probably most nearly correct.

Production data suggests that pinyon-juniper sites chained since 1964 are not as favorable in terms of increased production as those chained prior to 1964.

14. Age of sagebrush treatment had no impact on significant changes in cover. Some general trends indicated that production increases (if they occur) on sagebrush ripping and sagebrush chaining treatments are slightly more dramatic for more recent treatments than for older ones.

15. Though attempts were made to relate production to cover (through regression techniques) on both treated and untreated sites on all improvement practices, the results were not promising.

16. Gully plugs on loam soils have a projected life expectancy of 37 years.

17. Contour furrows on sandy loam and clay loam soils have a projected life expectancy of 30 and 36 years, respectively.

Management Recommendations

Assuming that there is validity in the results obtained in these studies, but with awareness of the artificial conditions necessary for research, and the variability in the results, the following land and water management recommendations might reasonably follow in efforts to reduce salt on the land types studied.

1. Erosion Control. Because of the relationship observed between sediment and salinity production, erosion reduction may reduce salt outflows. Thus the erosion control measures customarily applied for the sake of on-site soil conservation and downstream reservoir protection should be considered on suitable sites for the goal of salinity control as well. Based on other studies, the primary purpose of treatments such as gully plugs and contour furrowing on Mancos shale is to control erosion (and also possibly salt) rather than improve vegetation.

2. Runoff Control: Insofar as erosion only occurs with water as the initiating force, the transporting vehicle, and the cutting agent, runoff control should be a goal of land management to reduce salt flows. Reduction of the opportunity for dissolution of resident salts should reduce salt production from both overland flow areas and downstream microchannels.

Any runoff reductions effected should result in greater soil water storage. Given the present low runoff rates (0.25 - 0.50 inch per year), there should be ample opportunity with, for instance contour furrowing, to store and transpire or evaporate this without causing seepage and possible interflow, and thus base flows of higher salinity. This may or may not be true in the case of gully plugs.

3. Cover Management: Based on the results of the multiple regression study described in Hydrology, the management of plant and litter cover alone in the Price basin (on the Mancos shale) could be expected to have little or no effect on runoff from overland flow, and thus little effect on total salt production from these areas or from receiving downstream channels. Although widespread throughout the Price basin, the Mancos environment is a hydrologic extreme. Cover increases due to various range improvement practices are not automatic and therefore require careful site selection criteria for best results.

As for grazing, grazing related cover changes alone would probably have an insignificant impact on runoff. However, the accompanying effects of grazing (soil disturbance, impact on range condition, trailing, access roadways, water developments, etc.) have not been covered, but should be considered.

4. Soil Management. The cover/hydrology relationships inferred strongly suggest that the soil itself is the overpowering influence on runoff, erosion and sediment production, and thus on salt flows. Therefore, any control activities should deal physically with soil itself. Such measures as contour furrowing or gully plugs can be expected to be more productive (for salinity control) than pure vegetation management (though results of this study are not as conclusive on this point as one might like). Chemical alteration of the soil structure and chemistry was not studied, but might be considered insofar as infiltration rates and soil water storage may be influenced.

5. Priorities. The salt production from microchannels has been shown to be several times that from overland flow sources. Salt production from vegetation is nil. Therefore, efforts to control flow into and thus erosion from gullies and rills should be the primary initial focus. Similarly the higher salt productin geologic types should be accented, albiet they tend to be the more difficult sites to manage.

6. Design and Impact Evaluation Methodologies: The use of the salt/soil ratio ("B") appears to be the most viable approach presently available to forecasting sediment related salt release. Unfortunately, however, the most widely accepted erosion prediction technique in current use (Universal Soil Loss Equation) has not been locally or regionally correlated. In the case of gullies and intermittent channels, no acceptable erosion mass erosion calculation methodology is known. The formula given for estimating "B" in terms of soil 1:1 conductivities and clay contents can be used safely only in areas representative of the study sites. In other areas, column leaching tests of composited soil samples might be used to approximate "B". The runoff curve number approach appears

relatively consistent, and thus useable, for the higher runoff potential areas.

7. Representative Pilot Areas: Insofar as this study was spawned as a result of insufficient on-site information or reference data, the establishment of administrative instrumentation for runoff, sediment, and salinity would be most appropriate. Representative small watersheds should be established for the goal of baseline data supply, pilot testing of land treatment measures, and refinements of hydrological parameters (curve numbers) and salt/sediment ratios. Although they should be pragmatically established and operated, they should be of sufficient accuracy and precision to be credible.

These areas might be considered as the hydrologic data collection equivalent of permanent transects or exclosures common in range management or permanent established growth plots used in forest management.

Recommendations for Future Research Related to Land Processes

1. The impact of gully plugs on possible subsurface flow and leaching patterns as a function of storm size and frequency should be studied on the Mancos shale.

2. Range condition may have an impact on both erosion and surface runoff, and therefore salt. Studies at Badger Wash indicate this may be true. Studies are needed to relate range condition to various grazing schemes such as rest rotation, etc.

3. New techniques for initiating soil stabilization on critical areas should be explored. These techniques might include chemical soil treatments as well as new and innovative land-forming techniques.

4. Studies are needed to validate erosion prediction equations such as the Universal Soil Loss Equation.

5. A comprehensive mineralogical study of Mancos shale is needed with emphasis on the type and amount of evaporite salts present.

6. Additional kinetics of salt dissolution studies would be useful to evaluate if the derived kinetic expressions are applicable to the variety of saline soils found in the upper Colorado River Basin.

7. The kinetic studies should be expended to include the affect of temperature on salt release, the rate at which individual ions are released from the mineral and a more detailed look at the soil-water ratio effect.

8. The derived kinetic expressions for salt release in a laboratory soil column study should be validated to observe if the batch derived expressions can be applied to salt release in a flow system.

9. Studies are needed to investigate the wetting and drying cycle on relatively unweathered soils in terms of its affect on kinetics of salt release.

II. INTRODUCTION AND DESCRIPTION OF MAJOR STUDY AREA

Salinity in the Colorado River is of major national concern for not only has it resulted in losses to regional economy but, in addition, high salinity levels have aggravated relations with the Republic of Mexico. Even in its virgin state, the salt load of the Colorado River in its lower reaches was about 600-700 ppm. However, man's development of water resources has affected both the quantity and quality of water supplies. Salinity levels in the lower reaches of the river now average 850 ppm with a predicted concentration of 1,300 ppm by the year 2000.

The sources and causes of dissolved solids within the Colorado River are of importance, for if they can be identified, strategies may be developed for effective management and control. In addition, this information would allow estimates to be made of downstream costs associated with upstream salt production. Thus, facilitating the development of economic trade-offs on a basin wide level.

Recent estimates suggest the largest single man-caused source of salinity is irrigation return flow amounting to about a third of the total salt load. Natural sources as salt wells and springs plus concentration by evaporation account for another third. The remaining salt load is attributed to diffuse sources originating on immense areas of wildland watersheds.

Methods are presently available to quantify salt input from point sources. However, the same is not true for diffuse sources. The summation of salt inflows from wide spread natural diffuse sources can result in significant mineral concentrations at tributary outlets. In view of the present, as well as future concern for water quality, it is imperative that reliable methods to predict salt loading from diffuse sources be developed. Such information will be valuable in the design of effective control and management procedures.

Salt input from diffuse sources can be divided into two categories: 1) land processes and 2) channel processes. This project is directed toward the understanding of the land processes involved in salt pickup from diffuse sources with the ultimate objective of determining structural and nonstructural treatments for salinity control within the hydrologic cycle.

In the spring of 1974, a study of land processes involved in diffuse salinity production was started in the Price River Basin of Utah (Figure II-1).

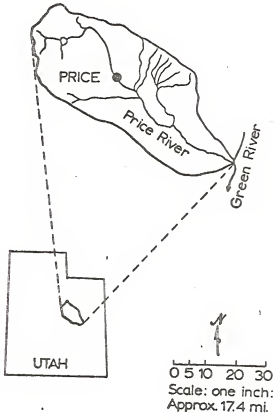

Figure II-1. The Price River Basin in East-Central Utah.

This study was jointly supported by the Bureau of Land Management, the Bureau of Reclamation and the Utah Agricultural Experiment Station. The overall objectives of the projected three year study are:

1. To determine the vegetative influence on salt movement in the hydrologic cycle.
2. To determine the role of overland flow on salt movement for selected land and vegetative types.
3. To determine the relative magnitude of surface erosion from overland flow for selected land and vegetative types.
4. To determine the relative worth of selected treatments on control of salt movement in the hydrologic cycle.

This report discusses the entire project as of October 1, 1977, and represents the final completion report for research conducted under currently existing funds.

THE STUDY AREA

The Price River basin was selected for the study area. It is one of the major sources of salinity to the Colorado Rover and, in addition, has both climate and vegetation typical of the Upper Colorado River basin (

The Price River basin encompasses nearly 4921 square kilometers (km^2) and is located principally in Carbon and Emergy Counties of east-central Utah. The altitudinal range varies from about 3170 meters (m) in the headwaters to nearly 1280 m at the confluence of the Price and Green Rivers.

Precipitation varies widely within the basin. Altitude, topography, and geographic location relative to the predominant west-to-east storm track are factors that effect the amount of precipitation. In general, annual precipitation in the headwaters area ranges between 50 and 63 centimeters (cm), while the lower portion of the basin receives about 20 cm. Nearly 65 percent of the total precipitation occurs as snow during the period of late October through early May. Of the total annual precipitation, about 50 percent falls on the upper 30 percent of the basin, while 70 percent falls on areas having altitudes greater than 1830 m. Consequently, approximately 70 percent of the basin may be classified as semi-arid.

The Price River has a length of 158 km and flows in a southeasterly direction. The majority of flow originates in the upper third of the watershed. Stream flow is greatly affected by irrigation use in the central portion of the basin as illustrated by long term mean discharge records at strategic locations. Near Scofield (drainage area about 401 km^2) mean discharge is 1.7 cubic meters per second (cms), at Heiner (drainage area 1075 km^2) mean discharge is 3.14 cms while at Woodside (drainage area 3885 km^2) mean discharge is only 2.92 cms.

Land use is primarily the raising of cattle and sheep, while about two percent of the area is irrigated and produces sugarbeets, hay and grain. The major industry of the area is underground coal mining.

GEOLOGY OF THE BASIN

Geographically, the Price River basin contains portions of the Uinta Basin, the High Plateaus and Canyon Land sections of the Colorado Plateau province. Although the geology of the area is complex, it has been well documented. Figure II-2 illustrates the major graphic units present in the basin.

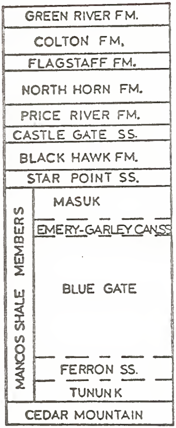

Figure II-2. Major geologic stratigraphic units present in the Price River basin.

The Cedar Mountain formation is located in the south-eastern portion of the basin and may be thought of as a pivot point with the other geologic formations forming a semi-circular pattern around it. The strata are of sedimentary origin, dipping 10 degrees away from the Cedar Mountain formation, with Tertiary deposits comprising the upper layers and Jurassic deposits at the base. Quarternary gravel capped pediment surfaces, which give rise to prominent benches, along with alluvial deposits are apparent throughout much of the basin.

The upper portions of the watershed are comprised of a series of cliff forming limestone and sandstone strata (Green River formation through Star Point Sandstone, Figure II-2). Surface waters that drain through these strata become relative hard, but are considered to be of high quality with the predominant water type being calcium-bicarbonate.

The central and lower portions of the basin are comprised predominantly of marine shale deposits intermixed with sandstone lenses or fingers and non-marine beds (Masuk member of the Mancos Shale through the Cedar Mountain formation, Figure II-w). The major marine shale deposit is the Mancos Shale, covering nearly 25 percent of the area and accounting for 61 percent of the altitudinal range (1159 m) in the basin. It is a drab, slightly bluish-gray shale intermixed with thin lenses of calcareous sandstone, limestone and a few concretionary beds. Traditionally, the Mancos Shale has been considered to be the prime source of salt in the basin.

The Mancos Shale is divided into three distinct members, Masuk, Blue Gate and Tununk, which are separated by identifiable sandstone fingers. As a result of the 10 degree dip of the strata, each member of the Mancos is exposed in the basin. The Masuk member is the youngest and is separated from the Blue Gate member below by the Emery and Garley Canyon sandstones. The Masuk forms a relatively large band above the Bluegate and accounts for six percent of the basin area.

The Blue Gate member is the most extensive, extending 655 m vertically and covering nearly 17 percent of the basin. It is very high in evaporites which is evidenced in the literature and the numerous saline deposits observed in the field.

Below the Blue Gate member, separated by the Ferron sandstone, is the Tununk, which is the oldest member of the Mancos formation in the basin. It forms a very narrow band, generally less than two kilometers in width and accounts for only two percent of the total basin area.

The remainder of the basin is composed of miscellaneous geologic types, mostly of non-marine origin, and consequently contribute relatively few salts into the drainage water.

III. SURFACE HYDROLOGY, SALT PICKUP, MICROCHANNEL EROSION

Richard H. Hawkins
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Introduction

The land surface hydrology and the rill/microchannel erosion studies were carried out separately, although the results do interrelate. They are temperally dependent insofar as the research choices and directs were strongly influenced by ongoing information and previous findings. The infiltrometer and microwatershed studies were carried out by Ponce (1975) in 1974 and 1975, and the rill/microchannel erosion studies by White (1977) in 1976. For the sake of clarity they will be discussed separately, at least in the descriptive material.

Infiltrometer Studies: In the summer of 1974, as an initial broad scale study to identify the general location and scope of the problem areas, rainstorm overland flow from the source and surfaces was examined. The strategy was a simple sampling of various representative land types within the lower Price basin (where BLM holdings predominate) using a Rocky Mountain Infiltrometer with 2.5 square foot plots to simulate rainstorm hydrology. In the absence of adequate wildland soil mapping, lands were categorized on the basis of their geologic origin, as is shown in several of the following tables. In order to simulate the high quality of the input rainfall, distilled water was used in the experiment. Thus, through appropriate sampling, the hydrology for the plot (1' x 2.5'), the chemical quality of the surface runoff, and the suspended sediment (erosion) could be sampled. These studies were carried out in 1974, and highlighted heavy salt production areas. The geologic origin and numbering of the plots is given in Table III-1.

Table III-1. Site numbers of the geologic types sampled in the reconnaissance survey.

Geologic type (Identification code)	Site number
A. Mancos Shale members	
1. Masuk (M)	
2. Blue Gate (BG)	1, 2, and 3
a. Upper BG (UBG)	4 and 5
b. Middle BG (MBG)	6 and 7
c. Lower BG (LBG)	8 and 9
3. Tununk (T)	10, 11, and 12
4. Mancos Undivided (MUD)	13, 14, and 15
B. Cedar Mountain (CM)	16 and 17
C. Alluvial Deposits (AD)	18 and 19
D. Gravel Caps (GC)	20 and 21
E. Black Hawk Fm (BH)	22
F. Price River Fm (PR)	23
G. North Horn Fm (NH)	24
H. Colton Fm (C)	25
I. Green River Fm (GR)	26

Microwatershed Studies: Given the results from the infiltration plot runs, attention was then focused on the land types showing the most chemical runoff response, to larger (less artificial) drainage areas and to several infiltrometry questions. The geologic land types of interest were the Upper Bluegate member of the Mancos Shale formation and the so-called "undivided" Mancos type. These larger drainages were actually magnified infiltration plots or microwatersheds (about 40 ft^2). The infiltrometry questions centered on the extrapolation of plot results, and dealt with plot length, run duration, and run intensity. As with the 2.5 $ft.^2$ plots, rainfall was simulated using distilled water. Again as with the smaller infiltrometer plot, sampling and data anlaysis provided information on the hydrology chemical runoff, and erosion. The microwatersheds are summarized in Table III-2.

Rill and Microchannel Studies: Results from the two above studies and subsequent applied hydrology calculations strongly suggest that 1) overland flow pickup of salt per se was a very small component of the Price River salt budget, and 2) there is relationship between erosion and salt release. Thus, the role of surface waters after they leave the overland flow source areas became of interest. Usually, these waters conbribute first to a network of small rills, which then collect into microchannels, gullies, and eventually into major waterways. Erosion usually accompanies the water over head cuts and through the microchannels. Field observations had confirmed the notion that this collector system is very productive of sediment.

Thus, in the summer of 1976, studies were undertaken to evaluate these immediate areas (between the overland flow sources and the major channels) as sediment and salt producers. Flow was induced in selected small intermittent channels by importing Price City domestic water by tank truck, and

Table III-2. Microwatershed Data.

Watershed #	Area (ft^2)	Slope (%)	Cover 1/ (%)	Geology Type	Location	Associated Plots
1	37.84	10	38.0	Mancos Undivided	Emery/Carbon County Line	#14
2	37.13	8	36.5	do	do	#14
3	38.93	9	36	do	do	#14
4	42.15	12	37.5	do	do	#14
5	41.07	10	41.5	do	do	#14
6	45.42	7	46	do	do	#14
7	43.75	8	47	Upper Bluegate	Wattis Road	#5
8	42.93	7	38	do	do	#5
9	43.27	5	27	do	do	#5

Notes: 1/ From 100 systematic point sample of two adjacent areas. Cover includes grass, forbs, shrubs and litter, but not rocks.

monitoring the inputs and outputs in a series of 100 ft sections for 30 minute durations. Flow rates were measured, and chemical and sediment data were again collected. The channels were chosen as representative of the geologic types of concern, and downslope from overland flow source areas previously studied. The Price City supply was of the same approximate total concentration as the overland flow waters from the infiltrometer runs.

Details on the research methodology beyond the above will be developed subsequently as necessary, but can be found in some depth in theses by Ponce (1975) and White (1977).

Hydrology

The infiltrometer runs were made on a total of 27 separate sites, and 14 geologic settings, totalling 157 plot runs. The microwatersheds, 9 in number, were at only two sites, but were run a total of 15 times. Additionally, some special infiltrometer plot runs were made, varying plot length, run duration, or input rainfall intensity. Regardless of the research intent, each run/plot/site provided physical hydrology information of value per se, without considering the chemical and sediment data also available. The hydrologic parameters identified are the terminal infiltration rates (f_c) and the runoff curve number (CN) for the sites studied.

Infiltrometer Studies: The infiltrometer plots (2.5 ft^2) were run for a total of 28 minutes, with rainfall and runoff measurements taken at 3 minutes, and every 5 minutes thereafter. Analysis of this data is the primary means of hydrologic analysis. The intended "storm" intensity was 2.5 inches per hour: in practice this varied in field application from 2.20 to 4.17 in/hr, with a mean value of 2.80 in/hr. Table III-3 shows a summary of the hydrology data by sites.

In retrospect, these simulated storms represent somewhat rare events for the area. Comparisons can be made to the frequency-duration-intensity relationships for both Price and Hiawatha. Table III-4 gives this as taken, with interpolation, from Richardson (1971).

Table III-3. Applied rainfall and runoff data for infiltrometer plots.

Site (Geologic Code)	P				Q			
	$\bar{x}$ (in)	s (in)	$\bar{x}$ (mm)	s (mm)	$\bar{x}$ (in)	s (in)	$\bar{x}$ (mm)	$\bar{s}$ (mm)
1 (M)	1.70	0.34	42.3	8.6	0.28	0.26	7.2	6.7
2 (M)	1.67	0.38	42.5	9.7	0.96	0.51	24.5	12.9
3 (M)	--	--	--	--	--	--	--	--
4 (UBG)	1.33	0.18	33.7	4.6	0.35	0.20	8.8	5.1
5 (UBG)	1.62	0.37	41.2	9.5	0.84	0.53	21.4	13.5
6 (MBG)	1.33	0.19	33.8	5.0	0.62	0.14	15.7	3.7
7 (MBG)	0.95	0.19	24.5	4.7	0.50	0.16	12.8	4.1
8 (LBG)	1.14	0.19	28.9	4.8	0.56	0.31	14.1	7.8
9 (LBG)	1.09	0.21	27.8	5.3	0.62	0.20	15.7	5.2
10 (T)	1.17	0.16	29.8	4.0	0.63	0.30	16.1	7.6
11 (T)	1.18	0.11	29.9	2.9	0.45	0.12	11.4	3.1
12 (T)	1.04	0.24	26.5	6.1	0.31	0.17	8.0	4.3
13 (MUD)	1.09	0.17	27.8	4.3	0.73	0.16	18.6	4.0
14 (MUD)	1.22	0.36	31.0	4.0	0.71	0.13	18.0	3.2
15 (MUD)	1.14	0.20	29.0	5.2	0.82	0.22	20.9	5.6
16 (CM)	1.20	0.14	30.6	3.6	0.47	0.11	12.0	2.7
17 (CM)	1.30	0.29	33.0	7.4	0.52	0.21	13.1	5.4
18 (AD)	1.69	0.22	42.9	5.6	0.33	0.11	8.3	2.7
19 (AD)	1.17	0.10	29.8	2.5	0.84	0.06	21.4	1.5
20 (GC)	1.35	0.22	34.3	5.6	0.40	0.14	10.2	3.6
21 (GC)	1.55	0.15	39.3	3.9	0.40	0.12	10.2	3.1
22 (BH)	1.96	0.32	49.6	8.2	0.68	0.04	17.3	1.1
23 (PR)	1.24	0.22	31.6	5.6	0.86	0.19	21.9	4.8
24 (NH)	1.21	0.15	30.7	3.9	0.85	0.11	21.6	2.8
25 (C)	1.15	0.16	29.1	4.1	0.76	0.16	19.4	4.0
26 (GR)	1.13	0.14	28.7	3.6	0.58	0.16	14.8	4.0

Note: No data were collected from Site 3 because of its unsuitability for setting up the infiltrometer.

Table III-4. Storm Rainfall (inches by Duration and Return Period, for Price and Hiawatha Stations.

Return Period (years)	Storm Duration - Minutes							
	Price				Hiawatha			
	28	30	60	100	28	30	60	100
2	.31	.32	.40	.46	.17	.18	.23	.34
5	.42	.44	.56	.64	.34	.35	.44	.56
10	.52	.54	.68	.77	.41	.43	.55	.68
25	.63	.65	.82	.96	.60	.62	.78	.79
50	.72	.75	.95	1.06	.67	.70	.88	1.03
100	.82	.85	1.08	1.21	.81	.84	1.06	1.22

Source: Richardson (19), with linear interpolations for 28 minutes and 100 minutes.

The smallest average simulated storm shown in Table III-3 (0.95 in) exceeds the 100 year event for both Price and Hiawatha for a 28 minute duration. Extrapolating the Price information on a logarithmic probability plot (not shown), the 0.95 inch event shows a return period of about 300 years. Similarly, the largest simulated rainfall (1.96 in) has a return period far beyond 10,000 years. The average, about 1.30 inches, indicates a return period of about 3600 years. These are obviously ludicrous citations; they are given for reference example only. The simulated storms were indeed unusual inputs; the outputs should be evaluated accordingly.

Miscellaneous Plot Runs: In the course of the infiltrometer/microwatershed studies, a group of miscellaneous runs were made in an attempt to isolate the effects of plot length, and input intensity and duration. Also, following preliminary data analyses in June and July 1975, some additional runs were made in late August to examine some suspected salt/sediment mechanisms and relationships. These site conditions and basic data are given in Table III-5.

Microwatersheds: The microwatershed runs were made in an attempt to test and confirm the results from the more productive infiltrometer runs, and to gain information from less artificial situations. Also, the microwatershed runs were scheduled to isolate any effect of storm interval time. The general hydrologic data from the microwatersheds is given in Table III-6.

Results and Analysis: The rainstorm hydrologic characteristics of small overland flow areas such as were studied may be most conveniently described by either a general runoff parameter (Curve Number) or an infiltration rate (f_c).

Curve Numbers: The curve number is a coefficient relating direct storm runoff depth to storm rainfall depth. It arises from an institutionalized hydrology system first established by and still strongly identified with the U.S. Soil Conservation Service ( ). The basic relationship is:

$$Q = (P - 0.2S)^2/(P + 0.8S) \qquad [III-1]$$

where P and Q are rainfall and runoff depths respectively in inches. S is a watershed retention index (inches), and related to the more commonly used "Curve Number" by

Table III-5. Miscellaneous Plot Runs, Site Information and Summary of Hydrologic Data.

DESCRIPTION Plot #	Date	Slope	Cover	P(in)	Q(in)
PLOT LENGTH TRIALS (28 minute deviations)					
Length--2.5 ft.					
1	June 26	9.8	4	1.05	0.62
2	"	9.8	2	1.69	1.18
3	"	9.8	3	1.37	0.95
4	"	10.5	3	1.13	0.67
5	"	10.5	3	1.59	1.16
6	"	10.5	4	1.53	1.10
Length - 5.0 ft					
1	"	8.5	2	1.18	.82
2	"	8.5	3	1.25	.97
3	"	8.5	3	0.88	.61
4	"	6.3	4	1.06	.51
5	"	6.3	2	1.21	.55
6	"	6.3	3	0.73	.30
Length 10.0 ft					
1	June 28	5.8	11	1.01	0.61
2	"	5.8	10	1.49	1.04
3	"	5.8	6	1.14	0.74
4	"	5.8	18	1.65	1.33
5	"	5.8	13	1.46	1.19
6	"	5.8	15	0.89	0.53
INTENSITY TRIALS (28 minute duration, 5.0 ft. plots)					
Low Intensity (approx 1"/hr)					
1	June 27	6.0	3	0.61	0.16
2	"	6.0	5	0.72	0.27
3	"	6.0	5	0.51	0.12
High Intensity (approx 5"/hr)					
1	June 27	6.8	5	1.21	0.77
2	"	6.8	7	1.92	1.47
3	"	6.8	12	1.79	1.33
DURATION TRIALS (5.0 ft plots, 58 minute duration)					
1	June 28	8.9	5	1.71	1.22
2	"	8.9	3	2.88	2.25
3	"	8.9	6	2.40	1.62
SPECIAL TRIALS (5 ft plots)					
100 minute Runs - Upper Bluegate - Wattis Road Site					
81	Aug 28	5.4	10	3.52	1.93
82	"	5.4	46	6.43	4.72
83	"	5.4	19	4.81	3.00
50 minute Runs -					
141	Aug 29	5.0	22	2.70	2.45
142	"	5.0	21	3.37	3.00
143	"	5.0	16	2.39	2.12
144	Aug 28	4.2	18	2.12	1.51
145	"	4.2	22	3.41	2.71
146	"	4.2	23	2.23	2.07

Note: All dates 1975. Slope and cover in percent. Cover includes litter, grass, shrubs, and forbs, but not rocks. Unless otherwise stated, all above runs on Undivided Mancos at County Line site. Plots 141-3 were prewet with about 5 minutes of applied rainfall.

Table III-6. Summary Microwatershed Hydrology Data.

Microwatershed	Date	P(in)	Q(in)
1	July 9	1.94	1.20
	July 24	1.74	1.27
2	July 9	1.44	1.14
	July 21	1.97	1.50
3	July 10	1.22	1.09
	July 15	1.55	1.39
4	July 21	1.70	1.28
	July 24	2.05	1.14
5	July 21	1.39	0.91
	July 23	1.57	1.41
6	July 22	1.61	1.00
	July 23	1.52	1.20
7	July 20	1.97	1.27
8	July 20	1.91	1.22
9	July 20	1.76	1.05

Note: Microwatersheds 1-6 near Site #14 ("County Line" site) on Undivided Mancos, and within approximately a 200 meter radius. Microwatersheds #7-9 near Site #5 on Waltis Road, on Upper Bluegate.

$$CN = 1000/(10+S) \qquad [III-2]$$

Solution of the runoff equation by the quadratic formula gives:

$$S = 5(P+2Q- \sqrt{4Q^2+5PQ}) \qquad [III-3]$$

Thus any P-Q pair can define an S and CN. Insofar as the curve number method is widely used to estimate storm runoff for design and environmental impact purposes, estimates of CN values have been calculated wherever possible. The calculation is direct and simple by equations III-3 and III-2. While CN is a dimensionless number, the equations shown above should be applied in the English system only (i.e., inches), although metric conversions are certainly possible.

Accordingly, CN values for the infiltrometer sites and geologic types, with cover effects included, are shown in Tables III-7 and III-8.

Table III-7. Mean ($\bar{x}$) and standard deviation (s) of the hydrologic soil-complex numbers (CN) for each site.

Site (Geologic Code	CN $\bar{x}$	CN s	Site (Geologic Code	CN $\bar{x}$	CN s
1 (M)	75	8.6	14 (MUD)	94	0.8
2 (M)	92	3.4	15 (MUD)	96	1.3
3 (M)	--	-	16 (CM)	90	1.2
4 (UBG)	84	4.9	17 (CM)	89	3.9
5 (UBG)	89	6.7	18 (AD)	78	1.9
6 (MBG)	91	0.7	19 (AD)	97	1.5
7 (MBG)	94	0.9	20 (GC)	86	2.6
8 (LBG)	92	4.5	21 (GC)	83	3.4
9 (LBG)	94	1.3	22 (BH)	82	6.6
10 (T)	93	3.1	23 (PR)	96	0.7
11 (T)	90	1.2	24 (NH)	96	1.1
12 (T)	89	1.4	25 (C)	96	0.4
13 (MUD)	96	0.7	26 (GR)	93	1.2

Note: 6 plots per site except for the following: #1(5); #15(5); #22(3).

Table III-8. Curve Numbers by Geologic Types for Infiltrometer Runs.

Geologic Type	N	Curve Number	
		$\bar{x}$	S
Masuk	11	84.3	10.6
Upper Bluegate	12	86.5	6.4
Middle Bluegate	12	92.5	1.7
Lower Bluegate	12	93.0	3.5
Tununk	18	90.7	2.7
Mancos Undiv.	17	95.3	1.3
Cedar Mtn.	12	89.5	2.9
Alluvial	12	87.5	9.7
Gravel Cap	12	84.5	3.3
Black Hawk	3	82.0	6.6
Price River	6	96.0	0.7
North Norn	6	96.0	1.1
Colton	6	96.0	0.4
Green River	6	93.0	0.2

Table III-9. Analysis of variance for the mean CN of all the sites.

Source of Variation	Degrees of Freedom	Mean Squares	F Test Value
Total	149		
Between Sites	125	209.10	16.60**
Within Sites	24	12.59	

**Significant beyond the 0.05 percent level.

Critical F = 2.22.

Tables III-9 and III-10 are summarized statistical analyses of the results. There are differences between the CN values for the different geologic types (Table III-9), and these may be identified in detail (Table III-10). The Curve Numbers as calculated are also given for the microwatersheds (Table III-11), and (in summarized form) for the miscellaneous plot runs (Table III-13). Also for further perspective and reference, the rainfall-runoff data from the USGS study watersheds at Badger Wash Colorado, also on Mancos Shale, have been used to calculate experienced curve numbers (Table III-13).

The consistency and the high values in Table III-8 should be noted. The curve numbers for Undivided Mancos values tend towards the mid 90's, and are seemingly independent of length, intensity, and duration. For these homogeneous high runoff situations, the curve number technique appears consistent. The effect of prewetting (about 0.25 in) on plots 141-3 has an effect of about +2 CN. Also, the distinct difference from the Upper Bluegate setting should be noted.

Infiltration: The infiltration parameter most often used as a hydrology or land condition descriptor is the terminal or constant rate attained after the initial wetting effects have become minimal. This measure will be herein identified as "f_c",, corresponding to the terminology in Horton's equation:

$$f = f_c + (f_o - f_c) \exp(-kt) \qquad \text{[III-4]}$$

Not only is f_c easily and intuitively identifiable from most printed or plotted data, but it has an easily envisioned physical interpretation, and has been found to be a stable index of soil/vegetation hydrologic condition. However, objective determination of it is difficult by purely computational methods. In addition, infiltrometer instrument

Table III-10. F test values for the contrast of mean CN between geologic types

Geologic Code	M	UBG	MBG	LBG	T	MUD	CM	AD	GC	BH	PR	PR	C	GR
M	--	6.35	42.85	47.09	30.91	84.21	20.29	8.11	0.51*	0.57*	52.79	54.58	51.70	33.10
UBG		--	16.21	18.86	7.84	41.17	3.94	0.11*	3.26*	7.91	27.13	28.42	26.35	13.66
MBG			--	0.10*	2.61*	4.02	4.17	0.11*	34.02	37.22	3.69*	4.17	3.41*	0.71*
LBG				--	3.83*	2.75*	5.56	16.12	37.81	40.44	2.76*	3.19*	2.52*	0.02*
T					--	16.35	0.39*	5.96	22.83	27.01	10.96	11.84	10.44	2.91*
MUD						--	18.00	36.69	70.48	64.91	0.20*	0.34*	0.14*	1.33*
CM							--	2.74*	14.37	19.66	12.88	13.77	12.34	4.31
AD								--	4.55	9.49	24.41	25.63	23.67	11.75
GC									--	1.79*	44.67	46.31	43.67	26.74
BH										--	48.26	49.74	47.36	31.78
PR											--	0.01*	0.01*	1.72*
NH												--	0.03*	2.00*
C													--	1.55*
GR														--

*Not significant at the 5 percent level. Critical F = 3.84.

and measurement errors occasionally produce unrealistic values (such as negative rates) or sporadic inconsistent behavior for some intervals. Thus, in the following, f_c values are not given for all data sets.

Least squares computer solutions from infiltrometer data are possible, however, albeit laborious and not completely automated. Results of such solutions are given in Tables III-14 and III-15 for the infiltrometer plot data.

Table III-11. Summary of Curve Numbers Rates for Microwatershed Data

Microwatershed	Date	CN
1	July 9	92.2
	July 24	95.4
2	July 9	97.0
	July 21	95.7
3	July 10	99.0
	July 15	98.8
4	July 21	96.7
	July 24	90.2
5	July 21	95.0
	July 23	98.5
6	July 22	94.4
	July 23	97.0
7	July 20	92.8
8	July 20	92.8
9	July 20	92.4

Table III-12. Summarized Curve Numbers from Miscellaneous Plot Runs

Description	N	Curve Number $\bar{x}$	Curve Number S
PLOT LENGTH TRIALS			
2.5 ft	6	95.3	0.4
5.0 ft	6	95.0	2.1
10.0 ft	6	96.2	0.7
INTENSITY TRIALS			
Low (ca 1.0 iph)	3	93.1	0.4
High (ca 5.0 iph)	3	95.5	0.2
DURATION TRIALS - 58 minute - 5 ft plot			
	3	93.8	1.2
SPECIAL TRIALS			
100 minute runs - Upper Bluegate			
	3	83.9	0.9
50 minute runs	6	96.4	1.9

Notes: Data for calculation from Table III-5. Unless otherwise noted, runs were at "County Line" site, on Undivided Mancos.

Table III-13. Rainfall - Runoff Data and Curver Number Summary for Badger Wash Watersheds.

Watershed	A (Ac)	$\bar{P}$ (in)	Q (in)	N	Curve Number $\bar{x}$	Curve Number S
1-A	42	0.46	0.14	54	94.2	3.5
1-B	54	0.52	0.15	40	93.0	3.9
2-A	95	0.44	0.12	66	93.7	3.7
2-B	101	0.48	0.11	54	92.3	3.4
3-A	38	0.41	0.13	66	94.6	3.3
3-B	31	0.44	0.13	62	94.0	3.3
4-A	14	0.49	0.14	57	94.3	3.5
4-B	12	0.48	0.12	51	92.6	4.3

Source: Lusby, Reid, and Knipe, 1971.

Tables III-16 and III-17 present summarized estimates of terminal infiltration rates for the microwatersheds and the special plot runs.

Discussion

Curve Numbers: The curve numbers calculated for the sites examined were notable for their high magnitudes. With few exceptions they were in the low or mid-90's range, which is indeed above handbook expectations. Table III-18 gives widely used values taken from the SCS Hydrology Guide ( ) for representative array of cover conditions. A comparison of Tables III-18 with III-7 and III-8, III-11, and III-12 indicates the unexpectedly high runoff potential of the Mancos Shale sites. The low

Table III-14. Infiltration Rates (f_c) for Infiltrometer Sites.

Site #	Geology	fc (cm/hr) $\bar{x}$	fc (cm/hr) s	N
1	Masuk	6.60	0.95	5
2	Masuk	3.19	1.07	6
2a	Upper BG	3.64	2.20	6
4	Upper BG	1.94	1.62	6
5	Upper BG	2.88	0.88	6
5a	Upper BG	2.20	0.64	6
6	Middle BG	2.57	0.48	6
7	Middle BG	1.65	0.30	6
8	Lower BG	1.32	0.79	6
9	Lower BG	1.47	0.54	6
10	Tununk	1.85	0.67	6
11	Tununk	2.91	0.45	6
12	Tununk	2.60	0.37	6
13	Undivided	1.70	0.76	6
14	Undivided	1.76	0.35	6
15	Undivided	1.70	0.46	5
16	Cedar Mtn.	1.70	0.84	6
17	Cedar Mtn.	2.38	0.61	6
18	Alluvium	5.46	0.82	6
19	Alluvium	1.75	0.59	6
20	Gravel Cap	3.18	0.83	6
21	Gravel Cap	5.03	0.78	6
22	Blackhawk	6.56	0.85	3
23	Price River	1.55	0.30	6
24	North Horn	1.52	0.24	6
25	Colton	1.69	0.14	6
26	Green River	2.65	0.53	6

Notes: Infiltrometer Runs on 2 1/2 ft plots. Determination by least squares trial and error method on Horton's equation.

standard deviations within specific sites suggests some local consistency, but the sporadic variability between sites within geologic types indicates a lack of generality at least within a geologic based soils grouping classification.

Aligning observed curve numbers with the Hydrologic Soil Groups in Tables III-18 shows that the soil factor in the cases studied is important, and beyond those currently available. A grouping more imperv-

Table III-15. Infiltration Rates (f_c) by Geologic-Soil Types. 28 Minute Infiltrometer Runs on 2 1/2 ft. plots.

Geology/Soil	# Sites	# Plots	f_c (cm/hr) $\bar{x}$	s
Masuk	2	11	4.74	1.85
Upper Blue Gate	4	24	2.67	1.61
Middle Blue Gate	2	12	2.11	0.61
Lower Blue Gate	2	12	1.40	0.68
Tununk	3	18	2.45	0.68
Mancos Undiv.	3	7	1.72	0.56
Cedar Mountains	2	12	2.04	0.81
Alluvium	2	12	3.61	1.99
Gravel Cap	2	12	4.11	1.23
Black Hawk	1	3	6.56	0.85
Price River	2	6	1.55	0.20
North Horn	2	6	1.52	0.24
Colton	2	6	1.69	0.14
Green River	2	6	2.54	0.53
TOTALS	31	157		

ious than "D" is necessary to resolve the differences in most cases. This should not be completely unexpected considering the unusual salt, clay, and cover conditions encountered, and the more moderate agricultural origin of the curve number methodology. On the other hand, the values shown in III-18 are for a moister situation (AMC-II), and the infiltrometer runs were made on (naturally) quite dry sites. This increases the contrast.

The average curve numbers observed for the Badger Wash watersheds, also on Mancos shale, vary little between watersheds (92.3 to 94.6) and are in consonance with those observed on the Mancos Undivided sites in this study. Tables III-7, III-8, III-11, and III-12 show curve numbers

Table III-16. Infiltration Rates for Microwatershed Runs.

Watershed	Geology	Date	f_c(cm/hr)
1	Mancos Undivided	9 July 24 July	3.74 1.98
2	Mancos Undivided	9 July 21 July	1.42 2.21
3	Mancos Undivided	10 July 15 July	0 0
4	Mancos Undivided	21 July 24 July	0.80 2.20
5	Mancos Undivided	21 July 23 July	1.82 .64
6	Mancos Undivided	22 July 23 July	1.83 0.98
7	Upper Bluegate	20 July	2.38
8	Upper Bluegate	20 July	2.76
9	Upper Bluegate	20 July	2.09

Notes: Above rates are averages for last 15 minutes of 30 minute runs.

Table III-17. Infiltration Rates for Miscellaneous Plot Runs.

Description	N	f_c - cm/hr $\bar{x}$	s
PLOT LENGTH TRIALS 1/			
2.5 ft	6	1.48	0.30
5.0 ft	6	1.09	0.46
10.0 ft	6	0	0
INTENSITY TRIALS 1/			
Low (ca 1.0 iph)	3	1.17	0.10
High (ca 5.0 iph)	3	1.95	0.51
DURATION TRIALS (58 minute 5 ft plot) 2/	3	0.82	0.21
SPECIAL TRIALS			
100 minute runs Upper Bluegate 3/	3	2.04	.31
50 minute runs 4/	5	.57	.24

Notes: 1/ Average infiltration rate for last 10 minutes of 28 minute run. 2/ For last 15 minutes of 58 minute run. 3/ For last 20 minutes of 100 minute run. 4/ For last 15 minutes of 60 minute run. All above at "County Line" site on Undivided Mancos, unless otherwise noted.

Table III-18. Handbook Curve Numbers Rangeland Soil/Vegetation Conditions, for Moisture Condition II.

Cover (%)	Herbaceous Soil Type		Sage-Grass Soil Type	
	C	D	C	D
0	90	94	87	1/
10	88	93	82	1/
20	86	92	77	1/
30	84	91	72	1/
40	82	90	67	

Notes: Source; USDA, SCS, NEH-4 ( ).

1/ No curve numbers suggested for "D" soils.

for Mancos Undivided from 93.8 to 98.8. The cover effects are included in these calculations, but were also studied briefly, and will be discussed subsequently.

There are, however, apparent differences between the observed curve numbers on different geologic types. Tables III-9 and III-10 pointed this out generally and specifically. Even within the general "Mancos" category differences exist: The Undivided sites comprise a distinctly different hydrology than all others except Lower Blue Gate. The Masuk and the Upper Blue Gate curve numbers correspond well with the Handbook suggestions in Table III-18.

Infiltration: The infiltration rates calculated present a mixed picture. At a specific site, rates tended to be comparable, yet between sites within geologic types, great variety exists. Table III-15 shows this clearly. For the multiple site trials with more than six plots ("Masuk" through "Gravel Cap"), the coefficients of variation (i.e., $s/\bar{x}$) ranged from about 27% to 60%. For the remainder ("Black Hawk through "Green River"), it was much lower; 8% to 21%. Thus, while some uniformity may exist locally, general geologic origin (type) is an inconsistent index or classification of infiltration within the type.

The microwatershed runs give expecially perplexing infiltration rates. As shown in Table III-16, there is little similarity or order between results on the same watersheds at different times. The reasons for this are not known, and the problem was not investigated. However, some effect may be suspected from either 1) differences in input intensity, or 2) instrumentation errors.

The miscellaneous plot runs (Table III-17) also illustrate the local uniformity/geologic variability phenomenon. Several of the cases indicate close uniformity, yet the overall pooled data for Mancos Undivided in III-17 gives $\bar{x}$ = .98 cm/hr and S = .62 cm/hr, producing a coefficient of variation of 63%.

In general, the infiltration rates are unexpectedly high: Table III-19 gives some expected associations between Hydrologic Soil Groups and infiltration rates as cited by Musgrave (19). These reference rates are thought to be for the bare "B" horizons of agricultural soils after prolonged wetting. These conditions were not present on the study sites, although the plots were near bare, the rates were approximations of a steady state situation, and the A horizons are but poorly developed. Even allowing generously for these differences, the experienced rates from most sites seem to be more in keeping with the "A" and "B" soils criteria than for the "C" and "D" criteria. This is in clear contrast to the soils inferences arising from curve number considerations. The solution to the contradictory logic of "high" infiltration rates with also "high" curve numbers is probably resident in Table III-19. However, there are no generally accepted authoritative relationships available solely for wildlands.

Table III-19. Relationship Between Hydrologic Soil Groups and Infiltration Rates.

Soil Group	Infiltration Rate	
	in/hr	cm/hr
D	0-0.05	0-0.13
C	0.05-0.15	0.13-0.38
B	0.15-0.30	0.38-0.76
A	0.30-0.50	0.76-1.27

Notes: Source: Musgrave (1955). Above rates are for bare "B" horizons of agricultural soils after prolonged wetting.

Effects of Cover: Plant cover and litter is often taken to have a moderating effect on rainfall caused runoff. Cover management - thus affecting runoff, erosion, and salt production -- is a water quality management option available to land management agencies. The relative abundance of hydrologic and cover data on a single geologic type (Undivided Mancos) in this study invited examination of cover effects. This was not a prominent project study objective, but rather an opportunity which was utilized without extensive follow-up.

Cover, rainfall, and runoff data were available for 48 different plot and watershed runs on Mancos Undivided sites, most in close proximity to each other. Cover ranged from 2 to 46 percent, total applied rainfall from 0.51 to 3.41 inches, and runoff from 0.12 to 3.00 inches. The data was analyzed in a routine least squares multiple regression program. The effects of rainfall and cover on runoff, and of cover alone on curve number were examined. The results of the former, given in Table III-20, indicate that although there is a strong association of runoff with rainfall, there is no statistically demonstrable effect of cover density on runoff.

The similar analysis of cover on curve number (not shown) was likewise improductive.

These findings are contrary to hydrologic tradition, and suggest that the site itself (i.e., soil) was the overwhelming influential factor. Error in both cover and hydrology measurements of course, played a role also. The informal and limited nature of the analysis leaves the matter without strong resolution, and deeper inquiry is certainly merited. However, the findings do impart a suggestion that surface runoff management on such extreme sites would demand more than mere vegetative cover control. Such measures as furrowing, contour-

Table III-20. Multiple Regression Results Effect of Cover and Rainfall on Runoff Mancos Undivided Sites

Source	DF	Mean Square	"F"	Prob(%)
Total	47	0.369649	-	-
Cover	1	0.000783	.0308	14
Rainfall	1	14.8699	586.96	>99.95
Model	2	8.1163	32.02	>99.95
Error	45	.0235	-	-

Note: Above results apply to the model Q = -0.3768 - 0.0003 * C + 0.9732 * P, where Q and P are runoff and rainfall in inches, and C is cover density in %. r^2 = 0.93, Se = 0.159 in.

ing, pitting, ripping, etc. which deal physically with the soil surface would be more effective.

Salt Pickup: Plot Studies

As described previously, under Hydrology, salt production was examined by a progression of methods: simulated rainfall on small plots, microwatersheds, and simulated rill and microchannel flow events. Additionally, some special plot studies were made in an attempt to isolate the effects of plot length, run duration, and rainfall intensity. The runoff quality was studied jointly with the hydrology, and thus the previous descriptions need only be augmented to cover water quality data collected. Details of both instrumentation, data, and results, are found in theses by Ponce (1975) and White (1977), and are thus covered only as necessary here to highlight significant matters.

Plot Studies and Salt Pickup: Plot studies run in the summer of 1974, measured the quality of overland flow runoff from representative geologic types within the Price basin, as simulated on 2.5 ft^2 plots using distilled water as artificial rainfall. Samples of sediment, conductivity, pH, and temperature were taken at regular intervals over 28 minute runs, and detailed chemical analysis made of runoff water composites. The purpose was a reconnaissance probe of the technique, and to spotlight the major salinity source areas as defined by the geologic origin of the soils. A geologic identification of site was necessary by default, insofar as the soils of the basin were not surveyed in sufficient meaningful resolution. Additionally, the Mancos Shale formation was of high interest as a suspect from previous general and geochemical studies, as a salt source area.

Miscellaneous Plot Runs: Following plot studies, questions arose concerning their validity as samples of overland flow: specifically the effects of differing the plot length, run duration, and applied rainfall intensity. Special examination of these variables was done in the summer of 1975 with other factors near constant. The plots were run on Undivided Mancos within a relativley small area. Data taken was essentially the same as on the previous plot studies, only the above factors were varied. Plots 2.5, 5.0 and 10.0 ft were used, runs were made up to 100 minutes, and intensities were varied somewhat during plot runs (instead of being held constant).

Microwatershed Studies: As an additional step towards reality, the microwatersheds as described previously, and summarized in Table III - 2, were established, and subjected to simulated rainfall using distilled water. Again, the data collected was essentially the same as on the plot studies. The main objective was to center attention on the Mancos Undivided and Upper Bluegate members as salt sources (a decision resulting from the plot studies), and to provide more adequate data for hydro-chemical modeling of the overland runoff. The artificial setting of the smaller plots, their small area, their variation, and the resulting questions of interpretation pointed to a larger more integrated approach. Even so, the microwatersheds were little more than enlarged plots, about 40 ft^2, although it was evident from inspection that they did indeed possess some of the rill and overland flow collection system attributes of small ephemeral watersheds.

Results:

Plot Studies: Summarized results (Total dissolved solids) for the various sites and geologic types are given in Tables III-21 and III-22, and show a strong tendency towards salt production from specific sites and geologic types. The Undivided Mancos sites yielded the highest concentration runoff of any of the upland sites. The alluvial deposits, with visible salt florescence and a moist foundation had very high concentrations on Site 19, but quite low concentrations from a "cleaner" site (#18). Although notable, these were considered exceptional circumstances and outside the main study objectives.

The march of runoff concentrations with time varied considerably, but the gradual retreat from an initial high value, as shown in Figure III-1 was characteristic of almost all data sets. The sequence suggests an initial washoff of easily available surface salts receeding to a base rate perhaps associated with surface erosion.

Composite sediment sample data for sites and geologic types is given in Tables III-23 and III-24. As with the hydrology data, great variety exists within and between types, although some uniformity exists between plots between sites. For example, Site #12, on the Tununk member of Mancos Shale (6 plots) exhibited a coefficient of variation of 6%, while on Site #5, on Upper Bluegate, it was 57%.

The variability patterns already identified with runoff (See Hydrology) were evident also in the water quality data, both chemical and sediment. As the sampling area and/or number increased, so did variability, although occasional close uniformity existed. Geologic type alone was insufficient to define chemical and sediment characteristics within the type, although differences between types were evident. These are apparent, even though no detailed statistical comparisons

Table III-21. The mean ($\bar{x}$) and standard deviation (s) of TDS values for the composite runoff samples at each site.

Site (Geologic Code)	$\bar{x}$ (mg/l)	s (mg/l)	Site (Geologic Code)	$\bar{x}$ (mg/l)	s (mg/l)
1 (M)	32	11	14 (MUD)	858	438
2 (M)	26	8	15 (MUD)	823	42
3 (M)	--	--	16 (CM)	36	7
4 (UBG)	52	15	17 (CM)	30	7
5 (UBG)	26	9	18 (AD)	64	14
6 (MBG)	53	17	19 (AD)	3049	787
7 (MBG)	226	91	20 (GC)	39	8
8 (LBG	131	27	21 (GC)	58	5
9 (LBG)	216	136	22 (BH)	35	3
10 (T)	44	18	23 (PR)	28	4
11 (T)	38	16	24 (NH)	47	22
12 (T)	485	119	25 (C)	47	5
13 (MUD)	70	11	26 (GR)	79	12

Table III-22. The mean ($\bar{x}$) and standard deviation (s) of TDS values of the composite runoff samples for the geologic types.

Geologic Type	$\bar{x}$ (mg/l)	s (mg/l)
Mancos Shale Members		
Masuk	29.4	10.0
Upper Blue Gate	38.8	18.2
Middle Blue Gate	139.8	109.8
Lower Blue Gate	173.5	103.5
Tununk	41.3	16.3
Mancos Undivided	539.0	450.7
Cedar Mountain Fm.	33.3	7.1
Alluvial Deposits	1556.8	1646.8
Gravel Caps	48.5	12.0
Black Hawk Fm.	35.1	3.2
Pricè River Fm.	28.5	4.4
North Horn Fm.	47.0	21.6
Colton Fm.	47.0	5.1
Green River Fm.	79.3	11.5

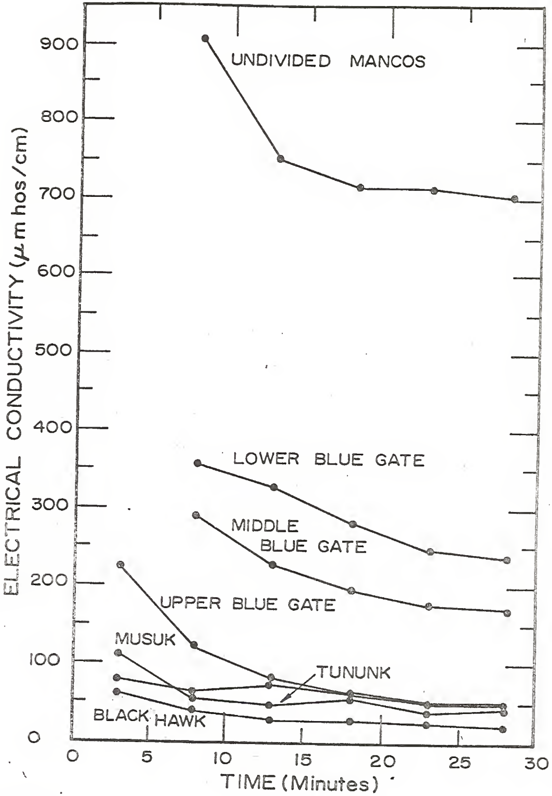


Figure III-1. Mean electrical conductivity of surface runoff for selected geologic types. Time is from the beginning of rainfall.

Table III-23. The mean ($\bar{x}$) and the standard deviation (s) of the suspended sediment (S.S.) for the various sites. All values represent a composite average for the plots at each site.

Site (Geologic Code)	S.S. $\bar{x}$ (g/1)	S.S. s (g/1)	Site (Geologic Code)	S.S. $\bar{x}$ (g/1)	S.S. s (g/1)
1 (M)	2.32	0.70	14 (MUD)	8.38	1.74
2 (M)	2.01	1.03	15 (MUD)	9.30	1.69
3 (M)	--	--	16 (CM)	2.72	1.08
4 (UBG)	2.47	1.14	17 (CM)	0.78	0.47
5 (UBG)	5.29	3.00	18 (AD)	1.82	0.55
6 (MBG)	6.13	3.24	19 (AD)	3.43	0.95
7 (MBG)	7.77	3.73	20 (GC)	2.21	0.46
8 (LBG)	6.98	0.97	21 (GC)	1.33	0.43
9 (LBG)	7.06	2.13	22 (BH)	2.54	0.87
10 (T)	2.14	0.58	23 (PR)	5.95	1.59
11 (T)	1.48	0.83	24 (NH)	5.90	1.78
12 (T)	4.00	0.24	25 (C)	5.50	1.82
13 (MUD)	3.71	0.44	26 (GR)	7.36	2.11

Table III-24. Composite suspended sediment concentrations from plot runs by geologic type.

Type	Suspended Sediment (gm/l) $\bar{x}$	Suspended Sediment (gm/l) S
Masuk	2.16	0.89
Upper Bluegate	3.88	2.67
Middle Bluegate	6.95	3.59
Lower Bluegate	7.02	1.65
Tununk	2.54	1.22
Mancos Undivided	7.12	2.82
Cedar Mountain	1.75	1.27
Alluvial	2.62	1.11
Gravel Cap	1.77	0.62
Black Hawk	2.54	0.87
Price River	5.95	1.59
North Horn	5.90	1.78
Colton	5.50	1.82
Green River	7.36	2.11

were made as with curve numbers in Tables III-10 and III-11.

The relationships between suspended sediment and dissolved solids concentration will be developed subsequently.

Miscellaneous Plot Runs: The chemical results of the plot length variation study are given in Table III-25. The results of the rainfall intensity study are given in Table III-26. The results of the duration study are given in Figure III-2. The plot length runs were statistically inconclusive, but the outcome hinted that plot length beyond 5 ft has little effect on runoff salinity. The intensity studies also contained high variation, but the lower salinity with higher intensities may be due to dilution of salts with higher runoffs. The duration runs merely confirmed the previously unstated assumptions that a base level of concentration had been reached in the shorter runs, and that no unexpected changes would occur in longer events.

The special plot runs #141 through #146 on Mancos Undivided, and #81 through #83 on Upper Bluegate were for internal checking of previous work and demonstration and served no other purpose. The results are not presented here, but were used subsequently in model development.

Table III-25. Results of Plot Length Study Composite Runoff Concentrations.

Plot Length (ft)	N	Concentration (mg/l)	
		$\bar{x}$	S
2.5	6	994	629
5.0	6	231	158
10.0	6	274	118

Notes: 28 minute runs on Mancos Undivided near Site 14 ("County Line" site).

Table III-26. Results of Rainfall Intensity Study Composite Runoff Concentrations.

Intensity (in/hr)	N	Concentration (mg/l)	
		$\bar{x}$	S
1.1	3	890	259
2.1	6	231	158
3.4	3	379	131

Notes: 28 minute runs on Mancos Undivided near Site 14 ("County Line" site). The 2.1 in/hr data is also used as the 5.0 ft. entry in Table III-25.

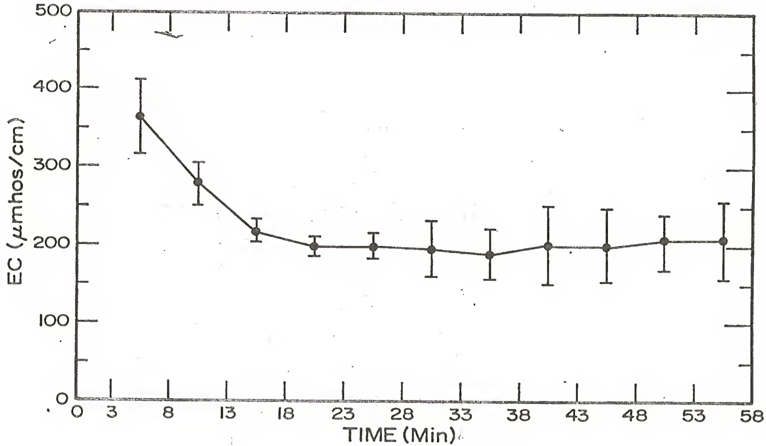


Figure III-2. Mean EC, plus and minus one standard deviation, for the three plots over time for the rainfall intensity study. This study was performed with 5 ft (1.5 m) plots at site 14. The time is from the beginning of rainfall.

Microwatersheds: The composite chemical and sediment results from the microwatersheds are given in Table III-27, although a great deal of more detailed data is available. Much is used subsequently in modeling attempts. Table III-27 reaffirms the previous observations in plot studies of the greater runoff salinity from Undivided Mancos. The relative consistency between repeated runs on the same watersheds should also be noted.

Table III-27. Summary of Composite Concentrations from Microwatersheds.

Watershed and Run	Concentrations TDS (mg/l)	Sediment (gm/l)
1-1	913	13.8
1-2	1080	17.4
2-1	423	18.9
2-2	500	13.5
3-1	1130	18.4
3-2	1580	19.8
4-1	685	14.0
4-2	755	14.1
5-1	264	8.0
5-2	215	4.2
6-1	318	5.9
6-2	355	8.6
7-1	389	19.2
8-1	657	15.4
9-1	153	18.1

Notes: Watersheds 1 through 6 on Mancos Undivided near Site 14 ("County Line" site). Sites 7 - 9 in Upper Bluegate near site 5 ("Wattis Road" site).

Soil Chemistry: The plot and microwatershed runs also included soil sampling of three layers of a nearby representative soils. The depths sample were 0-1, 1-6, 6-12 inches. These were analyzed for both 1:1 and saturation extract conductivity, and these results related to runoff concentrations. Only the 0-1 inch depth data was found to be meaningful: its 1:1 extract concentration correlated best with the runoff concentrations (r^2 = 0.91), and with calcium, magnesium, and sodium data combinations as well. That the 1:1 data correlated best is fortunate, insofar as the laboratory procedure for its determination is the simplest, quickest, and most objective.

That the 0-1 inch depth data was found meaningful is not surprising. Examination of the soil wetting front after a plot run showed that the water had only penetrated up to perhaps 2 inches at the most, even with the 100 minute runs. Thus the lower layers did not enter into the process: runoff chemistry as influenced by the soil is then only a thin surface layer process.

In several locations, samples of the surface "crust" were also taken, and its 1:1 conductivity determined. This crust, taken from adjacent undisturbed areas is about 1/10 to 1/4 inch thick and is easily identified when the soil is in an undisturbed state. Composite run quality correlated well with the crust chemistry through the least squares equation:

$$EC_w = -193 + .502 * EC_{crust} \qquad r^2 = 0.912$$

in which EC_w and EC crust are the electrical conductivities of the runoff water and crust (1:1 extract). This if further confirmation of the importance of the shallow surface soil layer in determining runoff salinity.

The detail soil chemistry data is available in Ponce (1976). The predominant cation/anion combination of the surface inch was calcium sulphate, although there were some notable exceptions. Sodium predominated at Sites 15, 16, and 17 (Mancos Undivided and Cedar Mountain). Bicarbonates were the major anions in the surface inch on sites 2, 4, 10, 16, 17, and 23. Thus the calcium sulphate is dominant, but not universal throughout the basin soils.

Site Variability: Insofar as the chemistry of the surface inch of soil is influential in runoff chemistry, an interesting assiciated study should be outlined. A soil chemistry sampling grid was established near Site 14 (the "County Line" site) to examine the areal distribution of soil surface salinity over a small area. The results are given in Figure III- 3. It is clear that great differences occur over short distances, even though the site may appear to the eye) to be essentially homogeneous as does Site 14. Given this perspective, the differences found in runoff hydrology and quality lose much of their mystery. As shall be subsequently shown, a similar violent variation occurs also with depth and distance along intermittent channel banks.

Salt-Sediment Relationships: The close association between plot sediment concentrations and dissolved solids has been obliquely suggested several times thus far. It is of interest, and will be developed in substantial detail elsewhere. Realization of the relationship and its importance arose as a result of the plot studies, which had insufficient sediment sampling within runs to define relationships adequately. Correlation with the site or type averages, that is Tables III-21 and 22 with III-23 and 24, is inproductive due to site differences.

The relationships that were found within sites or on individual plot or run for the special plots and the microwatersheds in Tables III-28 and III-29 present these correlations for internal data. Note that relationships are of variable fit; r^2 values range from 0 to .88; and that occasional negative slopes are found. These may occur because of complications due to the initial high concentration washoff of florescence without the rainfall or runoff breaking the protective soil crust. The interpretation of the slope

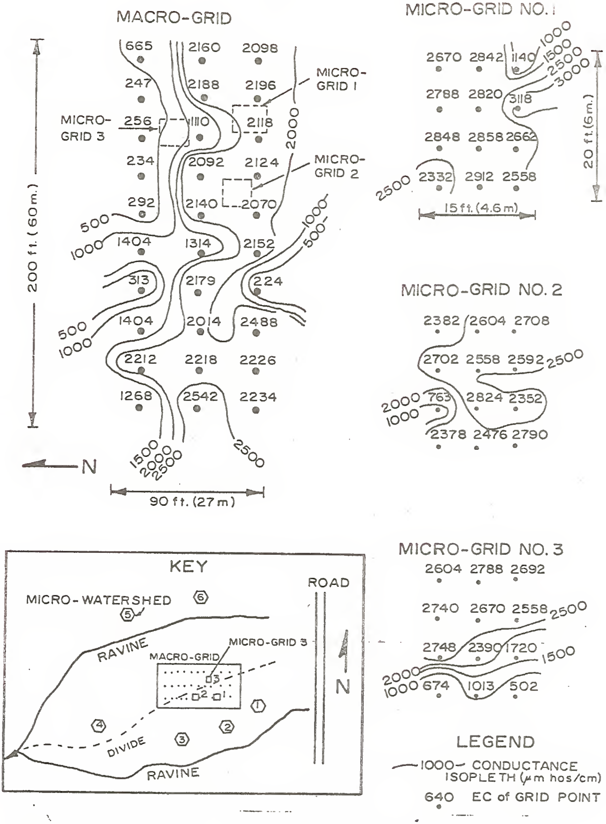


Figure III-3. Variation in salt content in the surface crust over a small area.

Table III-28. Results of the linear correlation between the suspended solids concentration (x) and the total dissolved solids concentration (y) for each plot of the variation in rainfall intensity and duration study

Plot	Duration (min)	Number of Sample Points	a (mg/1)	b (mg/1)	S_e (mg/1)	r^2
141	60	12	47.96	-0.66	2.3	0.52
142	60	12	46.94	0.82	1.8	0.79
143	60	12	40.06	0.15	1.5	0.28
144	60	12	438.12	-24.12	45.9	0.81
145	60	12	142.36	-2.20	13.7	0.60
146	60	12	39.87	2.04	7.6	0.78
81	100	14	391.39	-1.88	72.8	0.05
82	100	15	380.59	6.04	58.2	0.46
83	100	15	399.16	-0.01	45.8	0.00

Table III-29. Results of the linear correlation between the suspended solids concentration (x) and the total dissolved solids concentration (y) for each run of the micro-watershed studies

Plot	Duration (min)	Number of Sample Points	a (mg/1)	b (mg/gm)	S_e (mg/1)	r^2
MW11	30	6	841.7	3.5	150.5	0.11
MW12	30	6	471.6	21.5	54.3	0.41
MW21	30	6	252.5	14.4	337.5	0.21
MW22	30	6	-99.7	42.0	98.8	0.63
MW31	30	6	1042.6	14.2	85.5	0.69
MW32	30	6	1234.0	4.9	77.3	0.25
MW41	30	6	-257.2	71.1	96.0	0.61
MW42	30	6	373.9	22.9	151.9	0.15
MW51	30	6	12.9	25.8	37.0	0.88
MW52	30	6	-74.0	46.9	91.8	0.67
MW61	30	6	-17.4	39.0	58.9	0.84
MW62	30	6	42.5	36.7	80.3	0.74
MW7	30	6	521.6	-14.0	78.2	0.54
MW8	30	6	-129.6	42.6	158.5	0.72
MW9	30	6	83.8	00.3	22.8	0.12

Note: MW11 represents micro-watershed 1 run 1.

(b) is also not independent of the intercept (a): the negative slopes tend to occur with either high intercepts, or low r^2. The latter would indicate no relationship, and that the negative slopes could be "accidents" not to be taken seriously.

Modeling Runoff Salinity: Attempts were made to model the runoff concentrations with time as a function of rainfall intensity, and runoff rate, hopefully drawing out the processes of erosion and salt dissolution, and basic soil/site properties. Although basically only simple algebraic equations, the models tested varied in structure and design from mass conservation based dilution schemes to completely empirical. The data used was taken from 1) the microwatersheds; 2) the special plot runs (5 ft plots) 141-6 and 81-83, and 3) the rainfall-intensity plots (5 ft plots).

The basic structure of the various models attempted, and the average r^2 values of the fitted models are given in Table III-30. It should be noted that the best reasoned models (#1 and #2) gave the poorest fits. Also, the negative r^2 values indicat that the model application to the data left greater residual prediction error than simply using the mean alone.

The models and their rationale are described in detail by Ponce (1976). The least ornate model (#VI), a simple two term linear multiple regression, gave by far the best r^2 value. Application of it to salinity production in the Price basin will be given elsewhere in this report.

Table III-30. Models of Runoff Salinity and Calibration Results.

Model	Function	Mean r^2	
		Microwatersheds	All plots
I	$C = K \frac{Es}{q}$; $q > 0$	-2.02	-21.81
II	$C = K \frac{aP^b}{q}$; $q > 0$	-0.95	- 2.58
III	$C = aq^n$	0.12	0.38
IV	$C = aP^n$	0.19	0.04
V	$C = a + b \exp(Kt)$	0.15	0.18
VI	$C = b_0 + b_1P + b_2q$	0.64	0.46

Notes: In the above, p and q refer to interval rainfall and runoff rates (in/hr), t is time from beginning of runoff in minutes, a, b, n, K, Es, etc. are model coefficients.

Application

Storm Runoff Salinity: Given the "model" results, the local hydrology parameters and a set of reasonable hypothetical assumptions, an example can be drawn illustrative of possible application of the information gained to a land management situation. The setting imagined is a 5 acre watershed with overland flow only, a time of concentration (t_c) of 0.1 hour, and a 50-year - 6 hour design storm of 1.71 inches, drawn from Richardson (1971) for Price. The storm is disturbed according to a standard SCS array. The soil/geology is Mancos Undivided, and a treatment of contour furrowing is proposed. The storm flow and salinity hydrographs and the total salt produced are desired.

Using a curve number of 95 before contouring, and 85 following contouring, storm runoff and hydrographs may be calculated routinely by standard SCS methods. The runoff hydrographs are shown in Figure III-4.

The runoff salinity at 1/2 hour intervals during the storm may be calculated using the model and the coefficients found for the Mancos Undivided type; thus

$$Cq = 366.68 + 60.97p - 72.76q \qquad [III-4]$$

where p and q are in inches per hour, and are taken from the rainstorm and runoff distribution calculations, and the concentration of the input rainfall is assumed to be zero. Cq is expressed as Total dissolved solids in mg/l.

The total salt mass produced is then the sum of the interval concentrations and volume products

$$M = \gamma \sum_{i=1}^{n} (Q * C_q) \qquad [III-6]$$

where Q may be in cubic feet, and Cq in a decimal fraction, and γ the

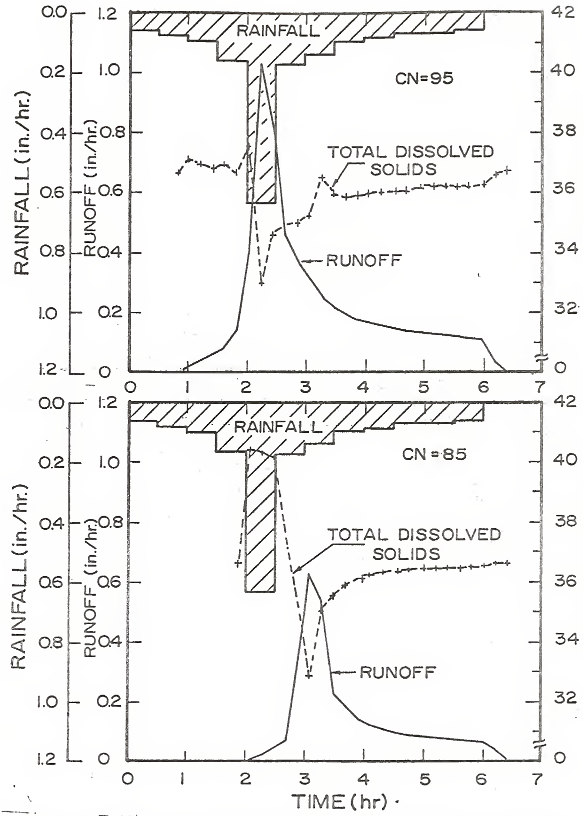


Figure III-4. The hyetograph, runoff hydrograph, and the salinity concentration hydrograph before (upper) and after (lower) contour furrowing in the example problem. mm/hr = in/hr x 2.54.

unit weight of water, 62.4#/ft^3. For the examples offered, the following results.

Table III-31. Hydrology and Salinity for Design Example-Design Rainfall = 1.71 in (6 hr - 50 years)

	Hydrology			Salinity		
	CN	Q(in) (in)	q_p (cfs)	Mass (lb)	Concentration (mg/l) Ave	Peak
I Before Contouring	95	1.21	3.25	492	360	405
II After Contouring	85	.59	5.24	239	358	405

The effects of the land treatment (contouring) may be seen in this example as largely hydrologic, and thus on the salt mass. The effect on the salinity concentration is negligible.

It is possible to infer processes activity from Figure III-4. For the post-treatment case, the rise in salinity corresponding to the peak rainfall intensity may be taken as a "digging" action from rainfall energy, followed by dilution from additional runoff. Contrarily, in the pre-treatment case, a dilution seems to prevail during the peak rainfall and runoff interval. Such reasoning should be done cautiously, and with full awareness of the capriciousness of empirically derived relationships. Also, the truncated salinity abcissa should not be overlooked: the model's performance is entirely within the range of 330 to 400 mg/l. The mid point of this span is a close approximation to the constant term (366.68 mg/l) in Equation III-5. This constant term can be seen to dominate the model over the activity of p and q.

Price River Salinity: Based on the information gained in the plot and microwatershed studies, some estimates may be made at the contribution of overland flow originated salinity from Mancos Shale lands to the total salt load of the Price River at Woodside. Some estimates and reasonable assumptions are necessary.

The average annual precipitation on the Mancos lands is found from regional isohyetal maps to be about 8 inches. Using either applied hydrologic engineering formulas or personal field judgement the annual runoff of overland flow may be taken as 3% of the rainfall or 0.24 inches. Given this as a basis for calculation (admittedly approximate), the relative areas of the different Mancos members, and their characteristic runoff concentrations (as in Table III-22), it is simple to compute a salt runoff mass from these lands. As described briefly above, this calculation leads to 3.94×10^6 # annually. The annual salt load of the Price River at Woodside is about 8.11×10^8 #, and thus the Mancos Shale lands overland flow salinity can be seen to contribute less than 1/2% of the total.

The approximate methods used in the above produce an insecurely founded statistic. However, doubling both the runoff fraction (to 6%) and the characteristic conductivities only raises the contribution percent to slightly less than 1.6%. Clearly, then, overland flow from these lands produce only a trivial part of the total.

Rill and Microchannel Erosion:

Following the plot and watershed findings of low overland flow contributions to Price River salinity, attention then focused immediately downslope from the land surface, i.e., in the collector channels that conduct storm runoff into the major waterways. Field observations during natural rainstorms had raised the suspicion of the rills and microchannels as important contributors, and the salt-sediment relationships briefly covered in the plot studies further promoted such a hypothesis.

The plots were essentially flat or general sloping surfaces with no discernible channel characteristics. Thus the erosion processes found in intermittent channels were not acting in the plot studies. Gully head cutting, bank erosion, and general mass wasting were absent, although they can reasonably be expected to contribute any soil associated salinity.

An obvious approach to the study of this source area contribution would be to instrument a number of small watersheds and then measure flows, sediment, and water chemistry during natural rainstorm events. This however would be both expensive and awkward, insofar as personnel would be needed on site during the events, which could cover several watersheds simultaneously. Also, given the arid environment, there would be a distinct danger of no runoff producing storms duringthe finite study duration. Thus, by necessity, the study strategy was one of measuring channel, salt and erosion effects of artificially induced flows through representative microchannels, as might be found hydrologically downstream from the plot studies.

Study Sites: A number of small intermittent channels, or gullies, were chosen for study within the Price River Basin. The criteria for selection were as follows:

1. Accessible by road.

2. On BLM managed land.

3. Somewhat obscured from public view.

4. In close proximity to the overland flow plots for the geologic types sampled, and/or other channel study sites.

5. Contain at least 100 ft of length typical of the area.

6. Have channel sections conducive to instrumentation.

The channels selected are summarized in Table III-32, and were all small (less than about 1 ft^2 of active flow area), 100 to 300 ft long, gently sloping, (less than 10%), and raw: there was little or no vegetation in the channel or side slopes. They were felt to be typical of the small gullies from small drainage areas very commonly found on Mancos Shale sites in the Price basin. Detailed descriptions are found in a thesis by White (1977).

Instrumentation:

Flow Rates: Upstream water input and downstream output was measured with one foot HS flumes using water level recorders with special clock gearing to record activity within the run durations (30 or 60 minutes) with sufficient resolution. The upstream flume was modified slightly to incorporate a box and baffle to insure that the water did not come into contact with the channel before the test section, and to damp out undue turbulence and allow a more accurate head measurement. In addition, to avoid excessive unnatural erosion as the water entered the channel, a three-sided sheet metal box served as a gentle transition into the channel at the upstream flume.

Water Supply: The water used was imported by tank truck in 6000 gallon loads. The water source was the Price City culinary supply, and had a conductivity in the range of 350 to 400 μmho/cm (at 25°C), which is

Table III-32. Description of channels sampled during the Price River basin micro-channel study

Site Number	Channel Numbers	Length of Channel Studied, in feet (meters)	Duration of Runs, in minutes	Geologic Type
1	1-1,1-2,1-3	100 (30)	30	Upper Bluegate member of Mancos
2	2-1,2-2,2-3	100 (30)	30	Mancos Undivided
3	3-1,3-2,3-3	100 (30)	30	Mancos Undivided
4	4-1	200 (60)	30	Masuk-member of Mancos
5	5-1	300 (90)	60	Middle Bluegate member of Mancos
6	6-1	100 (30)	30	Lower Bluegate member of Mancos
7	7-1	100 (30)	50	Tununk member of Mancos
8	8-1	100 (30)	30	Cedar Mountain formation

representative of the plot runoff quality from assumed upslope areas. The water supply, however, was essentially sediment free. Applied flow rates varied, but were in the range of 0.05 to 0.2 ft^3/sec.

Water Quality: The runs were made for either 30 or 60 minute durations, and samples were taken at regular 5 minute intervals, at 10, 25, 50, and 100 feet distances downstream from the input flume. Irregularly, samples were also taken at 200 feet, 300 feet, and as opportunity and personnel permitted, as far as 1000 feet downstream, although the latter were not regularly scheduled or planned.

Immediately following collection, the temperature, conductivity, and pH of the sample was measured in the field. On the same day the samples were vacuum filtered, and the filtrate of selected samples set aside for detailed chemical analysis. The filter residue was then used to calculate suspended sediment concentrations. Control samples of the input water were also taken subjected to similar analysis. Later ionic analysis of the filtered samples determined bicarbonate-carbonates, sulphate, chloride, calcium, magnesium, sodium, potassium, and lithium concentrations.

Bed material flow at the lower flume presented an unexpected problem because of depositions due to decreased velocities caused by the flume placement. The bed load deposited near and in the flume was regularly scooped out and stored in standby plastic buckets. Larger material was trapped in a large bucket into which the flume emptied. The stored material was later dried and weighed, and a size fraction analysis done using the hydrometer method.

Channel Chemistry: Prior to each run, soil samples were taken of the surface inch of the channel tobbom at the sampling points. Because of the ease of preparation and its utility as an index of salt production (determined from the plot studies), 1:1 extracts were made of all the samples, and their conductivities determined. In some instances this was done on composite soil samples rather than complete individual channel series.

At sites 1, 2, and 3, an adjacent representative channel was sampled in detail along the bottoms and banks; every 10 feet along the channel in the center bottom, and at 6 inches up the bank on both sides, and 1:1 extract conductivities determined. In addition, at Site #1, an even more detailed and extensive sampling grid of one of the channel banks was undertaken, and the 1:1 extract conductivities determined: These samples were taken every 10 feet at 0, 2, and 4 feet above the bottom. A further refinement of this was a 10 ft stretch with samples every 2 feet, also with 1:1 extract determinations as before.

Channel Geometry: In addition to the soils, flows, and quality data, channel and watershed characteristics were surveyed. The contributing watershed area was surveyed using stadia methods. The net channel bottom slope was determined by leveling. The channel cross section geometry was determined at regular spacings before and after each run using a tape measure and previously marked 1/8" metal stakes. The wetted perimeter, cross sectional area, and hydraulic radius was then calculated for each section and the entire channel.

Results and Analysis

Hydrology: From the runs made, two general types of inflow/outflow hydrograph pairs were observed as shown in Figure III-30. Most commonly, the outflow hydrograph volume was approximately the same as the inflow volume, and may be considered as such. This might be expected considering

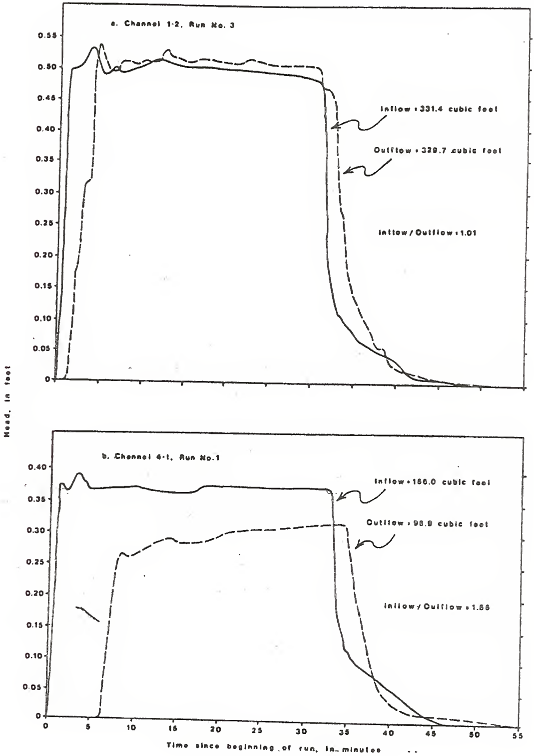


Figure III-5. Inflow and outflow hydrographs for (a) channel 1-2, run number 3 and (b) channel 4-1, run number 1 the high silt and clay content of the soils. In other cases, in sandier channels, a considerable fraction of the flow volume was lost in transit.

The return period perspectives considered in the plot studies were also covered in the channel studies. From the flow durations, volumes and peaks, the rainfall frequency-duration data from both Price and Hiawatha (Table III-4), the watershed areas, and the runoff characteristics from the plot studies, it was possible to estimate the frequency storm necessary to generate the input flows. These calculations were done by three separate methods, the rational method, an infiltration excess model, and the SCS Curve Number method. The results, for all three approaches, are given in Table III-33. While the methodological comparisons are interesting, the main message from the analysis is that the events represented are at least more common than the plot rainfall inputs. In most instances, a frequency on the order of an annual event (2 yr return period) is indicated

Water Quality: Figure III-6 illustrates the net water quality concentrations and ionic compositions. The ionic composition was very heavily proportioned with calcium sulphate, which is an obvious result of the high gypsum content common in Mancos Shale. The high variability between sites and sporadic consistency within sites is reminiscent of the plot study results. The total concentrations (TDS) are not obvious from Figure III-34. However, assuming a calcium sulphate composition, one meq/litre can be taken as 68.1 mg/l. Thus, average concentrations for the runs ranged from the vicinity of 20 mg/l (#8-1) to about 800 mg/l (#1-1). Some additional illustrative data is given in Table III-34 (both sediment and chemistry).

The variation of flow concentration for a representative channel

Table III-33. Results of storm frequency analyses for each channel and run

Channel	Run	Return Period, in years, by the Rational Method Approach	Infiltration Excess Model Approach	SCS Runoff Method Approach
1-1	1	3	71	220
	2	1+	18	53
	3	2	43	140
1-2	1	2	53	170
	2	1+	22	71
	3	6	180	670
2-1	1	1+	3	4
	2	1+	1+	2
	3	1+	3	4
2-2	1	1+	1+	1+
	2	1+	1+	1+
	3	1+	1+	1+
3-1	1	1+	2	2
	2	1+	1+	1+
	3	1+	2	3
3-2	1	1+	2	2
	2	1+	1+	1+
	3	1+	2	2
4-1	1	1+	53	150
5-1	1	1+	5	11
6-1	1	1+	2	4
7-1	1	1+	6	45
8-1	1	1+	4	35

Note: 1 acre = 0.4 hectare; 1 inch = 25.4 mm

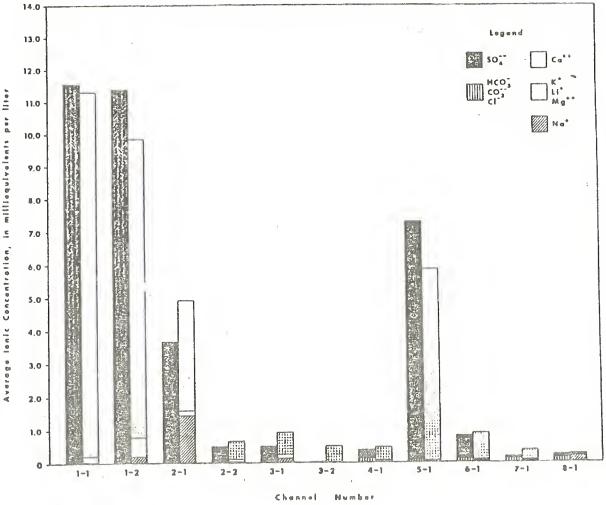


Figure III-6. Average ionic concentration at the 100 foot (30 m) station during run number one in all channels during the first 30 minutes of flow

Table III - 34. Salt loads per unit flow volume and total dissolved solids concentrations of composite one-to-one extracts of soil samples collected prior to runs for each channel and run at sites 1, 2, and 3. The indicated salt load is the total amount produced at the 100 foot (30 m) station within 30 minutes.

Channel	Run	Flow Volume, in cubic meters	Salt Load, in kilograms	Salt Concentration, in grams per liter	Total Dissolved Solids Concentration of composite 1:1 extract, in milligrams per liter
1-1	1	5.54	4.34	0.80	2884
	2	2.40	1.19	0.50	2423
	3	5.18	1.52	0.29	2304
1-2	1	4.77	4.95	1.04	2522
	2	2.46	1.81	0.74	2545
	3	8.89	5.76	0.65	2474
2-1	1	5.49	2.85	0.52	2739
	2	2.36	1.24	0.53	5920
	3	5.01	2.21	0.44	5841
2-2	1	5.03	0.33	0.07	1108
	2	2.11	0.18	0.09	626
	3	7.71	0.49	0.06	448
3-1	1	5.22	0.53	0.10	1330
	2	1.92	0.17	0.09	317
	3	6.12	0.49	0.08	353
3-2	1	3.67	0.57	0.16	2009
	2	1.62	0.24	0.15	1443
	3	4.54	0.50	0.11	1427

(#1-1) is given in Figure III- 7. Three effects are obvious by inspection: 1) Concentration decreases with time, in a manner very similar to the behavior observed in the plot studies. This may again be for the same suggested reasons: an early immediate washoff of easily accessible surface salts or florescence followed by a constant supply, perhaps related to erosion: 2) concentration increases progressing downstream, and 3) sediment and salt behavior is similar.

The concentration - distance phenomenon is further elaborated in Figure III- 8 for three separate channels. An early rapid dissolved solids pickup gradually tapers off with distance, the ultimate concentration apparently a function of site. This may be related to the dissolution rate of different sized gypsum particles as a function of time and concentration. That is, the distance parameter in Figure III-8 is actually only a measure of the water's travel time.

Channel Chemistry: The detailed soil chemistry sampling offered additional confirmation of the considerable natural variability in homogeneous appearing natural settings. Figure III-9 shows the 1:1 extract conductivity of the bottoms and banks for channel 1-3, which was typical of the situations encountered. Tabular data for similar comparisons is given in Table III-33.

The data from Table III-35 was compared internally (ex., bottom 0-1 against bottom 1-6) for all combinations in the same channel by a series of "t" tests, the results of which are not presented here. While not universally different, 12 of the 16 comparisons in Channel 1-3 were significantly different at the .95 level, 7 of 16 in 2-3, and 16 of 16 in 3.3. Thus the chemical variety exists in the channel banks soils as well as in the runoff waters.

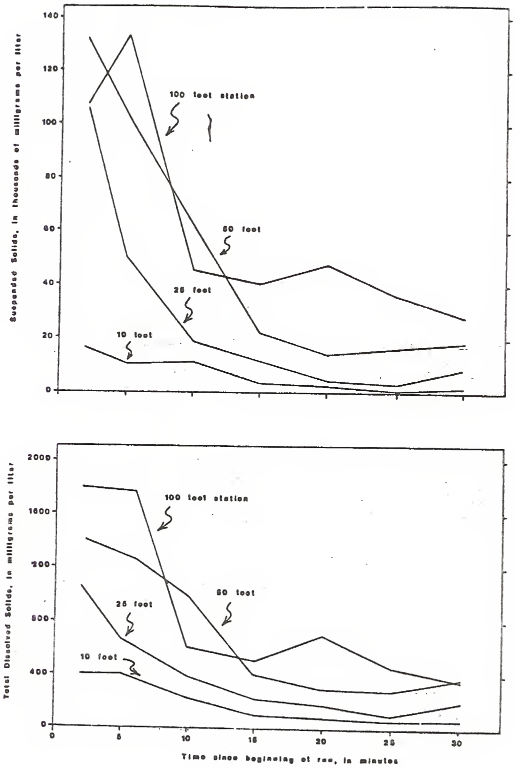


Figure III-7. Suspended solids and total dissolved solids concentrations through time for channel 1-1, run number 1

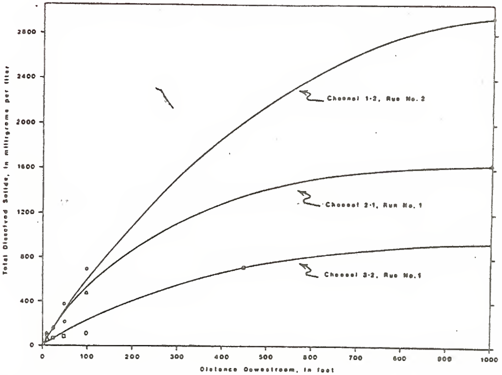


Figure III-8. Effects of flow distance on total dissolved solids concentration for channels 1-2 (run 2), 2-1 (run 1), and 3-2 (run 1). 1 foot = 0.305 m

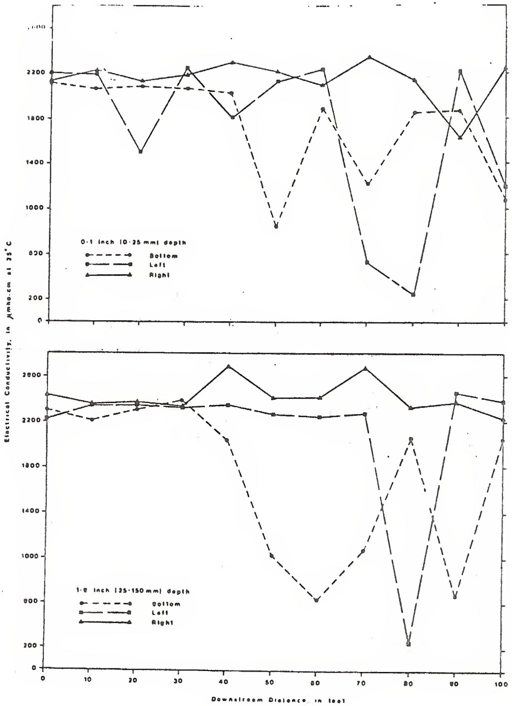


Figure III-9. Electrical conductivity of one-to-one soil extracts versus downstream distance for channel 1-3 at the 0 to 1 inch (0-25 mm) and 1 to 6 inch (25-150 mm) depths

Table III-35. Means and standard deviations of EC measurements from 1:1 soil extracts of samples taken from channels 1-3, 2-3, 3-3 (channel homogeneity test)

Location and Depth, in inches	Mean, in µmhos/cm at 25°C	Standard Deviation, in µmhos/cm at 25°C	Coefficient of Variation, in percent
CHANNEL 1-3			
Bottom, 0-1	1747	462	26.45
Bottom, 1-6	1710	702	41.05
Right, 0-1	2161	193	8.93
Right, 1-6	2422	140	5.78
Left, 0-1	1684	737	43.76
Left, 1-6	2128	634	29.79
CHANNEL 2-3			
Bottom, 0-1	278	92	33.09
Bottom, 1-6	454	637	140.31
Right, 0-1	463	331	71.49
Right, 1-6	749	984	131.38
Left, 0-1	1190	2328	195.63
Left, 1-6	1495	1830	122.41
CHANNEL 3-3			
Bottom, 0-1	5676	3591	63.27
Bottom, 1-6	6599	3513	53.24
Right, 0-1	13255	8331	62.85
Right, 1-6	14461	7893	54.58
Left, 0-1	12488	8597	68.84
Left, 1-6	20541	16363	79.66

Note: 1 inch = 25.4 mm

The bank sample grid results are given in Figure III-10. Iso-conductivity lines show the variation of bank soil salinity much as with surface soils. Variations by a factor of nearly 4.0 are found within the 100 foot sample grids in Figure III-10.

The bank and bottom soil characteristics, both textural and chemical, were examined for association with salt production, as shown in Figure III-11. The results indicate that some of these factors do influence the salt loading. The silt, and sand fractions and the 1:1 extracts are the most influencial, with the silt and the extract EC factors being significant at the 90% level.

Channel Geometry: Attempts also were made to relate the measured channel characteristics - wetted flow contact area, average wetted perimeter, hydraulic radius, cross sectional area and slope - to the salt loading. Figure III-12 shows the results (Slope is shown in Figure III-11 Both the hydraulic radius (area/wetted perimeter) and the slopes are significant at the 90% level.

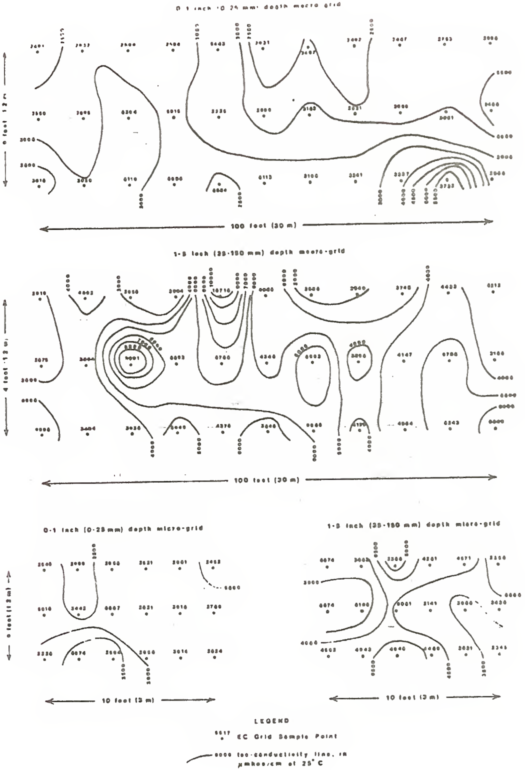


Figure III-10. Variation in the salinity of a channel bank downstream from site one

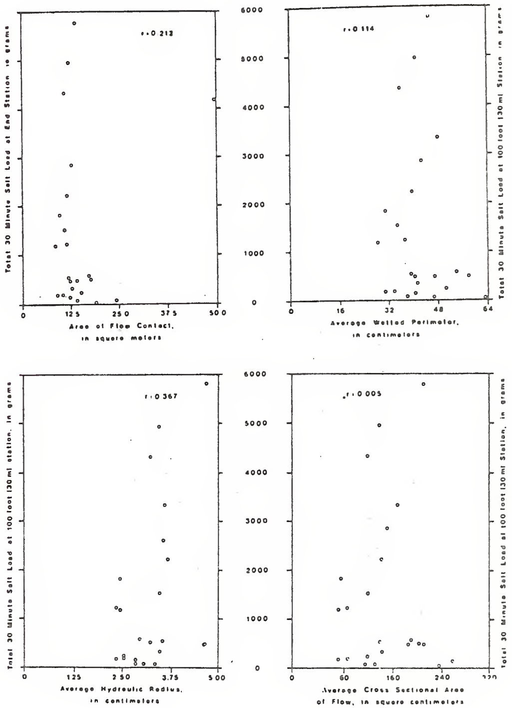


Figure III-11 Effects of flow parameters on salt loads resulting from each run in each channel

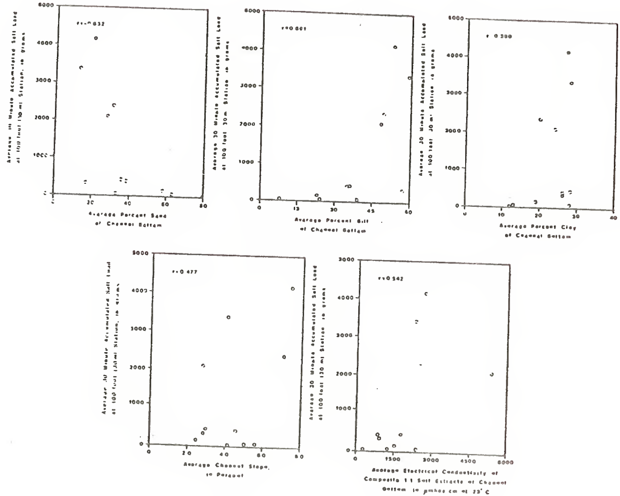
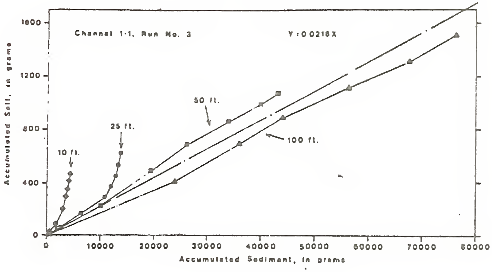


Figure III-12. Effects of channel parameters on salt loads resulting from each run in each channel

Sediment Salt Relationships: As has been indicated previously, the relationships between salt and sediment production seem related, but with variable reliability. The heretofore used interval concentrations as a basis for correlation provide inconsistent encouragement. For example, r^2 values in Tables III-28 and III-29 vary from 0 to 0.88, with values higher than 0.50 common (16 of 24 cases). Considering the physical activity on the plot or watershed, and the sampling time interval (5 minutes), it can be reasonably suggested that the salts (in solution) and the sediments (in suspension or in motion by saltation) move from their source at different average velocities, even though they may be produced essentially simultaneously. Additionally, the time and concentration dependent rates of dissolution of gypsum could be important within the plot/watershed travel time on the 5 minute sampling interval. Thus, poor fits of interval data might be expected, even though a tight on-site salt/sediment relationship might exist.

As a means of overcoming any of the possible above data problems, and to pragmatically order results to a more tractable form, the salt and sediment mass data were integrated (summed), which smoothed out interval to interval variation. This was a successful tactic, and results for several representative channels are displayed in Figure III-13. By forming a least squares regression line for the data through the origin, a characteristic coefficient "B" emerges; the ratio of salt to soil mass in the runoff water. These calculations were made for all the channel data, and are presented in Table III-36, and further summarized in Table III-37. They were also then done for all the suitable available data from the plot and microwatershed runs, as summarized in Table III-38.

The "B" values (salt/sediment ratio) vary from about 1 to 5 percent with few exceptions. The baisn wide channel average for all Mancos sites



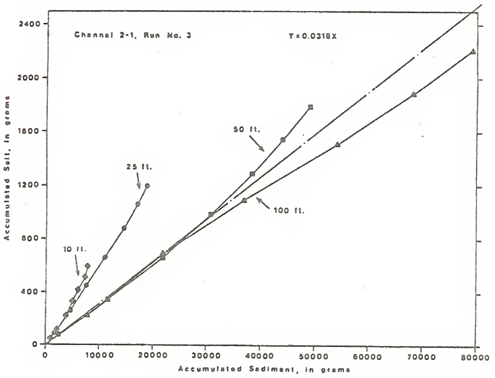


Figure III-13. Accumulated sediment versus accumulated salt for channels 1-1 and 2-1, run number 3 is 1.86%. This corresponds closely to the column tests of Whitmore (1976), who found that a given Mancos soil was capable of yielding 1.89% of its weight as salt, albeit the findings were under different conditions.

The findings may also be compared to field information collected by Mundorff (1972). Collecting samples from a variety of natural channels during a storm runoff event on August 29, 1969, salt/sediment ratios varied from 1.5% to 4.7%. These are shown in Table III-39.

The application of salt/sediment relationships in practical application is obvious. There is a well developed science of sediment mechanics, and numerous overland flow erosion prediction equations exist and are being constantly refined. By predicting sediment load and selecting the correct B value, the salt load under natural or managed conditions can be determined. This approach is essentially the same as suggested by McElroy et al (1976) for predicting the non-point source pollution loads from sediment related organic and morganic chemicals. The technical drawbacks lie in determining accurate erosion rates, and in selecting the value of B.

With the wealth of channel, soil, and bank chemistry and texture data, it was possible to relate B statistically to measurable items. By use of a stepwise regression program, and generously applying data transformations and interactions, B was found to be best expressed (higher r^2) by the equation:

$$B = -0.00143 + 10^{-7}(1.63X_1X_2 + 7.12\ X_2^{\ 3}) \qquad [III-7]$$

where X_1 is the electrical conductivity (umho/cm) at 25°C of the 1:1 extract of composite samples from the surface inch of the channel bottom; and X_2 is the average percent clay, also in the surface inch of the channel bottom. Ideally both of these could be determined from the same composit-

Table III-36. Results of linear regressions through the origin (Y = BX) of accumulated sediment (X) versus accumulated salt (Y) for all channels and runs

Channel	Run	B	S_e, in grams	r^2	r	Degrees of freedom	Level of significance of r
1-1	1	0.0139	226.2	0.967	0.984	26	**
1-1	2	0.0151	142.7	0.796	0.892	25	**
1-1	3	0.0218	165.1	0.835	0.914	26	**
1-2	1	0.0239	281.6	0.952	0.976	26	**
1-2	2	0.0252	156.1	0.878	0.937	26	**
1-2	3	0.0356	601.2	0.825	0.908	26	**
2-1	1	0.0260	251.1	0.907	0.952	25	**
2-1	2	0.0279	107.6	0.903	0.950	25	**
2-1	3	0.0318	244.8	0.839	0.916	25	**
2-2	1	0.0050	119.1	0.064	0.254	26	NS
2-2	2	0.0058	38.4	0.395	0.628	25	**
2-2	3	0.0071	103.3	0.458	0.677	26	**
3-1	1	0.0037	33.4	0.929	0.964	25	**
3-1	2	0.0090	49.6	-0.100	nd	25	nd
3-1	3	0.0089	109.3	0.342	0.585	26	**
3-2	1	0.0225	155.7	-0.084	nd	25	nd
3-2	2	0.0400	31.3	0.767	0.876	24	**
3-2	3	0.0431	121.1	0.212	0.461	25	*
4-1	1	0.0030	30.5	0.517	0.719	30	**
5-1	1	0.0226	281.7	0.981	0.991	55	**
6-1	1	0.0142	17.5	-0.281	nd	23	nd
7-1	1	0.0028	39.1	0.692	0.832	33	**
8-1	1	0.0047	6.6	0.711	0.843	25	**

NS - r not significantly different from zero at 0.95 level
* - r significantly different from zero at 0.95 level
** - r significantly different from zero at 0.99 level
nd - r not defined

Table III-37. B value summarization for various channels, sites, and geologic types in the Price River basin

Comparison	Mean B value	Standard Deviation	Coefficient of Variation
Channel 1-1, all runs	0.0169	0.0043	0.254
Channel 1-2, all runs	0.0282	0.0064	0.227
Site 1, all runs	0.0226	0.0079	0.349
Channel 2-1, all runs	0.0286	0.0030	0.104
Channel 2-2, all runs	0.0060	0.0011	0.178
Site 2, all runs	0.0173	0.0125	0.726
Channel 3-1, all runs	0.0072	0.0030	0.421
Channel 3-2, all runs	0.0352	0.0111	0.316
Site 3, all runs	0.0212	0.0170	0.801
Bluegate, all runs	0.0215	0.0073	0.338
Mancos Und., all runs	0.0192	0.0144	0.747
All Mancos, all runs	0.0186	0.0124	0.665
Non-Mancos (Site 8)	0.0047	-	-

Table III-38. Salt-sediment ratios resulting from overland flow on soil of various geologic origins in the Price River basin (from Ponce, 1975)

Geologic Type (Formation)	Mean Salt-Sediment Ratio	Standard Deviation	Coefficient of Variation
Alluvial Deposits	0.256	0.232	0.906
Black Hawk	0.016	0.007	0.438
Cedar Mountain	0.033	0.029	0.879
Colton	0.009	0.003	0.333
Gravel Caps	0.032	0.017	0.531
Green River	0.011	0.004	0.364
Mancos Shale			
Upper Bluegate	0.015	0.011	0.733
Middle Bluegate	0.019	0.011	0.579
Lower Bluegate	0.027	0.021	0.778
Musuk	0.015	0.006	0.400
Tununk	0.053	0.043	0.811
Mancos Undivided	0.063	0.038	0.603
North Horn	0.009	0.005	0.556
Price River	0.005	0.002	0.400

Table III-39 Salt-sediment ratios resulting from storm runoff events in major channels in the Price River basin (from Mundorff, 1972)

Map Number	Total Dissolved Solids Concentration, in milligrams per liter	Suspended Solids Concentration, in milligrams per liter	Salt-Sediment Ratio
31	2770	184,500	0.015
32	2620	130,000	0.020
37	2320	49,000	0.047
38	1020	22,700	0.045
46	1780	49,700	0.036
69	3550	78,800	0.045

Note: All samples collected on 29 August 1969

Table 18. Average 30 minute salt load and concentration for micro-watersheds seven through nine (from Ponce, 1975) and channel 1-2. Values are averaged over all runs and corrected for differences in storm sizes

Study area[a]	Average Flow Volume, in liters	Average Salt Load, in grams	Average Salt Concentration, in grams per liter
MW, 7-9	27	11.8	0.44
1-2, 10 ft	5775	644	0.11
1-2, 25 ft	5760	1153	0.20
1-2, 50 ft	5730	1748	0.31
1-2, 100 ft	5670	4176	0.74

[a] MW 7-9 refers to the micro-watersheds of corresponding numbers studied by Ponce (1975). 1-2, 10 ft refers to the 10 foot station of channel 1-2, and so forth. 1 foot = 0.305 m

ed sample, although the subject channel reach should be well sampled in forming the composite.

A graphical presentation of Equation III-7 is given in Figure III-14, and its limits of application shown in Figure III-15.

Application: The fraction of the annual salt load of the Price River at Woodside that arises from microchannels is central to this study and is of high interest. However, there is little appropriate in the technical literature which incorporates erosion in intermittent channels as a function of flow and channel characteristics.

A review of the available literature gave several net watershed erosion rates which could be used as starting points however. Thomas (1955) found gully plugs near Cisco in Eastern Utah trapping an average of 1.99 tons/acre. Considering the similarities between the two areas, this was used as a microchannel erosion rate for the Price River basin's Mancos lands. The figure compares favorably with the estimates of annual sediment yields from the entire Price Basin (2.19 tons/acre) reported by Mundorff (1972), and for the entire upper Colorado River basin (2.81 tons/acre) reported by Todd (1970).

Taking the above erosion rate of 1.99 tons/acre as entirely from microchannels, and applying the "B" factors for the different Mancos members and their areas, Table III-40 results: A total of 9791 tons/year from microchannels on Mancos shale lands. Applying this to the total salt flow used previously (8.11×10^{11} lb or 4.06×10^{5} tons), only 2.4% of the total flow arises from microchannels. The summarized results of the overland flow and microchannels is given in Table III-41.

Table III-40. Estimated Salt and Sediment Yields from Mancos Shale Microchannels in the Price Basin.

Member	Percent of Basin	Area (Ac)	Sediment Yield (tons)	B	Salt Yield (tons)
Masuk	4.40	53150	105520	.003	316
Bluegate	9.29	112240	222800	.022	4789
Tununk	1.21	14630	29020	.003	82
Undivided	10.00	120810	239810	.019	4604
TOTAL	24.90	300830	597150		9791

Notes: "B" values chosen from Tables III-36 and III-37. Some small inconsistencies due to rounding.

Table III-41. Sediment Source Summary for Mancos Shale lands in the Price Basin.

Source	Tons/yr	Percent
Overland Flow	1,970	.48
Microchannels	9,791	2.41
Other Sources	393,739	97.11
TOTAL	405,500	100.00

Given the assumptions, and the overlapping sources inferred in using the 1.99 tons/acre figure, the calculation might be legitimately challenged. However, even increasing the production by a factor of 2 or 3 to account for these unknowns still leaves only a minor portion of the total salt production from these lands.

IV. Impact of Native Vegetation as a Source of Diffuse Salt

Gerald F. Gifford
Ali Malekuti

For more than one and one-half centuries reports have appeared in the literature indicating a loss of minerals and nutrients from plant leaves by the leaching action of rainfall, mist and dew. However, the potential of foliage leachates as a diffuse source of salinity in streams on wildland watersheds has not been studied. Leaching conceivably could be one of the main factors affecting salt movement in the hydrologic cycle under natural conditions, thereby causing detrimental effects on downstream water quality.

The overall objective of this portion of the total research project was to determine the influence of foliage and litter leachate from selected natural vegetation in the Price River Basin on the amount of diffuse salt movement from rangeland watersheds. Relative contributions of salt (total dissolved solids) from both foliage and litter of select species were determined, as well as the concentrations of selected ions (Na^{+}, K^{+}, Ca^{+2}, MG^{+2}, Cl^{-}, HCO_3^{-}, and SO_4^{-2}).

METHODS AND PROCEDURES

A preliminary study provided information for narrowing the number of species by determining their susceptibility to leaching processes. A dipping technique was used for this cursory survey. Live foliage, including leaves, stems, and flower heads were collected and immersed in a known volume of distilled water. Conductivity of the water was measured at 1-minute time intervals until it reached a constant level.

Plant materials were then oven-dried. This test was conducted for several species including grasses, forbs, and shrubs during October, 1974 and July, 1975.

In addition, a maximum potential contribution of dissolved solids was determined by using ground samples of recent litter deposits. In this instance the litter samples, each representing 50 grams of oven-dried litter, were ground through a 20-mesh screen and mixed with 1230 ml of distilled water. The solution was filtered after 24 hours and the leachates were used for chemical analyses.

Finally, leaching tests were performed in the laboratory and the field to determine the amount of salt that could be washed from plants and litter by simulated rainfall. Rainfall of different durations and intensities was provided by a modified version of the rainfall simulator designed by Meeuwig (1971)(Figure IV-1). Distilled water was utilized in all these determinations. Salt contributions due to dust accumulations were minimized through gentle blowing and shaking of dust from both litter and live plant materials.

Leaching studies in the laboratory were carried out on 50 gram samples (four replications) of oven-dried recent litter. The litter was placed in 15 cm diameter plexiglass containers with a perforated false bottom and the samples were exposed to two simulated rainfall intensities (7.6 cm/hr, 60 minute duration; 3.8 cm/hr, 120 minute duration). Leachate was collected at 5-minute intervals and electrical conductivity measured. At the end of each test, electrical conductivity of the accumulative leachate from each replication was read then a composite sample was prepared for chemical analyses.

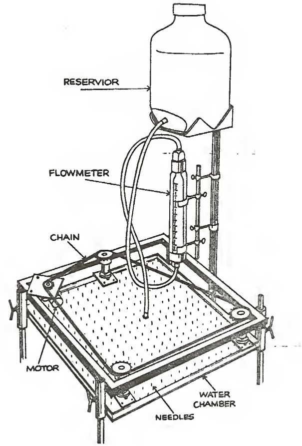


Figure IV-1. Rainfall simulator utilized in both field and laboratory studies. The water chamber is 60.92 and 60.92 x 2.54 cm (2 x 2 ft x 1 inch) and produces rain over a plot size of 3413 cm^2.

Two different size plexiglass gauges were used in the field studies (60.9 cm x 30.9 cm and 30.4 cm x 30.4 cm with 25.4 cm walls and 3.8 cm and 1.9 cm central openings, respectively). The large gauge was used for the larger shrubs or bushes and the smaller gauge was used for the smaller plants. These gauges were constructed to two halves and assembled around the plant stem. The central opening around the stem was sealed with plaster of paris as filler and then covered with Dow Corning encapsulant to prevent any leachate loss. An outlet was provided for each half of the gauge to collect the leachate from the total surface area of the gauge. The infiltrometer was set above the gauge to simulate rainfall on the plant canopy. For the field studies a 3.8 cm/hr rainfall intensity was used for a period of 2 hours. After each 5-minute interval a sample of leachate was taken for an electrical conductivity reading. In addition, a cumulative electrical conductivity reading was taken. At the end of each run the residual leachate in the gauge was drained into the volumetric flask and a composite sample of leachate was taken and stored in an ice chest for chemical analysis. The leached plant was clipped at the end of the leaching period and oven-dry weight was determined. Three plants of each species were sampled during the late spring and mid-summer of 1975.

RESULTS

Preliminary Studies

Eleven shrub, two tree, 2 forb and 2 grass species were examined in the preliminary survey and all yielded salt to some degree. Results from 14 species are shown in Figure IV-2. The cumulative curves show that leaching processes are continuous and the pattern and magnitude of these

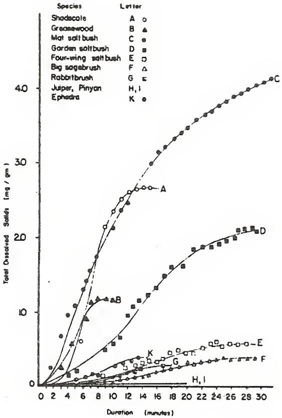


Figure IV-2. Quantity of salt released in a known volume of distilled water as a function of time per gram of plant material during July, 1975 (five minute time intervals).

salt removals are different among the different species. This same idea has been demonstrated in other studies (Wallace, 1930; Tukey and Tukey, 1962; Morgan, 1963). Tukey and Tukey (1962) related this variability to physiological stages of plants, plant health, and plant vigor, leaf surface wetability and other physical properties of the leaves. Pinyon and juniper proved to be the most resistant plants with species like mat saltbush (*Atriplex corrugata* S. Wats.), Gardner saltbush (*Atriplex gardneri* (Moq.) D. Dietr.) and shadscale contributing much greater quantities of salt per unit weight of plant material.

Maximum Potential Loss of Salt

Figure IV-3 illustrates the relative maximum potential of total salt which was removed from 50 grams of ground plant litter while immersed in distilled water for 24 hours. It may be concluded that of the 13 species tested, recent litter from mat saltbush, halogeton (*Halogeton glomeratus* (Bieb.) C. A. Meyer), Gardner saltbush, salt cedar (*Tamarix pentendra* Pall.), shadscale, greasewood and four-wing saltbush (*Atriplex canescens* (Pursh) Nutt.) have the highest potentials for releasing salt. There was a significant correlation (r=0.90) between salt production from live plant material and from recent litter of the respective species.

Litter Leaching with Simulated Rainfall

Figure IV-4 shows the quantity of salt in mg/gm of plant material washed from recent litter of various plant species under high (6.7 cm/hr) and low (3.8 cm/hr) intensity simulated rainfall and also the maximum potential salt production (determined from ground samples). Fifty-five percent of the species litter, including shadscale, greasewood, four-wing saltbush, big sagebrush (*Artemisia tridentata* Nutt.), big rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britton) and pinyon did not show

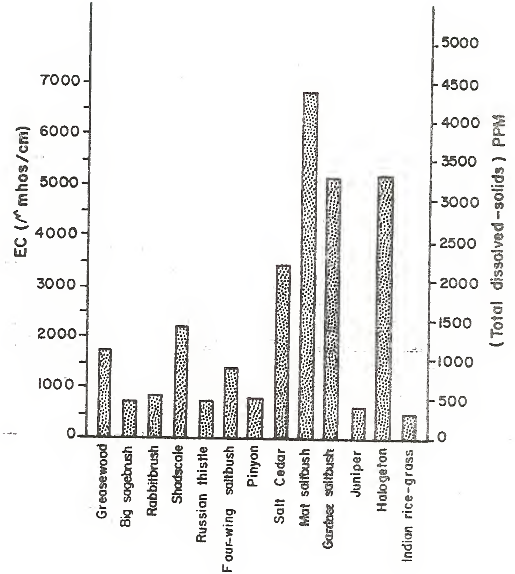
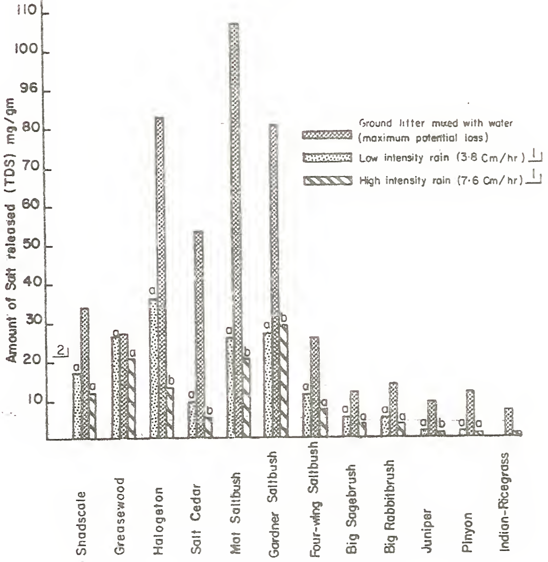


Figure IV-3. Variation in conductivity, based on leachate from 50 grams (dry weight) gound up litter mixed with 1,230 ml of distilled water and filtrated after 24 hours for selected species. The relationship of electrical conductivity (EC) to parts per million (PPM) was as follows: $(EC \times 10^3) \times 640 = PPM$.



1/ Mean of 4 replications

2/ Any two means with different alphabetical superscripts (for each species) are significantly different at 5% probability level.

Figure IV-4. Amount of salt released per gram of recent litter under different leaching treatments.

significant differences between the high and low intensity rainfall. About 45 percent of the selected species, such as salt cedar, halogeton, and mat saltbush had significantly higher concentrations of salt in the leachate under the low intensity rain. Gardner saltbush was the only species that released more salt under the high intensity rainfall.

As for specific ions, considerable amounts of bicarbonate, sulfate, calcium, and chloride were leached from almost all of the species. Sodium and potassium were lost in moderate amounts, with magnesium losses being extremely minimal. No carbonate concentration was detected in leachates from any plant species.

Chemical analysis of the leachate collected from 50 grams of greasewood litter shows under the high intensity rain (7.6 cm/hr and 1-hour duration) a total concentration of 721.1 mg/l salts including 264.5 mg/l of sodium, 42.9 mg/l potassium, 4.0 mg/l calcium, 6.0 mg/l magnesium, 49.0 mg/l sulfate, 305.0 mg/l bicarbonate, and 49.7 mg/l chloride. No carbonate was observed. During the 1 hour about 78 percent of the total salt in the greasewood litter was leached.

Gardner saltbush released the next highest percent (33 percent) of the total potential removal salt that existed in its litter. The nutrient content in leachate of Gardner saltbush, under the same conditions as above, was: 340.4 mg/l sodium, 54.6 mg/l potassium, 5.0 mg/l calcium, 9.6 mg/l magnesium, 249.9 mg/l sulfate, 128.1 mg/l bicarbonate, and 209.5 mg/l of chloride.

The concentration of mineral constituents removed from shadscale by the heavy rain of 1-hour duration was 322.2 mg/l, which is about 24 percent of the initial potential removal salt content. Chemical analysis shows that 108.1 mg/l sodium, 39.0 mg/l of potassium, 4.0 mg/l calcium, 3.6 mg/l magnesium, 24.5 mg/l sulfate, 36.5 mg/l bicarbonate, and 106.5 mg/l of chloride were leached from the litter of shadscale.

The balance of the species have been ordered relatively to the percentage potential salt loss experienced by litter of each species under heavy rains as follows: four-wing saltbush (17 percent); big sagebrush (16 percent); rabbitbrush (16 percent); halogeton (15 percent); mat saltbush (13 percent); pinyon (11 percent); salt cedar (6 percent); Indian rice grass (*Oryzopsis hymenoides* (Roem. & Schult.)) (5 percent); and juniper (2 percent).

Foliage Leaching with Simulated Rainfall

The total dissolved solids washed from different species in terms of milligrams per gram dry weight of foliage (including stems) under the 3.8 cm/hr simulated rainfall over a 2-hour period were 21.16, 21.14, 11.51, 8.63, 7.15, 6.10, 5.10, 4.14, 3.16, 2.61, 2.29, 1.15, and 1.05 from mat saltbush, Gardner saltbush, halogeton, shadscale, salt cedar, winterfat, four-wing saltbush, greasewood, big sagebrush, little rabbitbrush, big rabbitbrush, juniper, and pinyon, repsectively. The average cumulative quantity of salt leached from various species is shown in Figure IV-5.

From the quantities of nutrients in the water collected under the different plants, average values were obtained for each species. Mean ion contents in leachate of various plant species were compared by use of Duncan's multiple range test (Figure IV-6). Considerable amounts of bicarbonate, sulfate, calcium, and chloride were leached from almost all of the species. Sodium and potassium were lost in moderate amounts. The amount of magnesium in rainwater under all of the

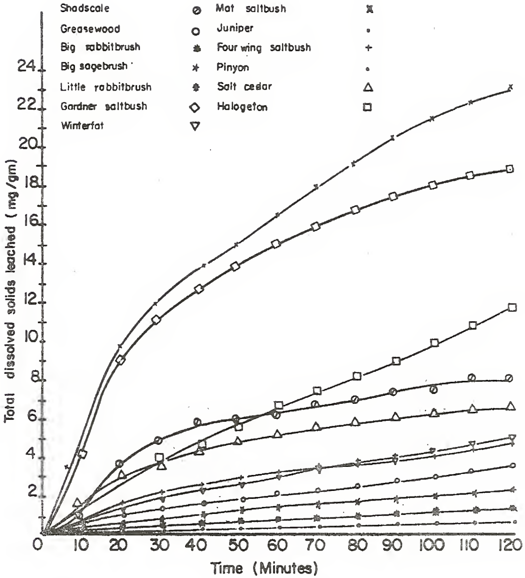


Figure IV-5. Average cumulative quantity of salt in leachate collected at 5-minute intervals from various plant species exposed to simulated rainfall falling at 3.8 cm/hr for 2 hours.

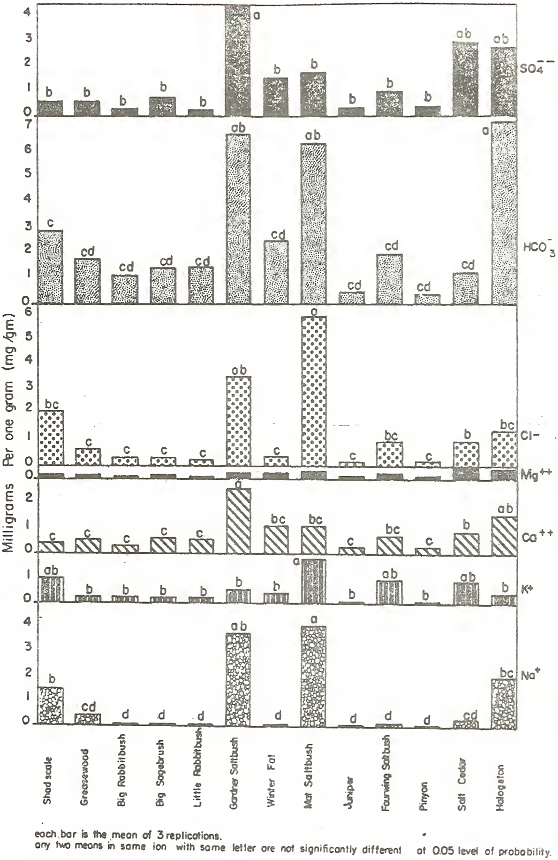


Figure IV-6. Average rate of chemical components reaching the soil surface by foliage leaching (3.8 cm/hr simulated rainfall and 2 hours duration).

plant species was minimal. No carbonate concentration was detected in leachate from any plant species.

Mat saltbush and Gardner saltbush lost the most calcium, bicarbonate, chloride, and sodium. Mat saltbush released 1.05, 6.37, 5.94, 4.07 mg of calcium, bicarbonate, chloride, and sodium, respectively, per 1 gram dry weight of plant material.

Pinyon and juniper were the two species with the lowest rate of loss of ions. Total dissolved solids removed from 1 gram dry weight of the materials (leaves and stems) were 1.15 mg for pinyon and 1.05 mg for juniper trees.

PROBABLE SALT LOADING

In light of the above data, the question remained of whether there was a significant salt contribution based on characteristics of two range sites (as determined by the Soil Conservation Service) whose present condition is typical of the lower portion of the Price River drainage. These range sites are briefly described below:

> In the Desert Shallow Shale range site, which has an average annual production of about 168 kg/ha/year (150 lb/ac) air dry, important species such as mat saltbush, winterfat, Indian ricegrass, greasewood and other species, contribute 40%, 8%, 10%, 6% and 36%, respectively of the total dry weight of production. Under 3.8 cm/hr rain intensity and 20 minutes duration, the amount of salt reaching the soil surface from foliage leachate in the tested species was approximately .749 kg/ha.
>
> The Desert Alakli Flats range site, with an average annual production of 840 kg/ha (750 lb/ac) air dry, had only three of the selected species; greasewood, shadscale, and winterfat. These three contributed about 40%, 20%, and 20%, respectively, of the total dry weight production under the prescribed conditions. The salt washed off from foliage of these three species under 3.8 cm/hr rain intensity and 20 minutes duration was estimated to be about 1.16 kg/ha.

Considering that almost 1132 km^2 of the Price River Basin is covered by these or similar range sites, it was calculated that on the average about 0.95 kg/km^2 of salt will reach the soil surface from current foliage production under a 3.8 cm/hr, 20-minute rainfall. Assuming that litter accumulated on each range site amounts to perhaps one-half the average annual production and recognizing the increased potential for salt release from litter, then potential salt production is increased to about 2.85 kg/km^2 per 20-minute storm. Then, assuming an average annual rainfall of 20 cm, of which there may be four storms at most per year, each 20-minutes in length and delivering 1.3 cm of precipitation, and assuming 25% of the storm precipitation becomes runoff, then the salt loading factor becomes, in fact, 14.25 kg/km^2/year or .04 $tons/mi^2$/year. Presently annual salt production from the Price River Basin averages (at Woodside) about 270 $tons/mi^2$/year. Therefore, plants contribute between .01 and .02 percent or less of the total annual salt load to the Price River based on characteristics of two range sites that would be expected to be high-salt producers in the first place. Based on these calculations it must be concluded that plants are not a significant source of diffuse salt within the Colorado River Basin.

V. SOIL CHEMISTRY STUDIES

It has been documented by many studies that mineral pollution is the primary water quality problem in the Colorado River Basin. It is also the problem which is greatest affected by the natural background conditions of the basin.

The mineral quality of a stream is closely related to the hydrogeology and soils of a given basin. The highland areas of the Colorado River Basin contain relatively weather resistant igneous and metamorphic rocks which contain few soluble minerals. These rocks and their derived soils in the presence of relatively high annual precipitation produce runoff with low concentrations of dissolved salt although the total salt load may be large because of the amount of flow involved. As the stream enters the lower lying lands the channel crosses easily eroded alluvium or residuum situated on ancient saline marine shales (e.g. Mancos shale) deposited prior to the uplifting of the Colorado Plateau during Paleocene and Eocene time. The process of channel erosion and dissolution increases the salt and sediment load of the water and usually results in the stream bed being deeply entrenched in saline marine sediment. This situation fosters mass wasting from the channel sides which further adds to the salt and sediment load of the stream. In addition, precipitation entering permeable aquifers at higher elevations may emerge further downstream as flow mineralized by contact with soluble soil minerals and geologic strata encountered during subsurface flow.

Summertime thunderstorm events in the arid valleys produce runoff on easily eroded marine sediment outcrops which quickly develops rills and gullies. This soil erosion produces both sediment and salinity which finds its way into stream channels thus also contributing to the salt production of the basin.

The natural processes briefly described are among the many diffuse sources of salinity which have been contributing to the salt and sediment loads in the waters of the Colorado River Basin since the beginning of its geologic history. This hydro-geochemical cycle cannot be altered easily by man.

Land processes involved in diffuse salt production are intimately connected with chemistry of the soil. Although the objectives of this project did not encompass a comprehensive chemistry study of the Price River Basin soils, certain aspects were investigated to provide some insight into the salt pickup mechanisms of land processes.

The Price River Basin situated in East Central Utah, is reported (Blackman et al., 1973) to be one of the primary salt producing areas in the upper Colorado River Basin. The marine derived Mancos shale formation is considered to be a major contributor to the diffuse salt load of the basin. This saline marine shale covers about 25 percent of the basin and serves as a parent material for a significant fraction of alluvial soils in the region.

The salinity of Mancos shale is associated with the constituent mineral gypsum ($CaSO_4 \cdot 2H_2O$) and variable amounts of lime ($CaCO_3$). Also occurring are evaporite compounds which include sodium sulfate, sodium chloride, calcium chloride, magnesium sulfate and magnesium chloride. The presence of highly soluble evaporites serves as a significant source of salt in water that percolates through or intersects Mancos shale. In principle, evaporites can affect salinity production of the Price River Basin by (1) Their presence in Mancos shale derived soils causes the soil water and hence the drainage and interflow to have an appreciable salt load. (2) The presence of sodium in the evaporites can disperse the soil colloids thus reducing infiltration and increasing surface runoff and erosion. Both salt and sediment loading could increase. (3) The presence of evaporite salts affect the solubility of both gypsum and carbonate minerals. The solubility of these minerals is increased by ion pair-formation and the indifferent salt effect and reduced by the common ion effect. The aspects of soil chemistry investigated in this project were

1. The influence of various electrolyte solutions on the solubility of gypsum and $CaCO_3$ (calcite).

2. The rates of salt release occurring from a representative Mancos shale derived soil.

3. The potential salt production from a representative Mancos derived soil.

The above studies will be discussed with reference to their implication to field level management. Theoretical discussion and methodology have been reported in previous reports and therefore, experimental details are only briefly described.

GYPSUM AND CALCITE SOLUBILITY

Gypsum Solubility in the Presence of Electrolytes

Additions of various amounts of NaCl, $MgCl_2$, $CaCl_2$ and Na_2SO_4 were each added to 3 grams of pure $CaSO_4 \cdot 2H_3O$ (gypsum) suspended in

100 ml of distilled water to simulate the effect of evaporite salt on the stoichiometric solubility of gypsum. The suspensions were shaken in a water bath maintained at 25 ± 1C for 72 hours. Table V-1 shows the experimentally determined equilibrium concentrations of each ionic specie in solution. The data show that both NaCl and $MgCl_2$ increase the solubility of gypsum as noted by the increase in both the Ca^{2+} and SO_4^{2-} concentrations. The presence of NaCl increases the solubility by the indifferent salt affect. That is, the activity coefficients of both Ca^{2+} and SO_4^{2-} in solution decrease. In the presence of 100 me/L of NaCl the solubility of gypsum increased 45 percent. The presence of $MgCl_2$ increase the solubility of gypsum by both the indifferent salt effect and by the formation of $MgSO_4^o$ ion pairs. The data show that $MgCl_2$ increases the solubility of gypsum more than does NaCl at any given salt treatment. At a concentration of 100 me/L $MgCl_2$ the solubility of a gypsum increased 67 percent.

The solubility of gypsum is correspondingly decreased by the addition of both $CaCl_2$ and Na_2SO_4. When $CaCl_2$ is added, the presence of Ca^{2+}, a common ion, is effective in reducing gypsum solubility as noted in the decrease in the SO_4^{2-} concentration shown in Table 1. In the presence of 100 me/L $CaCl_2$ the solubility of gypsum is reduced 43 percent. The solubility of gypsum is less affected by the addition of Na_2SO_4 then by $CaCl_2$. Even though SO_4^{2-} is a common ion, the formation of $CaSO_4^o$ ion pairs increases the concentration of Ca^{2+} in solution, as seen in Table 1, thus countering to some extent the common ion effect. The difference between the Ca^{2+} concentrations in solution resulting from the Na_2SO_4 treatments with the SO_4^{2-} concentrations resulting from the $CaCl_2$ treatments is a measure of the $CaSO_4^o$

Table VI-1. Affect of electrolyte concentration on the solubility of gypsum at 25 ± 1C. The ionic concentrations are in mmoles/Liter*.

Species	pH	EC x 10^6	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{2-}	Cl^-
$CaSO_4 \cdot 2H_2O$	4.90	2,287	15.45			15.52	
10 meq NaCl	4.42	3,390	16.68	10.64		16.91	10.50
25 meq NaCl	4.51	5,050	19.98	25.06		20.03	26.54
50 meq NaCl	4.55	7,460	21.48	49.82		21.84	52.38
100 meq NaCl	4.59	12,200	22.39	95.74		22.56	99.51
10 meq $MgCl_2$	4.55	3,180	17.37		4.46	17.87	11.42
25 meq $MgCl_2$	4.55	4,786	21.82		13.42	22.13	25.01
50 meq $MgCl_2$	4.51	7,180	23.47		24.67	23.98	50.30
100 meq $MgCl_2$	4.40	11,700	25.86		46.39	25.77	99.18
10 meq $CaCl_2$	4.56	2,850	13.50			13.79	10.68
25 meq $CaCl_2$	4.51	4,238	16.75			11.06	28.50
50 meq $CaCl_2$	4.48	6,540	22.75			9.54	51.34
100 meq $CaCl_2$	4.38	10,700	47.18			8.83	100.20
10 meq Na_2SO_4	4.74	2,550	13.84	10.13		13.46	
25 meq Na_2SO_4	4.85	3,442	11.41	25.14		21.87	
50 meq Na_2SO_4	4.98	4,200	10.98	48.19		28.53	
100 meq Na_2SO_4	5.06	6,420	10.41	89.19		47.40	

*Mean value of 3 replications.

ion pairs (1.6 me/L at the 100 me treatment) formed in the Na_2SO_4 system. The data show that gypsum solubility is reduced 33 percent in the presence of 100 me/L Na_2SO_4.

Table V-1 shows that regardless of the interaction of gypsum with the added electrolyte, the EC of the solution increases noticeably with the addition of the salt. The effect of both the common ion effect and ion pair formation on gypsum is to reduce the rate at which the solution EC increases upon addition of the electrolyte. The effect is most evident in the Na_2SO_4 system. Comparing the addition of 100 meq of NaCl with an equal treatment of Na_2SO_4 shows that the gypsum plus salt system had an EC of 12.2 mmhos and 6.42 mmhos, respectively. The low EC in the presence of Na_2SO_4 is due to the reduced solubility of gypsum plus the formation of the neutral $CaSO_4^o$ species both of which suppress the EC value.

Calcite Solubility in the Presence of Electrolytes

Table V-2 shows the affect of electrolytes on $CaCO_3$ solubility. The electrolytes NaCl, Na_2SO_4 and $MgCl_2$ all increase the solubility of $CaCO_3$ by the indifferent salt effect and, in the case of Na_2SO_4, by the formation of $CaSO_4^o$ ion pairs. The increase in solubility of $CaCO_3$ by the presence of 100 me/L of NaCl, $MgCl_2$ and Na_2SO_4 is 59 percent, 90 percent and 112 percent, respectively. Although this is a relatively large increase in $CaCO_3$ solubility, the initially low solubility of $CaCO_3$ precludes the increase as having a marked effect on the salinity of the system. As was expected the overall EC values of the solutions were lower than the comparable solutions containing gyspum. The

Table V-2. Affect of electrolyte concentration on the solubility of $CaCO_3$ at 25 ± 1C. The ionic concentrations are in mmoles/Liter.

Species	pH	EC x 10^6	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{2-}	Cl^-
$CaCO_3$	8.32	450	0.41				
10 meq NaCl	7.98	1,225	0.46	8.66			16.25
25 meq NaCl	7.93	2,769	0.72	26.11			29.58
50 meq NaCl	8.04	5,283	0.56	49.61			54.58
100 meq NaCl	8.17	10,157	0.65	100.30			104.17
10 meq $MgCl_2$	7.74	1,170	0.49		3.96		15.42
25 meq $MgCl_2$	7.71	2,681	0.58		8.75		30.83
50 meq $MgCl_2$	7.84	4,928	0.66		23.04		55.00
100 meq $MgCl_2$	7.95	9,349	0.78		46.59		101.68
10 meq Na_2SO_4	7.97	1,138	0.55	10.95		7.42	
25 meq Na_2SO_4	8.06	2,485	0.65	25.33		17.77	
50 meq Na_2SO_4	8.17	4,695	0.71	50.26		26.69	
100 meq Na_2SO_4	8.30	8,557	0.87	102.70		50.53	
10 meq $CaCl_2$	7.18	1,006	4.94				13.85
25 meq $CaCl_2$	7.24	2,320	10.73				25.73
50 meq $CaCl_2$	7.20	4,244	25.28				49.48
100 meq $CaCl_2$	7.00	7,590	49.40				93.42

*Mean value of 3 replications.

$CaCl_2$ solution had the lowest EC value for any given electrolyte solution showing the common ion effect of Ca^{2+} on reducing the solubility of $CaCO_3$.

Conclusions of Solubility Studies

This study essentially confirms existing literature on the electrolyte effect on gypsum and $CaCO_3$ (Tanji, 1969; Nakayama, 1968, 1971). Translating these results to the field situation indicates that indeed the presence of evaporite salts will affect the solubility of these minerals. The mixed electrolyte status of natural systems, however, makes quantitative predictions hazardous. The solubility of $CaCO_3$ is low enough to be essentially nonsignificant to the overall salinity status of the system. Gypsum solubility, particularly in the presence of NaCl and $MgCl_2$, does increase to a marked degree. The presence of the common ions, Ca^{2+} and SO_4^{2-}, suppress gypsum solubility as predicted by the general laws of chemistry. The evaporite salts themselves, when present, have a major impact on degrading water quality. Their overall affect on the solubility of soil minerals is complex. However, this study suggests that the inherent solubility of the evaporite salts is of more importance to the salinity of the system then their affect on increasing the solubility of constituent minerals.

KINETICS OF SALT RELEASE

In defining the chemical processes that operate in producing non-point sources of salinity in natural systems both the equilibrium and kinetic aspects of the reactions must be considered. Of interest, is the rate at which the salt is released from a relatively unweathered wildland soil upon contact with water. To gain insight into this process a kinetic study was conducted. The theory of salt dissolution will be presented in a brief form to allow the results to be more easily discussed.

Theory of Salt Dissolution

It is generally accepted that the dissolution of a solid in a liquid medium is diffusion controlled (Berner, 1971; Stumm and Morgan, 1970). In accordance with this concept, Fick's first law of diffusion

$$J = -D \frac{\partial C}{\partial X} \qquad (1)$$

where J is the diffusive flux of salt (mass/area/time), D the molecular diffusion coefficient (area/time), C the concentration of salt (mass/volume) and X distance (length), has been used under various assumptions to describe the dissolution process and the subsequent increase in measured solution concentrations of dissolved species. This study investigated the applicability of two sets of assumptions in the description of the soil mineral dissolution process.

From Berner (1971), equation (1) can be rewritten with appropriate intermediate steps to describe the dissolution of a particle into a rapidly mixed solution. That is:

$$\frac{dC}{dt} = \frac{DA}{L} (C_s - C) \qquad (2)$$

where D is the diffusion coefficient ($cm^2\ sec^{-1}$), A the total surface area of the material undergoing dissolution per unit volume of water (cm^2), L the width of a stagnant boundary layer surrounding the particle and through which diffusion occurs (cm), C the concentration of the uniformly mixed bulk solution into which the particle is dissolving (mole cm^{-3}), and C_s the concentration at the surface of the particle which is assumed to be the equilibrium solubility (mole cm^{-3}). This equation therefore assumes that the mass of dissolving material is in large excess compared to the mass needed for saturation, a fundamental assumption making possible the straightforward integration presented below.

The simplest application of equation (2) requires an isothermal closed system with the solid present in considerable excess of that required to saturate the solution. Integration of equation (2) with appropriate boundary conditions gives

$$\log\left(1 - \frac{C}{C_s}\right) = -k\, t/2.3 \qquad (3)$$

where k = DA/L. A plot of $-\log\left(1 - \frac{C}{C_s}\right)$ vs. t should produce a line with a slope of k/2.3 if dissolution is a simple diffusion controlled reaction.

It is also possible to consider concentration as being time and distance dependent upon diffusion across the boundary layer L. That is, mixing in the bulk solution is not proceeding so rapidly that there is no net change in the mass of dissolving material delivered to the edge of the boundary layer. In such cases the flux of material and its concentration in the bulk solution become both time and space dependent upon diffusion within the boundary layer. Fick's second law of diffusion

$$\frac{\partial C}{\partial t} = D\,\frac{\partial^2 C}{\partial X^2} \qquad (4)$$

may then be used to describe the rate of transfer of material across the distance X where $0 < X < L$ and ultimately the rate of change of the concentration of the bulk solution. The solution to equation (4) for the correct boundary conditions is given by Crank (1957) as

$$C = C_2 \left(1 - \text{erf} \left[\frac{X}{2\sqrt{Dt}}\right]\right) . \qquad (5)$$

If the appropriate differentiation and integration are performed, then the mass M_t of diffusing substance having left the outer edge of the boundary layer and entering the bulk solution is given by

$$M_t = 2\ C_s \sqrt{\frac{Dt}{\pi}} . \qquad (6)$$

Or alternatively

$$M_t = k' \sqrt{t}$$

where

$$k_2'' = 2\ C_s \sqrt{D/\pi} .$$

Since the cumulative mass M_t dissolved is directly proportional to the concentration of the bulk solution, it may be further stated that

$$C = k' \sqrt{t} \qquad (7)$$

where k' is a new constant including k'' and additional factors relating concentration to mass. Thus, a plot of C vs. $\sqrt{t}$ should produce a line with a slope equal to k'.

MATERIALS AND METHODS

A composite sample was taken of the surface soil (0-8 cm) within a wildland micro watershed study site area in the Price River Basin located in east central Utah. The study site was in a region which has an annual precipitation of about 200 mm. The soil is derived from Mancos shale and is a member of the clayey, mixed calcareous, mesic, shallow family of Typic Torriorthent.

The soil was air dried and one half of the sample was passed through a 2 mm sieve; this fraction is referred to as natural soil. The other half of the sample was sieved into its size fractions of > 1 mm and > 0.25 mm. A ten gram sample of each size fraction and natural soil was placed in a 125 ml Erlenmeyer flask and distilled water added to obtain a given soil-water ratio. The suspensions were shaken in a water bath maintained at 25 ± 1C. At various time intervals the suspensions were vacuum filtered using GF/A glass fiber filter paper. The electrical conductivity (EC) of the filtrates was measured using a Beckman model RC 19 conductivity meter incorporating a pipette solution cell. The rate of dissolution was measured during a time period of approximately 2 seconds to 4320 minutes (72 hours). The reaction time was recorded as the time span between water addition to the soil and start of suspension filtration. The dissolution reaction was allowed to proceed for 7 to 9 days to attain the apparent equilibrium solubility data. The apparent equilibrium EC on the 1:1 soil-water extract of the natural soil was 2310 μmhos/cm where for the larger size fractions it was about 2520 μmhos/cm. In all cases, electrical conductivity (EC) was assumed to be proportional to solubility. The data presented represent the average of 2 replications.

RESULTS AND DISCUSSION

The salt release data for a Mancos shale derived soil plotted as a first order reaction (equation 3) are shown in Figures V-1, V-2, and V-3. These data (1:1 soil-water ratio) show that during the initial 72 hours of reaction, dissolution can be described by three, diffusion controlled, first order reactions. The first reaction (Figure V-1) was rapid and was completed during the initial 0.5 minutes of contact with water. The specific rate constant, calculated from the slope of the line was 0.68 min^{-1}. Figure V-2 shows that a considerably slower reaction, $k_2 = 0.8 \times 10^{-3}$ min^{-1}, occurred between 0.5 to 480 minutes. This was followed by a still slower reaction (Figure V-3), $k_3 = 0.48 \times 10^{-4} min^{-1}$, in the time span of 480 to 4320 minutes (8 to 72 hours). Since the information that can be obtained from empirically derived rate constants is limited one can only speculate as to the reactions which result in the three dissolution stages which were noted during the 72 hours of reaction.

It is important to note that the curves in Figures V-1 and V-3 result from assuming that C_s is a equilibrium concentration value which is reached instantaneously at any given mineral-liquid interface. In a multiple solid phase system, as the soil, it is reasonable to assume that each mineral phase has a unique C_s value which depends on its chemical composition. Thus the three dissolution stages represent various reaction time spans each of which is dominated by a different mineral specie type. It is realized that upon contact with water all

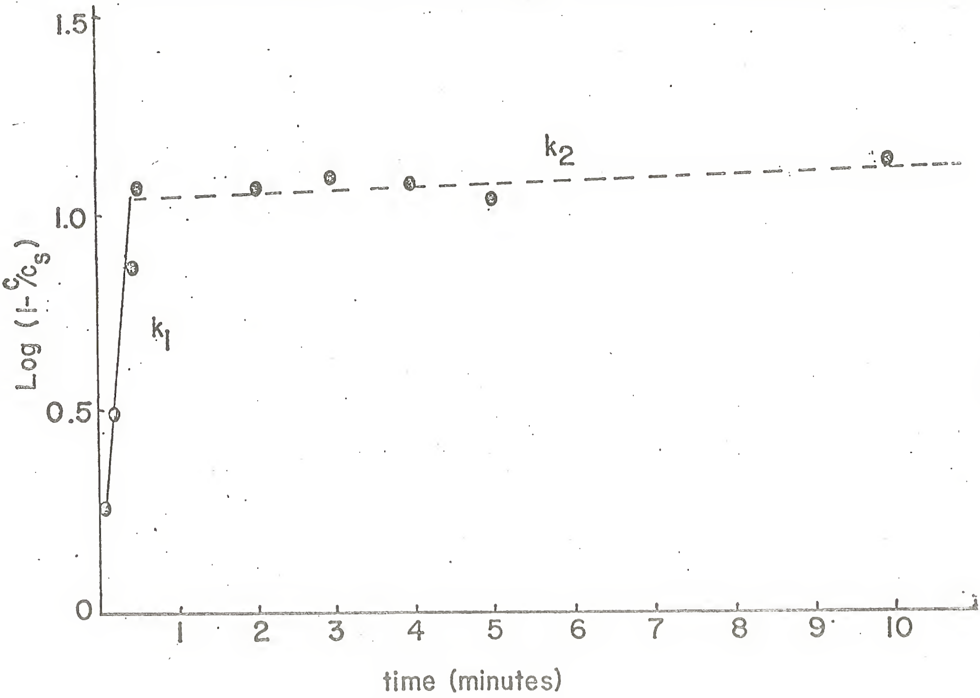


Figure V-1. Salt release data, plotted according to equation 3, showing the first dissolution reaction and the onset of the second dissolution reaction at T = 25C.

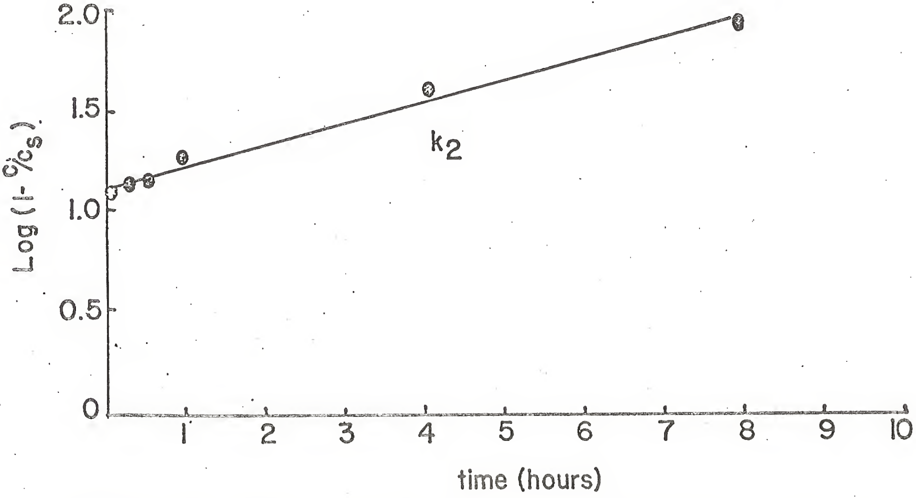


Figure V-2. Salt release data, plotted according to equation 3, showing the extent of the second dissolution reaction at T = 25C.

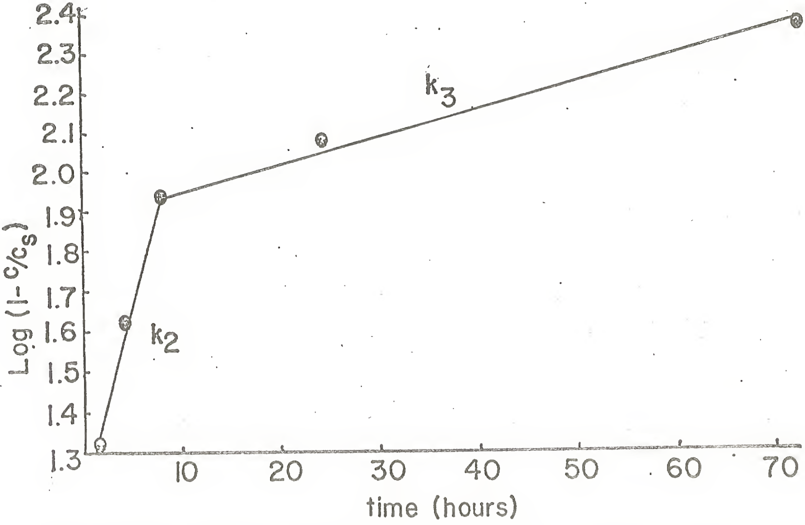


Figure V-3. Salt release data, plotted according to equation 3, showing the relation between the second and third dissolution reaction at T = 25C.

dissolution reactions necessarily proceed simultaneously. One can speculate that the initial rapid dissolution reaction indicates the presence of finely divided, highly soluble salts such as NaCl, Na_2SO_4, etc. When this reaction is complete, the relatively slow dissolving salts as $CaSO_4 \cdot 2H_2O$ (gypsum) and $CaCO_3$ dominate the dissolution reaction as shown by the marked decrease in the specific rate constant. The slowest dissolution reaction in the system is considered to be the hydrolysis of constituent primary silicate minerals which can account for the slow release of ions over the time period of the study (Busenberg and Clemency, 1976). Initial analyses indicated that the soil used in this study contained both gypsum and $CaCO_3$.

The same data, plotted according to equation (7), is shown in Figure V-4. As previously noted, 3 reactions were observed but the definition of the two slower reactions is noticeably less distinct than when the data were plotted according to equation (3). The values for k_1', k_2' and k_3' were calculated to be 1580, 8.3 and 0.37 μhmos $min^{-1/2}$, respectively.

The use of an expression of the general form $C = k' \, t^{1/n}$ (equation 7) has been reported previously but primarily applied to the dissolution or desorption of soil phosphate (Cook, 1966; Evans and Jurinak, 1975; Olsen, 1975; and Kuo and Lotse, 1973). Equation (7), with n = 2, was used to define soil phosphate release by both Cook (1966) and Evans and Jurinak (1975). Olsen (1975) used a value of n = 3 for the release of soil phosphate into an EDTA extracting solution while Kuo and Lotse (1973) found a variable n value depending on the mineral surface desorbing phosphate. The dissolution kinetic study of feldspars in the presence of CO_2, by Bushenberg and Clemency (1976) is of interest.

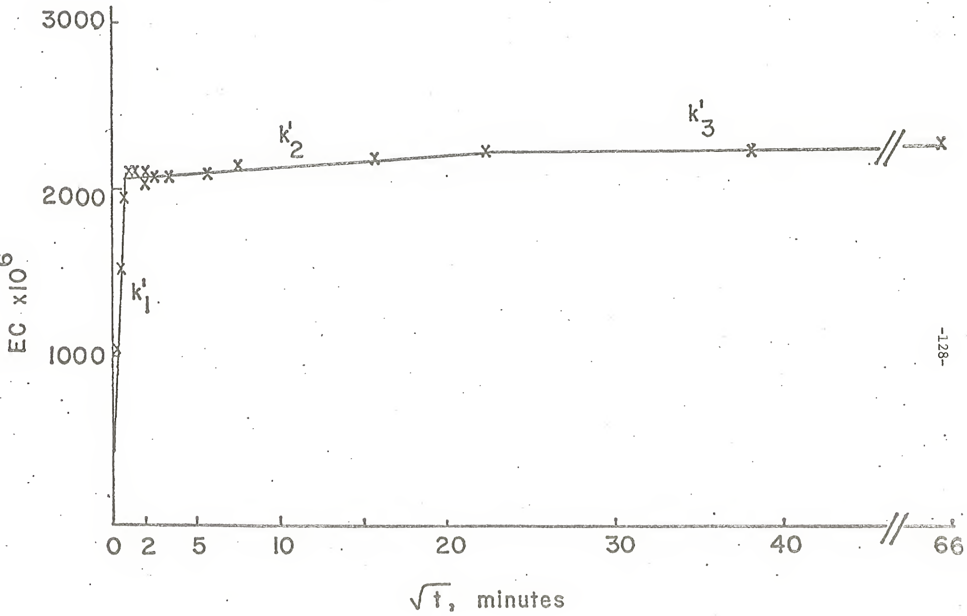


Figure V-4. Salt release data, plotted according to equation 7, showing the three dissolution reactions at T = 25C.

Their data indicated that after an initial fast reaction lasting approximately one minute, a second slower dissolution reaction occurred which could be described by $C = k\ t^{1/2}$ where C is the concentration of cations released into the solution and t is time. The value of k was a function of the feldspar mineral and the cations released. Four distinct dissolution stages (reactions) were noted in their study. The second dissolution stage had a duration of up to 4 days depending on the mineral studies.

The effect of the mean particle size (surface area) on the rates of dissolution (1:1 soil-water ratio) is shown in Figure V-5 where percent equilibrium is plotted vs. $t^{1/2}$. Figure V-5 shows that the three dissolution stages are a consistent phenomena even when the relative rates of reaction are considerably different. As expected the larger particles release salt at a slower rate and the approach to apparent equilibrium required considerable time.

Figure V-6 shows the affect of various soil-water ratios on the kinetics of dissolution of salt from the natural soil. It is noted that although three diffusion controlled dissolution reactions are evident, the plots are considerably different from those shown for the natural soil (1:1 soil-water ratio) in Figure V-5. The apparent equilibrium EC values for the 1:10 and 1:50 soil-water ratios were 2400 μmhos/cm and 1600 μmhos/cm, respectively. The equilibrium EC values reached in the 1:1 and 1:10 soil-water systems suggests that gypsum had a predominate role in the soil studied. The equilibrium EC value (1600 μmhos/cm) reached by the 1:50 soil-water ratio system indicated all the gypsum had dissolved and dilution had occurred. The kinetics of dissolution in the high soil-water ratio systems is

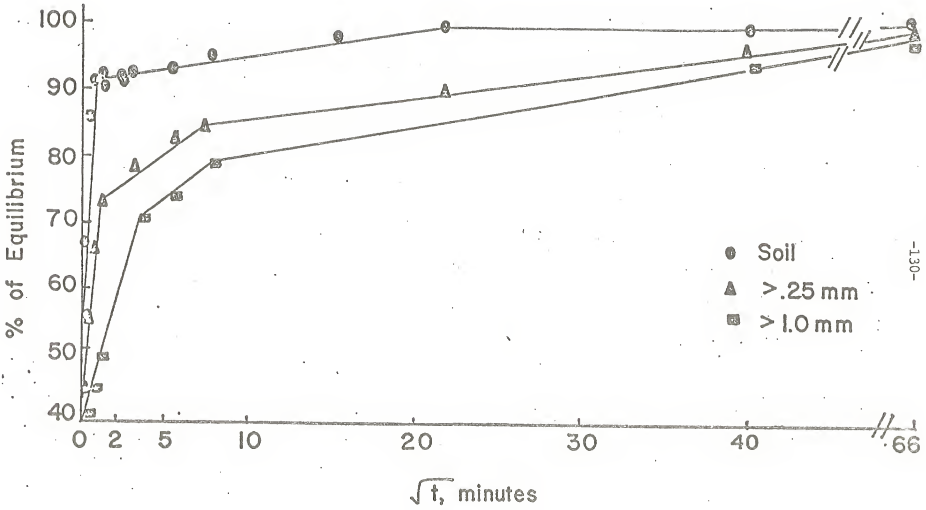


Figure V-5. The effect of particle size on salt release from a Mancos shale derived soil at T = 25C.

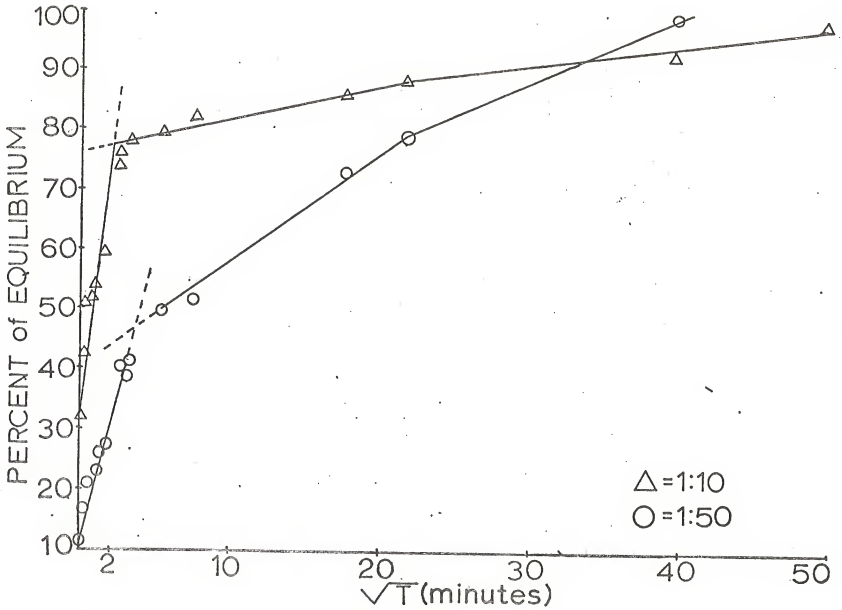


Figure V-6. Effect of dilution upon the dissolution rate of a Mancos shale derived soil at 25C.

considered to represent the situation when water moves through the soil matrix. Decreasing the soil-water ratio (e.g. 1:50) is considered to represent a system where the soil essentially acts as suspended stream sediment. The data of Figure V-6 show that indeed, the release of salt from suspended sediments is not an instantaneous process.

Conclusions--Kinetics of Salt Release

The data from this study show that two equivalent expressions both describe a series of diffusion controlled dissolution reactions which can be used to define the kinetics of soil mineral dissolution. The number and extent of the various dissolution stages exhibited by a given soil can be expected to reflect the mineral composition of the system. The data show that, in unweathered soils, the release of salt into the soil solution is a slow continuous process after the initial pulse of highly soluble salt moves through the profile. The same general statement can be made of the simulated sediment system.

These kinetic studies have direct application. The pulse effect noted in the salt loading from ephemeral streams, micro channels and overland flow all reflect the initial fast release of salt observed in this study. The decay in salt loading, with time, during a given event can represent the slower dissolution stages of salt from the soil or sediments upon continual contact with water. The simple relation, $C = k' \sqrt{t}$, found to define the dissolution processes makes possible the inclusion of a kinetic term in modeling salt release from natural saline systems. In addition, this finds an appropriate place in both the quality of irrigation return flow and hydro salinity stream modeling. Studies are currently under progress to incorporate the salt release parameter in existing salinity management models.

SALT PRODUCTION STUDIES

Using the same Mancos shale derived surface soil as used in the kinetics of dissolution study, a salt release curve was obtained from a laboratory column study. A soil column was made from 10 grams of natural air-dried soil and an equal amount of silica sand to promote water percolation. A constant head mechanism controlled the flow rate of distilled water in the column at 5 ml per hour. An automatic fraction collector was used to collect the effluent which was analyzed for electrical conductivity.

Figure V-7 shows the salt release curve obtained. The initial effluent had an EC of about 2350 μmhos/cm whereas final effluent reached a relatively stable EC of about 300 μmhos/cm. The two plateaus, noted in Figure 7, indicate the region where gypsum dissolution dominates the effluent EC (2000 μmhos/cm) and where $CaCO_3$ dissolution dominates the effluent EC (450 μmhos/cm). The EC of 300 μhmos/cm is assumed to represent the slow weathering of primary silicate minerals in the soil.

The data from Figure 7 allows the estimation of the total indigenous salt content of a typical Mancos shale surface soil. The relationship used for the calculation is (Richards, 1954)

$$[EC \times 10^3]640 = \text{ppm salt } (\mu g/ml) \qquad (8)$$

In a system saturated with gypsum about 30 percent of the ions in solution occur as uncharged $CaSO_4^o$ ion pair (Tanji, 1969) thus they are not included in the EC measurement of the solution. Equation (8) is modified to take this into account and becomes

$$[EC \times 10^3]832 = \text{ppm salt } (\mu g/ml) \qquad (9)$$

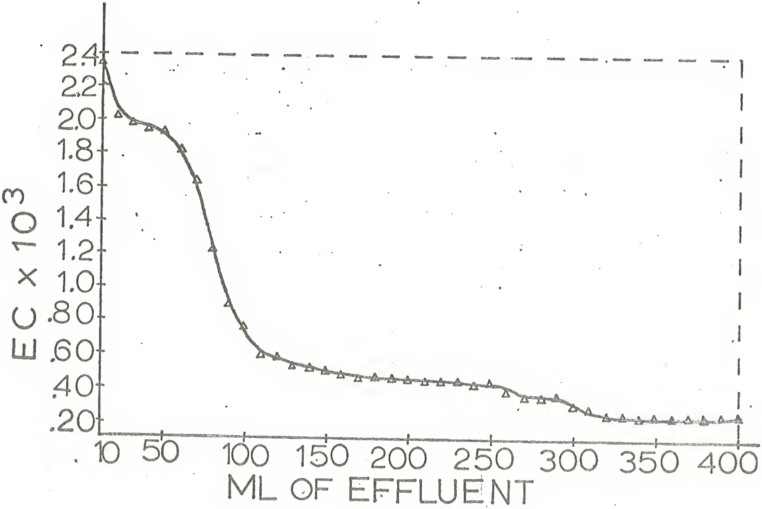


Figure-V-7. Salt release curve of a composite surface sample of a Mancos derived soil at 25C.

where the factor 832 is obtained from 1.30(640).

Both equat-ons (8) and (9) are used in calculating the total salt release of the soil sample. The method used is based on the integrated area under the salt release curve (Figure V-7). The method is initially calibrated by determining the mass (weight) of graph paper that represents a known quantity of salt. For example, assuming the initial 60 ml of column effluent is saturated with gypsum and about 340 ml of effluent was gypsum free then for the initial 400 ml amount of effluent using equations (a) and (b)

$$(832)(2.35)(60\ \text{ml}) + (640)(2.35)(340\ \text{ml}) = 6.3 \times 10^5\ \mu\text{g of salt}$$

where 2.35 is the EC in mmhos/cm. The area under the curve represented by the dashed lines in Figure 7 therefore represents 6.3×10^5 μg of salt. The area, enclosed by the dashed lines, was correlated to a mass of graph paper by cutting out the appropriate figure and weighing the cut-out on an analytical balance. In this case, 6.3×10^5 μg of salt was represented by 1534 mg of graph paper. Next, the experimental salt release curve shown in Figure 7 was cut out and weighed. The salt release curve for 10 gms of soil was represented by a mass of 468 mg of graph paper. To estimate the μg of salt released from the 10 grams of soil the relation used was

$$\text{salt released} = \frac{(468\ \text{mg})(6.3 \times 10^5\ \mu\text{g})}{1534\ \text{mg}} = 1.9 \times 10^5\ \mu\text{g} = 190\ \text{mg}$$

The 10 g sample of soil contained 190 mg of salt or, in other words, the soil has a 1.9 percent salt content. Assuming a hectare-15 cm weighs 2.24×10^6 kg, the top 3 cm of this soil will release 8.5×10^3 kg or 8.3 M tons of salt per hectare (about 3.2 tons/acre-inch of soil). The value calculated as the salt producing potential of a representative Mancos shale derived soil is considered a reasonable first approximation and emphasizes the importance of this type of soil as a source of salinity in the Price River Basin. The calculations do not include the slow baseline weathering which continues after the $CaCO_3$ is removed by leaching.

VI. IMPACT OF VARIOUS RANGE IMPROVEMENT PRACTICES ON ANNUAL PRODUCTION, COVER, AND SOIL PROFILE SALT CONCENTRATIONS

Gerald F. Gifford
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Various range improvement practices (chaining, plowing, railing, pitting, contour furrowing, gully plugs) have been used in the past to "restore" various aspects of productivity to a multitude of rangeland landscapes. However, little thought has been given as to how such activity might impact potential salt yields from these same sites. Certainly any impact on hydrologic processes which control both surface and subsurface runoff would conceivably have some impact on potential salt yield. Examples would include increases or decreases in either production or cover due to treatment practices.

The objective of this portion of the total research project was to determine the impact of various range improvement practices located in Utah, Colorado, New Mexico, and Arizona on annual production, cover, and soil profile salt concentrations.

GENERAL DESCRIPTION OF STUDY AREA

The various study sites are located primarily in Utah, Colorado, and New Mexico, with one site in Arizona (Figures VI-1, VI-2, VI-3). The range improvement practices studied include contour furrowing, pitting, pinyon-juniper chaining, gully plugs, and various mechanical sagebrush control treatments. The sites in Utah lie primarily in Grand, Emery, Carbon, and San Juan counties; in Colorado, Montrose, Gunnison, Dolores, and San Miguel counties; in New Mexico, Valencia, Sandoval, Rio Arriba, and San Juan counties; and Maricopa county in Arizona.

The highest point among the sites in 2438m. (8000 ft) above sea level in San Juan county in Utah, and the lowest is 396m. (3519 ft) in Maricopa county in Arizona (Table VI-1). The Canyonlands country, located in the Colorado plateau province, is characterized by many deep, rugged canyons through which flows the Colorado River. The major part of the area is composed of tablelands, or mesas, and the topography is undulatings to gently rolling. In Colorado and New Mexico the terrain is most gentle, and the sites are located mainly on recent alluvium and alluvial fans. Generally pinyon-juniper chaining practices are located at higher elevations in rougher terrains than most of the other improvement practices. The mean annual temperature among the various sites ranges from 9.4°C (49°F)to 11.6°C (53° F). Most of the sites, except those at a higher elevation, have a mesic soil temperature regime. The higher elevation sites are considered frigid.

Precipitation varies markedly among the sites, with the average annual precipitation varying from seven inches in continental and semi-arid areas to almost 30 inches in dry subhumid climate regions (Table VI-1.) The climate

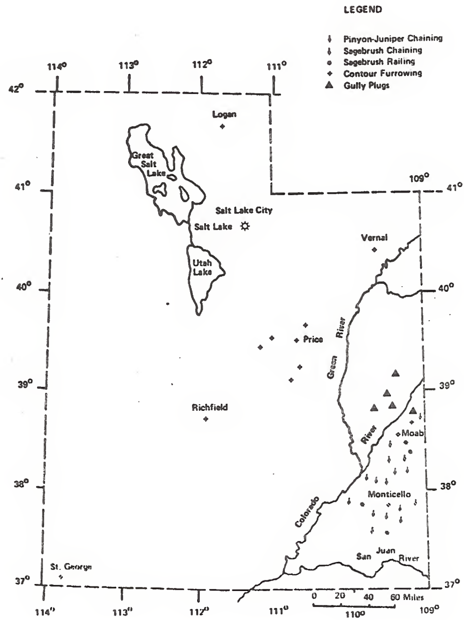


Figure VI-1. Map of Utah showing location of treatment sites.

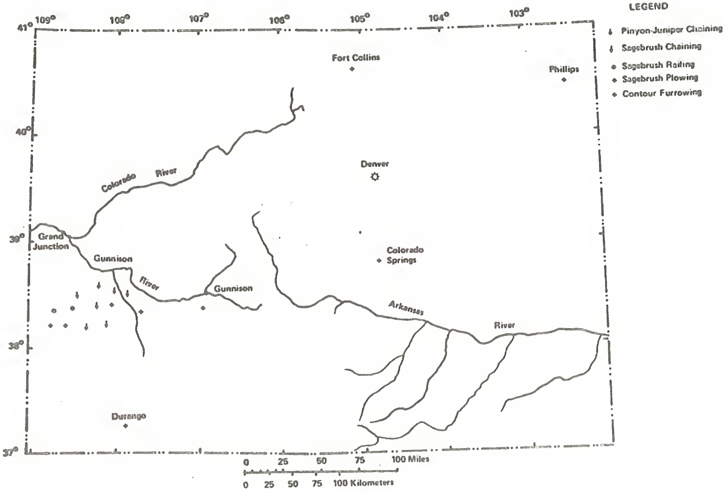


Figure VI-2. Map of Colorado showing location of treatment sites.

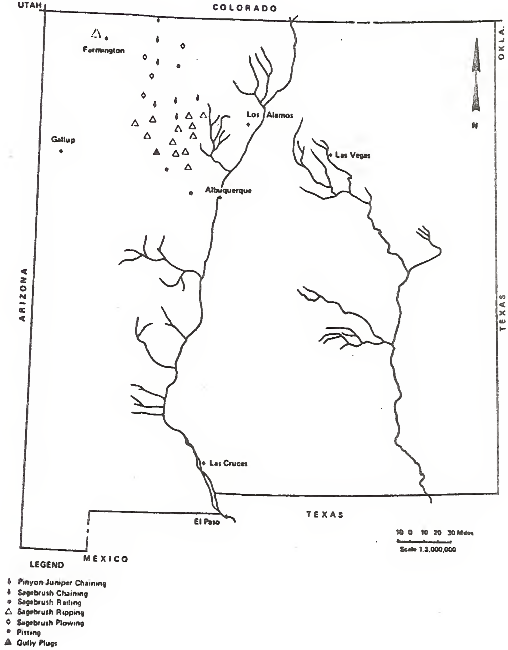


Figure VI-3. Map of New Mexico showing location of treatment sites.

is characterized by cold winters and relatively hot and dry summers, with the highest rainfall in August, September, and October, and lowest during May and June. Much of the precipitation in summer falls as showers and moisture is rapidly evaporated or transpired.

Parent materials in the study areas vary among the sites. Most of the soils on the gully plug sites and also on a few contour furrow sites have formed on parent materials derived from soft shale and sandstone of cretaceous and early Tertiary ages called the Mancos formation (Wilson, 1975). Other sources of parent materials include a brown mantle of eolian sediments, calcareous sandstones, glacial tills, hardshales, and recent or old alluvial deposits. The genesis of soil among the sites is related to climate, vegetation, parent material, topography, and time. Soil of high elevations (Mollisols, Alfisols) are commonly leached, well developed, and acid in reaction. This is due to higher precipitation, lower temperature, and coniferous type trees. On sites where annual rainfall is lower, leaching of carbonates from the soil is not well developed (Aridisols), and there has been little translocation of clay in the profile (Wilson 1975). Table 2 shows the classification of soils on all treatment sites.

Vegetative characteristics of the sites vary with elevation, amount of precipitation, seasonal distribution, of moisture, and soil characteristics. In general principal native plant communities in the lower valleys, plains, mesas, and plateaus, where the climate is semi-arid and average annual precipitation is low, are dominated by grasses, shrubs, and forbs. Species such as mat saltbush (Atriplex corrugata), nuttal saltbush (Atriplex nuttallii), fourwing saltbush (Atriplex canescens), shadscale (Atriplex confertifolia), greasewood (Sarcobatus vermiculatus), indian ricegrass (Oryzopsis hymenoides), and galleta (Hilaria jamesii) are most dominant in saline soil sites. However, on sites with less salt, true mountain mahogany (Cercocarpus montanus), bitterbrush (Purshia tridentata), gamble oak (Quercus gambelii), serviceberry (Amelanchier alnifolius), rabbitbrush (Chrysothamnus viscidiflorus), snake weed (Xanthocephalum sarothrae), big sagebrush (Artemisia tridentata), alkali sacaton (Sporobolus airoides), sand dropseed (Sporobolus cryptandrus), blue grama (Bouteloua gracilis) are found. In higher elevations pinyon-pine (Pinus edulis) and Utah juniper (Juniperus osteosperma) are the dominant species which are found mainly on mountain slopes, plateaus, and foothills terraces on shallow and stony areas where the climate is dry-subhumid or moist-subhumid.

During the period of 1945 to 1970 (Table VI-1), conversion of "undesirable plants" to desirable grasses was attempted on the study sites. The purpose of the conversion was to improve range condition through increasing soil moisture, grazing capacity, and nutritional value of forage. Crested wheatgrass (Agropyron cristatum), tall wheatgrass (Agropyron elongatum), western wheatgrass (Agropyron smithii), russian wildrye (Elymus juncus), side-oats grama (Bouteloua curtipendula), alkali sacton (Sporobolus airoides), sand dropseed (Sporobolus cryptandrus), sweet clover (Mellilotous officinalis), and fourwing saltbush (Atriplex canescens) are the main species which were seeded on the site.

Table VI-1. Elevation, precipitation, and treatment date for various range improvement practices.

Type of Treatment	Job Number	Elevation (m)	Precipitation (mm)	Completed Date (Year)	General Location
Contour Furrowing					
	0535	2438	305	1962	West Central CO
	0871	1768	356	1963	West Central CO
	Joe's Valley*	2438	762	1963	East Central UT
	Joe's Valley*	2438	762	1948	East Central UT
	1208	1768	356	1965	West Central CO
	4010	1838	356	1966	East Central UT
	3519	396	178	1969	Central AZ
	1034	2073	229	1964	West Central CO
	1489	1737	203	1968	East Central UT
	2517	1707	203	1969	East Central UT
	1453	1707	229	1967	East Central UT
Pitting					
	2594	1829	254	1958	Northwestern NM
	2420	1829	254	1975	Northwestern NM
Pinyon-Juniper chaining					
	0689	2316	508	1961	Southeastern UT
	0741	1768	356	1960	Southeastern UT
	0759	2195	356	1960	Southeastern UT
	0005	1829	356	1961	Southeastern UT
	0049	2316	406	1962	Southeastern UT
	0285	1768	356	1962	West Central CO
	0313	2073	330	1964	Southeastern UT
	1124	2195	406	1964	West Central CO
	1148	2073	356	1965	West Central CO
	4030	2073	305	1968	East Central UT
	0082**	2012	356	1968	Northwestern NM
	3512	2134	356	1969	Southeastern UT
	4011	2012	203	1970	Southeastern UT
	4147	1999	279	1971	West Central CO
Gully plugs					
	0654	1280	203	1960	East Central UT
	0045	1280	203	1963	East Central UT
	4010	1838	356	1966	East Central UT
	0127	1280	203	1964	East Central UT
	0021	1280	203	1962	East Central UT
	1624	1890	254	1963	Northwestern NM

Table VI-1. Continued

Type of Treatment	Job Number	Elevation (m)	Precipitation (mm)	Completed date (Year)	General Location
Sagebrush Ripping					
	2402	1859	254	1957	Northwestern NM
	2511	1829	254	1958	Northwestern NM
	2582	2054	406	1958	Northwestern NM
	0079**	1829	254	1959	Northwestern NM
	0022	1859	254	1960	Northwestern NM
	0776	1890	279	1961	Northwestern NM
	1671	1920	305	1963	Northwestern NM
	1284	2042	406	1963	Northwestern NM
	2721	1859	254	1965	Northwestern NM
	2538	2103	305	1965	Northwestern NM
	1774	1615	203	1965	Northwestern NM
	2836	1859	406	1967	Northwestern NM
	3518	1920	305	1969	Northwestern NM
Sagebrush Plowing					
	0382	2347	305	1945	West Central CO
	0932	2012	279	1954	Northwestern NM
	0001	2073	279	1960	Northwestern NM
	0689	1981	356	1961	Northwestern NM
	1120	2134	305	1962	Northwestern NM
Sagebrush Chaining					
	0504	2408	305	1948	West Central CO
	0498	2073	356	1949	East Central UT
	0546	2012	330	1951	Southeastern UT
	0655	1971	279	1956	Southeastern UT
	0048	2073	203	1960	West Central UT
	0010	2073	279	1961	East Central UT
	0080**	2195	406	1962	Northwestern NM
	0232	2042	279	1962	Northwestern NM
	0081**	2195	406	1964	Northwestern NM
	2537	2073	305	1965	Northwestern NM
	0499	2012	305	1966	East Central UT
	4030	2073	305	1966	East Central UT
	4010	1838	356	1966	East Central UT
	0083**	2073	305	1970	Northwestern NM
	0598	1951	356	1951	Northwestern NM
Sagebrush Railing					
	0480	2134	305	1950	East Central UT
	0552	2438	508	1952	Southeastern UT
	0659	1888	305	1955	Southeastern UT
	4240	2134	305	1956	East Central UT
	1033	2134	330	1958	West Central CO

Table VI-1. Continued

Type of Treatment	Job Number	Elevation (m)	Precipitation (mm)	Completed Date (Year)	General Location
Sagebrush Railing					
	0283	2012	356	1961	West Central CO
	0800	2073	279	1962	Northwestern NM

* - Improvement practices have been accomplished by USDA Forest Service

** - Job number is arbitrary.

Table 2. Soil Classification of the study sites.

Job Number	Family	Subgroup	Order
0535	Coarse-loamy, skeletal, mixed	Typic Cryoboralfs	Alfisols
0871	Fine, mixed, mesic	Ustic Torriorthents	Entisols
Joe's Valley	Fine, mixed, frigid	Typic Argiborolls	Mollisols
Joe's Valley	Fine, mixed, frigid	Typic Ustifluvents	Entisols
1208	Fine-loamy, mixed, mesic	Ustic Torrifluvents	Entisols
4010	Fine-loamy, mixed, mesic	Ustic Torriorthents	Entisols
3519	Coarse-loamy, mixed, thermic	Typic Calciorthids	Aridisols
1034	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
1489	Fine, mixed, mesic, shallow	Typic Torriorthents	Entisols
2517	Fine, mixed, mesic, shallow	Typic Torriorthents	Entisols
1453	Fine, mixed, mesic, shallow	Typic Torriorthents	Entisols
2594	Fine, mixed, mesic	Typic Torriorthents	Entisols
2420	Sandy, mixed, mesic	Typic Torrifluvents	Entisols
0689	Fine-loamy, mixed, mesic	Typic Argiustolls	Mollisols
0741	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0759	Fine-loamy, mixed, mesic	Aridic Haplustolls	Mollisols
0005	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0049	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0285	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0313	Fine-loamy, mixed, mesic	Typic Calciorthids	Aridisols
1124	Loamy-skeletal, mixed, mesic	Ustollic Calciorthids	Aridisols
1148	Fine-loamy, mixed, mesic	Aridic Argiborolls	Mollisols
4030	Coarse-loamy, mixed, mesic	Typic Calciorthids	Aridisols
0082	Fine-loamy, mixed, mesic	Typic Argiustolls	Mollisols
3512	Fine-loamy, mixed, mesic	Typic Haplustolls	Mollisols
4011	Fine, mixed, mesic, shallow	Typic Argiustolls	Mollisols
4147	Fine-loamy, mixed, mesic, shallow	Ustollic Haplargids	Aridisols
0654	Fine, mixed, mesic, shallow	Typic Torriorthents	Entisols
0045	Fine-loamy, mixed, mesic, shallow	Typic Torriorthents	Entisols
4010	Fine-loamy, mixed, mesic	Ustic Torriorthents	Entisols
0127	Fine-loamy, mixed, mesic, shallow	Typic Torriorthents	Entisols
0021	Fine-loamy, mixed, mesic, shallow	Typic Torriorthents	Entisols
1624	Fine-loamy, mixed, mesic	Ustic Torrifluvents	Entisols
2402	Fine, mixed, mesic	Ustic Torriorthents	Entisols
2511	Fine-loamy, mixed, mesic	Typic Camborthids	Aridisols
2582	Fine-loamy, mixed, mesic	Ustic Torriorthents	Entisols
0079	Mesic, coarse-loamy, montmorillonitic	Typic Torrifluvents	Entisols
0022	Fine-loamy, mixed, mesic	Typic Camborthids	Aridisols
0776	Fine-loamy, mixed, mesic, hallow	Typic Torriorthents	Entisols
1671	Fine-loamy, mixed, mesic	Ustic Haplargids	Aridisols
1284	Fine-silty, mixed, mesic	Ustic Torrifluvents	Entisols
2721	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
2538	Fine, montmorillonitic, mesic	Ustic Torriorthents	Entisols
1774	Fine-loamy, mixed, mesic	Typic Torrifluvents	Entisols
2836	Fine, mixed, mesic	Ustic Torriorthents	Entisols
3518	Fine-loamy, mixed (Calcareous), mesic, shallow	Ustic Torriorthents	Entisols

Table 2. Continued

Job Number	Family	Subgroup	Order
0382	Fine-loamy, mixed, mesic	Calcic Argiustolls	Mollisols
0932	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0001	Coarse-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0689	Fine-loamy, mixed, mesic	Typic Argiustolls	Mollisols
1120	Fine-loamy, mixed, mesic	Typic Haploborolls	Mollisols
0504	Fine-loamy-skeletal, mixed, mesic	Ustollic Haplargids	Aridisols
0498	Sandy, mixed, mesic	Ustic Torrifluvents	Entisols
0546	Fine-loamy, mixed, mesic	Lethic Argiustolls	Mollisols
0655	Fine-loamy, mixed, mesic	Typic Calciorthids	Aridisols
0048	Fine-loamy-skeletal, mixed, mesic	Lithic Ustollic Haplargids	Aridisols
0010	Coarse-loamy, mixed, mesic	Ustic Torriorthents	Entisols
0080	Fine-loamy, mixed mesic	Borollic Haplargids	Aridisols
0232	Fine-loamy, mixed, mesic	Typic Haplargids	Aridisols
0081	Fine-loamy, mixed, frigid	Typic Ustifluvents	Entisols
2537	Fine-loamy, mixed, frigid	Ustic Torriorthents	Entisols
0499	Fine-loamy, mixed, mesic	Typic Calciorthids	Aridisols
4030	Fine-loamy, mixed, mesic	Ustic Torriorthents	Entisols
4010	Fine-loamy, mixed, mesic	Ustic Torriorthents	Entisols
0083	Coarse-loamy, mixed, frigid	Aridic Argiustolls	Mollisols
0598	Coarse-loamy, mixed, mesic	Typic Ustifluvents	Entisols
0480	Coarse-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0552	Coarse-loamy, mixed, mesic, eroded	Typic Argiustolls	Mollisols
0659	Coarse-loamy, mixed, mesic	Typic Calciorthids	Aridisols
4240	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
1033	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0283	Fine-loamy, mixed, mesic	Ustollic Haplargids	Aridisols
0800	Coarse-loamy, mixed, mesic	Ustollic Haplargids	Aridisols

METHODS AND PROCEDURE

This study was initiated in July, 1976. Job documentation reports and information from the appropriate Bureau of Land Management districts on age of various range improvement treatments, acreage involved, geographic location, and methods of applying treatments were used for determining the approximate number of sites to be sampled. Topographical maps were used to determine the general location of various sites, while field studies established the exact location of sampling sites. Specific criteria such as representativeness of the general area and predominant geologic type were considered in final site selections.

Field methods

A "treated" and nearby similar "untreated" sampling site, each with an area of approximately 23,409 m^2 (2.3 ha), were selected for each treatment location. Techniques outlined for measuring plant production and cover were the same for all sites throughout the study, but soil sampling procedures varied somewhat depending on the specific type of land treatments under consideration. All on-site measures and observations, including collection of soil samples, were taken only once at each site. Statistical evaluations are therefore limited to treated vs untreated comparisons within a given location rather than among all locations.

Soil sampling

Gully plugs

Soil sampling methods outlined below for gully plugs and contour furrows vary in sample size and sample location from other treatments included in this study. There were three replications for each gully plug treatment site, and in each replication soils from nine positions were sampled at the 0-0.5, 0.5-1, 1-7.5, and 7.5-17.5 cm soil depths. Soil samples at one position on each of the treated and untreated areas (regardless of treatment) were taken to greater depths (as often as possible at 7.5 cm increments) to allow for a more complete characterization of soil particle-size with depth. Within each gully plug replication there were two sampling positions termed "upper channel control," one position termed "lower channel control," two positions termed "upland control," and four positionsinside the gully plug basin (Figure VI-4.)

Contour furrows

Four line transects were established on a representative sampling site across each contour furrow treatment. Four positions were selected on each line: the first was on the upland area between the furrows, the second at the bottom of the furrow, the third on the spoil (ridge), and the fourth on lowland area between the furrows (Figure VI-4.).

Soil samples were taken at the same depths as those on gully plug sites.

Other range improvements

For the other range improvement practices such as pitting, pinyon-juniper chainings, and all selected sagebrush treatments, there were five replications (or sampling locations) for each treated and adjacent untreated site: one at each corner of the 2.3 ha sampling site and another in the middle. Soil sampling procedures and depth increments were the same as those used for gully plug and contour furrow treatments.

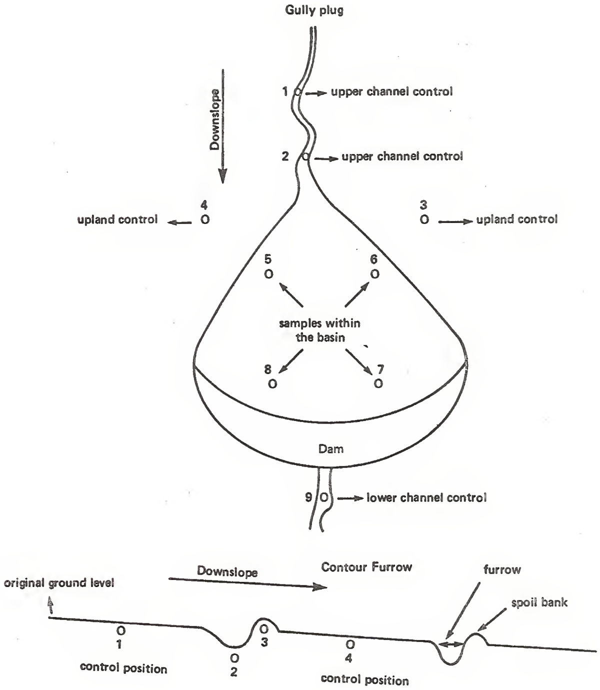


Figure VI-4. Plan view of gully plug and cross-section of contour furrow showing the sampling positions.

Soil classification

Soil at all sites was classified in the field according to procedures outlined in USDA handbook No. 436 (1975). The depth of sediment being trapped in the furrows and the gully plug basins was measured for all selected sites.

Production measurements

Current year's production (green weight estimates later converted to air-dry weight) on "treated" and nearby "untreated" sites was measured using a double-sampling technique modified after the weight estimate method (Pechanec 1937). Production was not determined on gully plug treatments. Samples were taken along transect lines using a circular 0.89 m^2 (9.6 ft^2) steel hoop at intervals of 18 m between plots. Twenty-five random plots were estimated on each area and every fifth plot (beginning with the first) was also clipped. Regression techniques were used to adjust all estimated plots. Production was not measured on heavily grazed sites.

Cover measurements

Canopy and ground cover (including litter and rock) of all species were measured on all sampling sites using the step-point method of sampling (Evans and Love 1957). Fifty points were read on each of 4 transects, for a total of 200 points. The mean cover percentage of the four transect lines on both treated and untreated portions of each treatment was then determined. Cover measurements were not taken on heavily grazed sites.

Laboratory methods

Soil analysis

Soil samples from all sampling sites were transported to the laboratory for electrical conductivity (EC) measurements and particle-size analysis. For the EC measures, extracts from a saturated soil paste (1:1 ratio; 100 gr. of soil and 100 cc water) were read using a Beckman Conductivity Bridge (Model RC-19). All conductivity data (in micromhos per centimeter) were converted to a standard reference temperature of 25°C (U.S.D.A., Handbook 60 1954).

Particle-size distribution was determined from soil samples taken from a single representative position on each treated and untreated site (see page under gully plugs) using the hydrometer method (Bouyoucos 1962).

Statistical analysis

All results from the field and laboratory analyses were analyzed using standard analysis of variance techniques on a per site basis. When analyzing EC data from the contour furrow treatments, values for control positions No. 1 and 4 (Figure VI-4.) were combined at similar depths on each transect line. There were therefore three positions, each with 4 depth increments.

For the gully plug treatment (Figure VI-4) EC values at similar depths at points 3 and 4 were pooled and EC measures inside the gully basin at sampling points No. 5, 6, 7, and 8 were also pooled for analysis. Data from the resulting five points were used in the statistical analysis. Significant differences among means for all analyses were determined using standard LSD procedures.

RESULTS AND DISCUSSION

Because of the large quantity of data obtained during the course of this study, it is impractical to include all the "raw" field results in this section. More details may be found in the thesis by Hessary (1977).

Impact of Range Improvements on Soil Profile Salt Distribution Patterns

Gully plugs

Salt accumulations in the soil profile were significantly different among sampling position on three out of six gully plug treatments (Figure VI-4). However, the significant differences showed no consistent trend. For instance, one site indicated higher salt concentrations in the upland control (position 3) than in the other positions. In another case, higher salt concentrations were indicated inside the gully basins (position 4) than in positions 1, 2, 3, and 5 (no signficant differences existed among these latter positions). On a third gully plug treatment, lower salt concentrations were found inside the gully basin (position 4) than at positions 1, 2, 3, and 5 with no signficant differences among the latter positions.

In four cases out of six salt distribution within the soil profile was significantly different among the depth increments. In two cases the two surface soil increments (depth 1 and 2) showed higher salt concentrations than the lower depths. The other two gully plug treatments had higher salt concentrations in the lower depths. In only one case was there a significant depth x position interaction.

Variations in salt concentration with different positions and soil depths were never consistent among the gully plug treatments. Soils on all gully plug treatments had fine-loamy texture and were classified as entisols (Table VI-2.)

Contour furrows

In three out of 11 contour furrow treatments salt concentrations were significantly different among the three sampling positions (see Figure 4). Two treatments had significantly higher salt concentrations inside the furrow (at position 2) while only one treatment had significantly higher salt concentrations outside the furrow (at position 1). For the three treatments there were few significant differences between ridge (spoil) and control (position 1), or spoil and furrow.

There were significant differences in salt concentrations as a function of soil depth on eight of the eleven contour furrow treatments. The general trend indicated higher salt concentrations in the two surface layers in nonsaline soils, with almost equal quantities of salt at the third and fourth depth increments. On saline soils the lower depths had higher salt concentrations than the two surface layers. There were few significant differences between the third and fourth depth.

Pittings

Analysis of variance for the two pitting treatments showed no consistent trend in salt concentration as a function of different soil depth increments.

Pinyon-juniper chainings

The impact of pinyon-juniper clearing treatments (chaining) on EC ratios (treated/untreated) at various soil depths as a function of soil texture is shown in Figure VI-5. On 3 of 14 pinyon-juniper sites salt accumulations were significantly lower in the surface 0.5 cm soil layer of treated sites. However, the only really consistent pattern at any soil depth was the lack of difference in salt concentrations between treated and untreated sites. Based on EC measures in surface soils (maximum EC value 675 mmhos/cm) and at greater depths (maximum EC value 445 mmhos/cm), salt concentrations should not be a major concern on pinyon-juniper sites such as those sampled in this study.

Sagebrush treatments

Figures VI-6, VI-7, VI-8, and VI-9, show EC ratios (treated/untreated) at various soil depths as a function of soil texture on chained, ripped, plowed, and railed sagebrush sites, respectively. For the most part there were few differences between treated and untreated sites, regardless of soil texture. Most of the significant increases in EC on treated sites (where they existed) were associated with a loam or more coarse-textured soil while clay loam and finer-textured soils seemed to be associated more with significant decreases in EC on treated sites. This pattern was not consistent, however. As with indicated salt concentrations on pinyon-juniper sites, EC values as measured on sagebrush sites in this study do not indicate a need for major concern as related to salt production within major river basins.

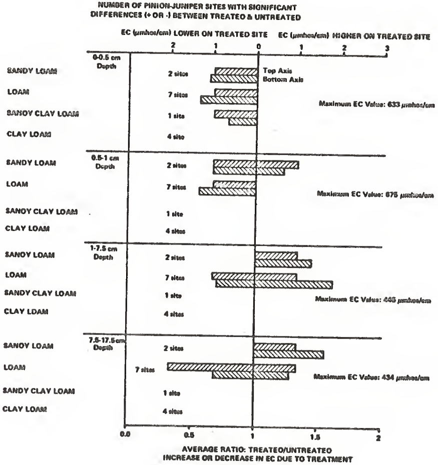


Figure VI-5. Impact of pinyon-juniper clearing treatments on electrical conductivity of soils at indicated depths. For each pair of bars, the top bar corresponds to the top axis and the lower bar corresponds to the bottom axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

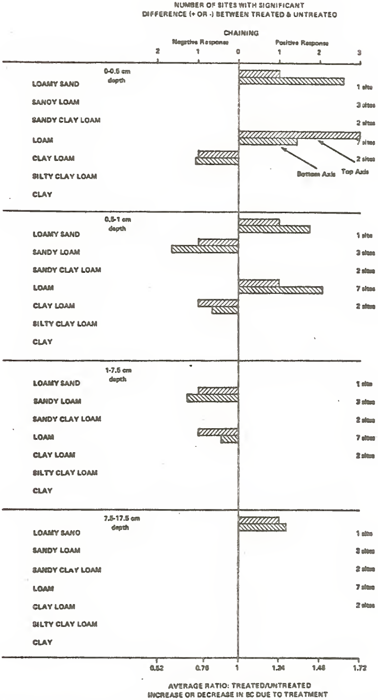


Figure VI-6. Impact of chaining treatments on various sagebrush sites on electrical conductivity of soils at indicated depths. For each pair of bars, the top bar corresponds to the top axis and the lower bar corresponds to the bottom axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

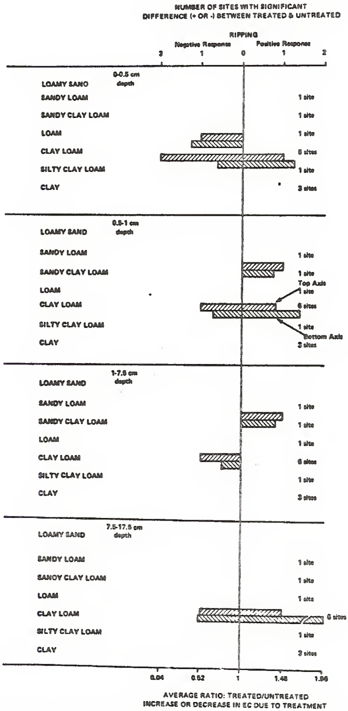


Figure VI-7. Impact of ripping treatments on various sagebrush sites on electrical conductivity of soils at indicated depths. For each pair of bars, the top bar corresponds to the top axis and the lower bar corresponds to the bottom axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

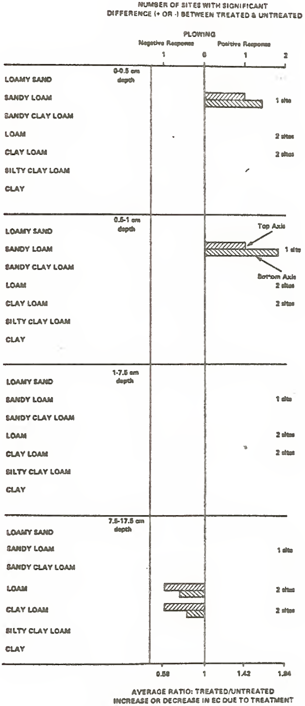


Figure VI-8. Impact of plowing treatments on various sagebrush sites on electrical conductivity of soils at indicated depths. For each pair of bars, the top bar corresponds to the top axis and the lower bar corresponds to the bottom axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

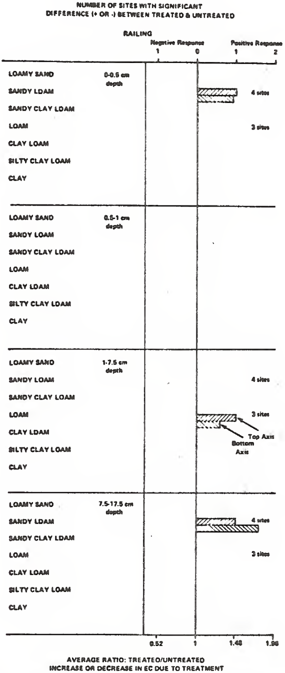


Figure VI-9. Impact of railing treatments on various sagebrush sites on electrical conductivity of soils at indicated depths. For each pair of bars, the top bar corresponds to the top axis and the lower bar corresponds to the bottom axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

Impact of Various Range Improvement Practices On Watershed Cover and Annual Production

Production measures

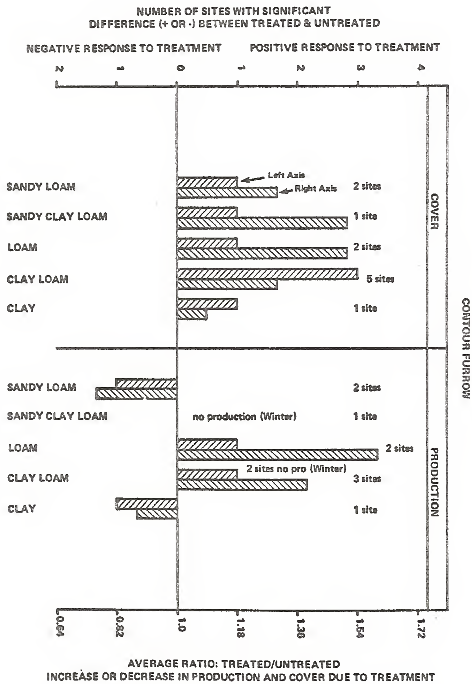
Contour furrowing. Figures VI-10, VI-11 indicate significant changes in annual production on various contour furrowing projects as a function of soil texture and soil type, respectively. From Figure VI-10 it is evident that a poor response to contour furrowing is generally associated with sandy loam and clay soils. In this study, no significant increases in production were noted on sites with soils in those textural classes. Increased production due to furrowing was measured on one site (out of two) on loam soils and on one site (out of three) on clay loam soils. There were no significant decreases in production as a result of contour furrowing on either the loam or clay loam soils.

From Figure IV-11 it is apparent that production on contour furrowing treatments is significantly increased on typic ustifluvents and ustollic haplargid soils. Annual production on contour furrow sites with typic cryoboralf and typic argiboroll soils was significantly decreased (one site each). No significant changes in annual production were measured on sites with other soil types.

Pinyon-juniper chaining. Figure IV-12 shows the impact of pinyon-juniper chaining on annual production as a function of soil texture. There was a significant increase in production on nearly all chained sites. The greatest increase in production was measured on sites with loam soils, followed closely by sites with sandy clay loam soils.

Figure VI-13 indicates that annual production was significantly increased across a variety of soil types. The greatest increase was on

Figure VI-10. Response of cover (vegetation, litter, rock) and production (all species) on various contour furrowing projects as a function of soil texture. For each pair of bars, the left bar corresponds to the left axis and the right bar sites where significant differences (P=0.1) occurred (either + or -).



NUMBER OF SITES WITH SIGNIFICANT
DIFFERENCE (+ OR -) BETWEEN TREATED & UNTREATED
NEGATIVE RESPONSE TO TREATMENT
POSITIVE RESPONSE TO TREATMENT
2
1
0
1
2
3
4
SANDY LOAM
SANDY CLAY LOAM
LOAM
CLAY LOAM
CLAY
Left Axis
Right Axis
2 sites
1 site
2 sites
5 sites
1 site
COVER
SANDY LOAM
SANDY CLAY LOAM
LOAM
CLAY LOAM
CLAY
no production (Winter)
2 sites no pro (Winter)
2 sites
1 site
2 sites
3 sites
1 site
PRODUCTION
CONTOUR FURROW
0.64
0.82
1.0
1.18
1.36
1.54
1.72
AVERAGE RATIO: TREATED/UNTREATED
INCREASE OR DECREASE IN PRODUCTION AND COVER DUE TO TREATMENT

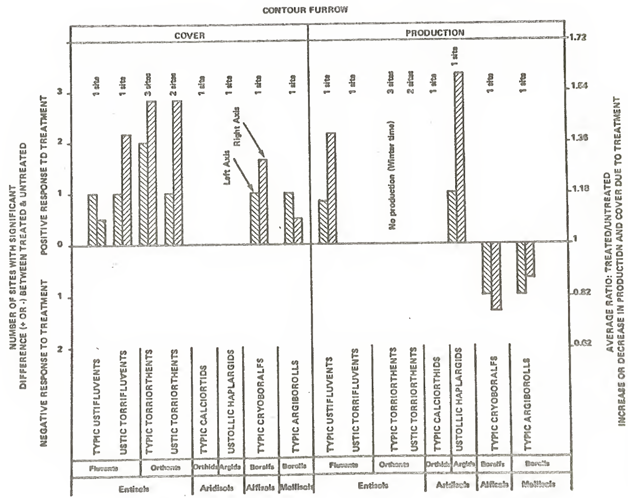


Figure VI-11. Response of cover (vegetation, litter, rock) and production (all species) on various contour furrowing treatments as a function of soils. For each pair of bars, the left bar corresponds to the right axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or −).

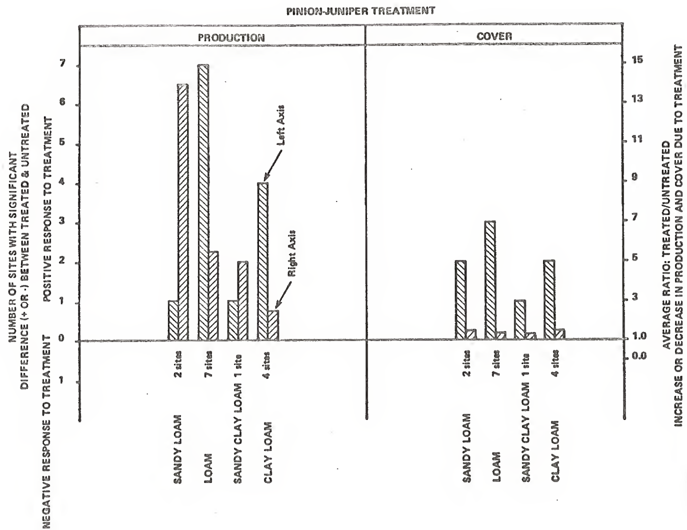


Figure VI-12. Response of cover (vegetation, litter, rock) and production (all species excluding pinyon and juniper trees) on various pinyon-juniper treatments as a function of soil texture. For each pair of bars, the left bar corresponds to the left axis and the right bar corresponds to the right axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

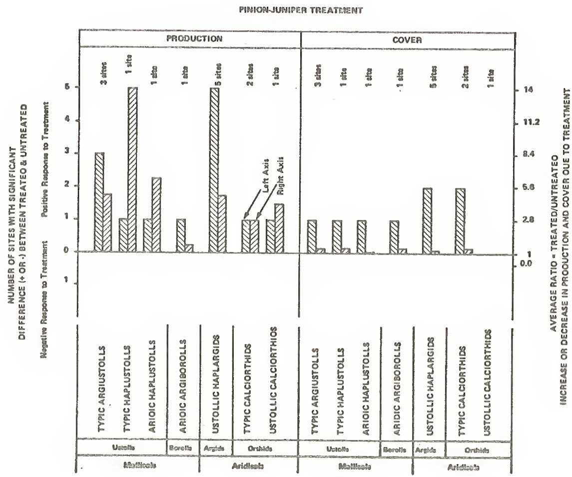


Figure VI-13. Response of cover (vegetation, litter, rock) and production (all species) on various pinyon-juniper treatments as a function of soils. For each pair of bars, the left bar corresponds to the left axis and the right bar corresponds to the right axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

one site characterized by a typic haplustoll and the smallest increase was on one site characterized by an aridic argiboroll.

Pitting. On the two pitting treatments a significant reduction in annual production due to treatment was noted on clay soils while on a sandy clay loam site no impact of pitting was measured. Soil on the former site was classified as a typic torriorthent and on the latter site as a typic torrifluvent.

Various sagebrush treatments. Figures VI-14 and VI-15 show the variable production response among various sagebrush treatments as a function of soil texture and soil type, respectively. There appears to be a general trend for sagebrush treatments to be most successful on loam soil, though significant decreases in production were noted for three treatments on loam soils. Plowing was the least successful sagebrush treatment studied.

Sagebrush railing. Figure VI-14 indicates that annual production was significantly increased on two out of four sites on sandy loam soils and on one of three sites on loam soils. Annual production on one site with loam soil was significantly decreased due to railing.

Figure VI-15 indicates that annual production on two of the five sites on ustollic haplargid soils was significantly increased due to railing while production on one site with the same soil type was significantly decreased. Annual production on a single site on typical calciorthid soils significantly increased due to treatment.

Sagebrush ripping. Five of 13 sagebrush ripping treatments showed a significant increase in annual production due to treatment. As shown in Figure VI-14, one site was on sandy clay loam soils, three sites were on clay loam soils, and one site was on a clay soil. One site (out of 13), on clay

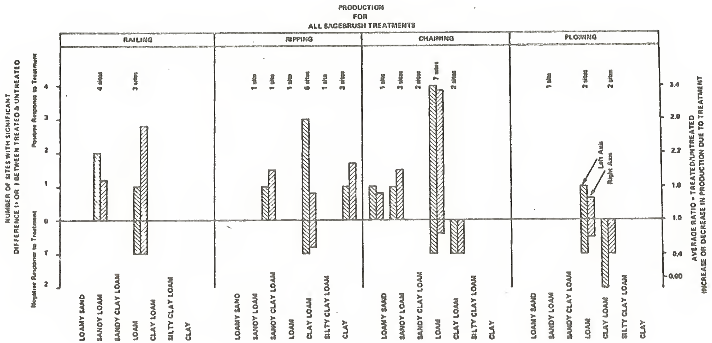
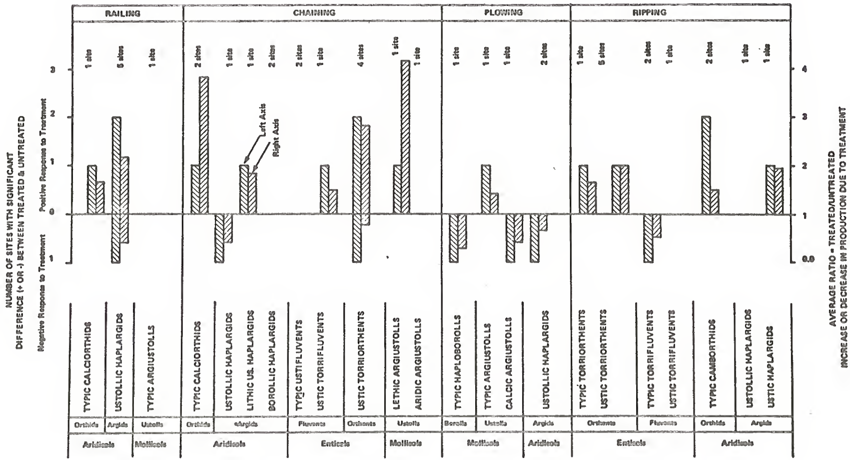


Figure VI-14. Response of production (all species) on various sagebrush treatments as a function of soil texture. For each pair of bars the left bar corresponds to the left axis and the right bar corresponds to the right axis. Bars represent <u>only those sites where significant differences</u> (P=0.1) <u>occurred</u> (either + or -).

Figure VI-15. Response of production (all species) on various sagebrush treatments as a function of soils. For each pair of bars the left bar corresponds to the left axis and the right axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

PRODUCTION
FOR
ALL SAGEBRUSH TREATMENTS



loam soils, had significantly less production on the treated portion.

From Figure VI-15 it is apparent that the most favorable response to ripping occurred on typic torriorthents, typic camborthids, and ustic haplargids. Sites on other soil types either responded negatively to treatment, showed no response whatsoever, or showed a poor response to treatment (for example, one site out of five on ustic torriorthents).

Sagebrush chaining. The most favorable response to chaining sagebrush was on loam soils, though not all sites showed a significant response to treatment and one site showed a significant decrease in production due to treatment (Figure VI-14). The least favorable sites appeared to be those on sandy clay loam and clay loam soils.

Figure VI-15 shows a mixed response to soil type, though greatest increases in production were noted on typic calciorthids and lethic argiustolls. The least favorable sites were on ustollic haplargids, borollic haplargids, typic ustifluvents, and aridic argiustolls.

Sagebrush plowing. It is evident from Figure VI-14 that plowing was not particularly effective in increasing production on any site. Soils on the loam site with a significant increase in production due to treatment was classified as a typic argiustoll (Figure VI-15).

Cover measures

Contour furrowing. Cover on seven of eleven contour furrow treatment sites increased across a broad spectrum of soil textures and soil types (Figures VI-10 and VI-11). Cover increases were greatest on sandy clay loam and loam textured soils and on typic torriorthent and ustic torriorthent soil types.

Pinyon-juniper chaining. Though cover increases due to chaining were noted on eight of 14 pinyon-juniper sites on a variety of soil textures and soil types, the increases were uniformly small (Figures VI-12 and VI-13). No clear pattern emerged with either soil texture or soil type.

Pitting. Significant changes in percent cover due to pitting were not detected on either the sandy clay loam or clay textured site sampled in this study.

Various sagebrush treatments.

Railing. As indicated in Figure VI-16, the only sites showing increased cover on railed treatments were those with a loam texture and with soils classified as ustollic haplargids (Figure VI-17). Four sites with sandy loam soils showed no response to railing in terms of either increased or decreased cover.

Ripping. Cover responses to ripping treatments on sagebrush sites were mixed and generally not impressive (Figures VI-16 and VI-17). Recommendations based on either soil type or soil texture are not evident at this time.

Chaining. The only sites showing increased cover due to chaining were four of seven sites on loam soils (Figure VI-16) classified as typic calciorthids, lithic ustollic haplargids, or ustic torriorthents (Figure VI-17). Cover response to chaining was otherwise nil or negative.

Plowing. Of the five plowing treatments sampled, not a single one indicated increased cover on the treated area (Figures VI-16 and VI-17). One site on clay loam soils indicated a significant decrease in cover on the treated area.

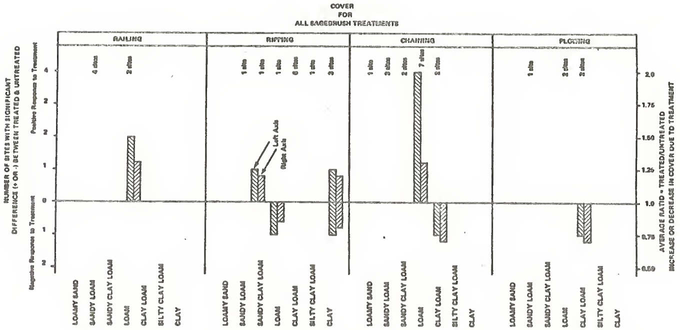


Figure VI-16. Response of cover (vegetation, litter, rock) on various sagebrush treatments as a function of soil texture. For each pair of bars, the left bar corresponds to the left axis, and the right bar corresponds to the right axis. Bars represent only those sites where significant differences (P=0.1) occurred (either + or -).

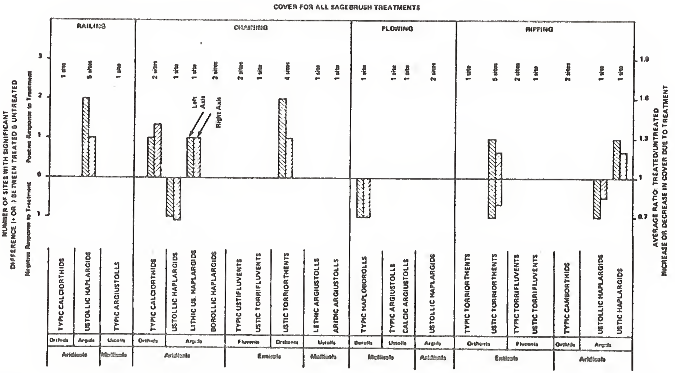


Figure VI-17. Response of cover (vegetation, litter, rock) on various sagebrush treatments as a function of soils. For each pair of bars, the left bar corresponds to the left axis and the right bar corresponds to the right axis. Bars represent <u>only those sites where significant differences</u> (P=0.1) <u>occurred</u> (either + or -).

Impact of Treatment Age on Production and Cover

Contour furrowing

Based on the significant points (either + or -) shown in Figure VI-18, it is obvious that age of treatment makes little difference as to whether there was a significant increase or decrease in either production or cover on contour furrowed sites. There is a tendency to infer that significant increases in cover (where they exist) are more dramatic on more recent treatments, but the lack of data points between 1948 and 1962 precludes such a conclusion.

Pinyon-juniper chaining

Figure VI-19 indicates the impact of age of treatment on significant changes in production and cover due to chaining pinyon and juniper. Figure VI-19a suggests either that significant increases in cover (where they occur) are slightly more dramatic on more recent treatments (linear interpretation) or that treatments which are approximately 11 years old represent conditions most ideal for enhanced cover (assuming again that an increase in cover occurs) (curvilinear interpretation). The former interpretation is probably most nearly correct. A linear interpretation of the data points also suggests that any cover differences that may exist would disappear after about 30 years.

Data shown in Figure VI-19b suggests that pinyon-juniper sites chained since 1964 are not as favorable in terms of increased production as those chained prior to 1964 (1969 data point ignored). This is understandable in that the pinyon-juniper sites with greatest potential would probably have been chained first.

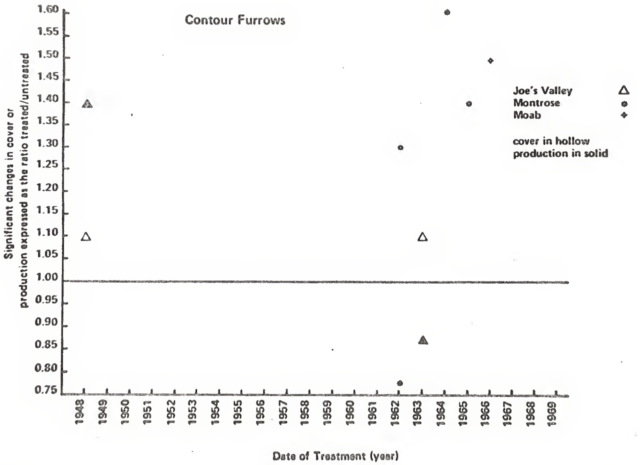
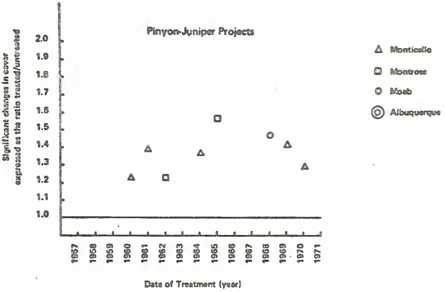


Figure VI-18. Impact of age of treatment on significant changes in cover and production due to contour furrowing.



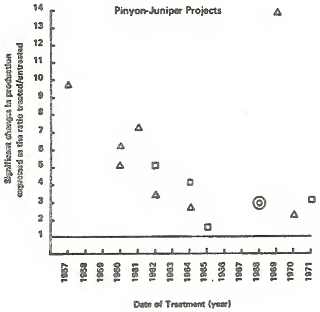


Figure VI-19. a: Impact of age of treatment on significant changes in cover due to chaining pinyon-juniper. b: Impact of age of treatment on significant changes inproduction due to chaining pinyon-juniper.

Various sagebrush treatments

Sagebrush railing. Impact of age of treatment on significant increases or decreases in production and cover on sagebrush sites which have been railed are shown in Figure VI-20. The few significant points provide little evidence that age of treatment (within the limits of this study) had any impact on measured site response.

Sagebrush ripping. Significant increases or decreases in cover on ripped sagebrush sites showed no apparent trend with respect to age of treatment, as shown in Figure VI-21. If one ignores the 1965 production data plotted at 0.50 in Figure VI-21, then a trend which indicates that production increases (if they occur) are slightly more dramatic for more recent treatments than for older ones, and that increases, once established, might be expected to last for about 20 years.

Sagebrush chaining. Data presented in Figure VI-22 indicates no clear pattern as to the influence of age of chaining treatment on significant changes in either production or cover. If the 1951 production point in Figure VI-22 is ignored, then it might be inferred that production differences due to chaining (where they occur) are more dramatic on more recent treatments.

Sagebrush plowing. From data plotted in Figure VI-23 it may be said that plowing treatments sampled in this study were nearly all detrimental in terms of increasing cover or production on the treated site, regardless of age of treatment.

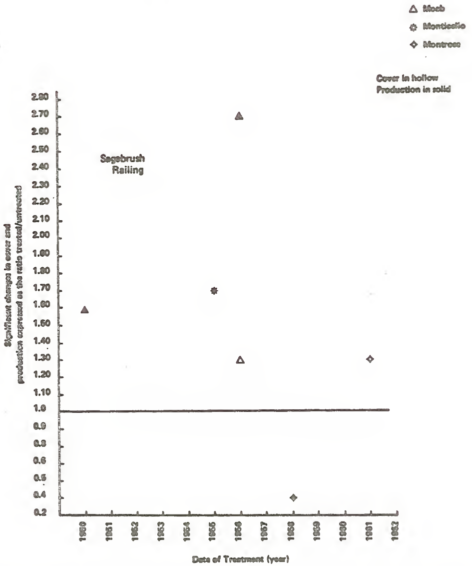


Figure VI-20. Impact of age of treatment on significant changes in cover and production due to sagebrush railing.

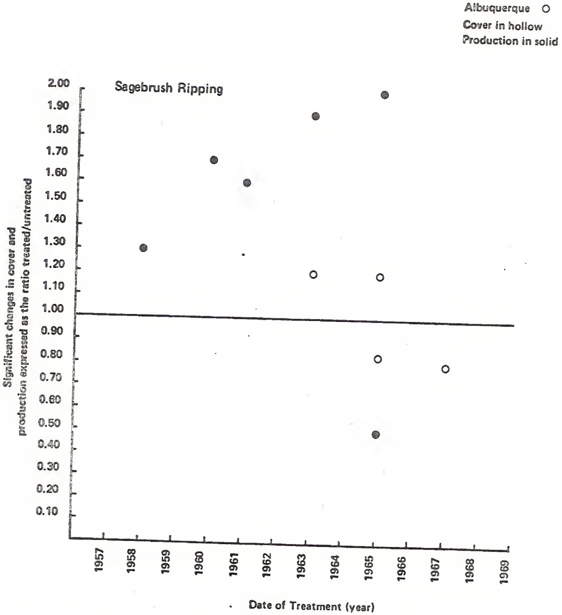


Figure VI-21. Impact of age of treatment on significant changes in cover and production due to sagebrush ripping.

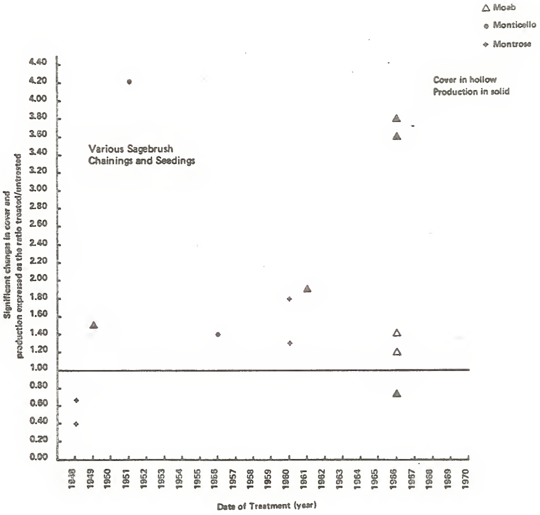


Figure VI-22. Impact of age of treatment on significant changes in cover and production due to sagebrush chaining and seeding.

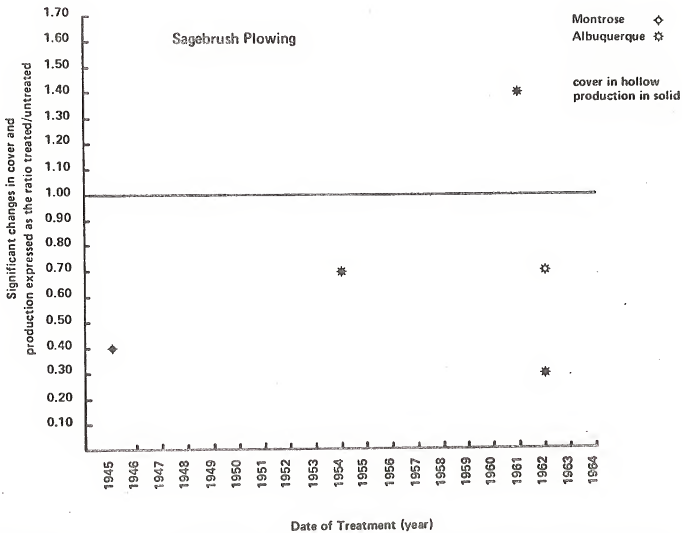


Figure VI-23. Impact of age of treatment on significant changes in cover and production due to sagebrush plowing.

Relationship Between Cover (Vegetation, Litter, Rock) and Annual Production on Various Range Improvement Practices

As part of this study it was of interest to determine the relationship between cover and annual production on both treated and untreated sites. Simple linear regression techniques were used and for each range improvement practice equations were developed for predicting either cover or production on both treated and untreated conditions. Standard errors of the estimates for each regression equation were also calculated (see Tables VI-3, VI-4, and VI-5). Only significant relationships are given in the tables.

Correlation coefficients for the various regression equations on treated range sites varied from 0.22 on pinyon-juniper sagebrush sites to 0.78 on contour furrowed sites. Only the relationship between cover and production on contour furrowed sites proved to be significant.

In general, cover and production were better related on untreated sites than on the treated sites. Correlation coefficients range from 0.39 on untreated sagebrush sites selected for chaining to 0.96 on sagebrush sites selected for plowing. Only the equations for contour furrowing sites, pinyon-juniper sites, and sagebrush sites selected for plowing were significant.

Table VI-3. Regression analysis of cover and production on contour furrowing sites.

	On Treated Sites	On Untreated Sites
Assuming production as independent variable (x) and cover as dependent variable (y)		
Regression equation	$\hat{Y} = 31.63 + 0.17x$	$\hat{Y} = 19.2 + 0.21x$
Correlation coefficient	r = 0.78	r = 0.95
Standard error of the estimate	$S_{y \cdot x} = 13.4$	$S_{y \cdot x} = 5.5$
Assuming cover as independent variable (x) and production as dependent variable (y)		
Regression equation	$\hat{Y} = 54.7 + 3.63x$	$\hat{Y} = -68.35 + 4.29x$
Correlation coefficient	r = 0.78	r = 0.95
Standard error of the estimate	$S_{y \cdot x} = 61.86$	$X_{y \cdot x} = 25.05$
Test of significance for correlation coefficient	t = 3.74*	t = 9.12*

* Statistically significant (P=0.10).

Table VI-4. Regression analysis of cover and production on pinyon-juniper sites.

	On treated sites	On untreated sites
Assuming production as independent variable (x) and cover as dependent variable (y)		
Regression equation	Not significant	$\hat{Y} = 50.52 + 0.171x$
Correlation coefficient	r = 0.22	r = 0.58
Standard error of the estimate	----	$S_{y \cdot x} = 13.17$
Assuming cover as independent variable (x) and production as dependent variable (y)		
Regression equation	Not significant	$\hat{Y} = -48.19 + 1.95x$
Correlation coefficient	r = 0.22	r = 0.58
Standard error of the estimate	----	$S_{y \cdot x} = 44.56$
Test of significance for correlation coefficient	t = 0.78	t = 2.46*

*Statistically significant (P=0.10)

Table VI-5. Regression analysis of cover and production on sagebrush plowing sites.

	On Treated Sites	On Untreated Sites
Assuming production as independent variable (x) and cover as dependent variable (y)		
Regression equation	Not significant	$\hat{Y} = 44.98 + 0.121x$
Correlation coefficient	r = 0.77	r = 0.96
Standard error of the estimate	----	$S_{y \cdot x} = 2.88$
Assuming cover as independent variable (x) and production as dependent variable (y)		
Regression equation	Not significant	$\hat{Y} = 331.18 + 7.6x$
Correlation coefficient	r = 0.77	r = 0.96
Standard error of the estimate	----	$S_{y \cdot x} = 22.8$
Test of significance for correlation coefficient	t = 2.09	t = 5.9*

*Statistically significant (P=0.10).

Life Expectancy of Gully Plugs and Contour Furrowing Treatments

Projected life for newly constructed gully plugs and contour furrowing treatments was computed on the assumption that when 60 and 50 percent of the original storage capacity for each type of treatment, respectively, was filled with sediment the treatments ceased to be effective. A linear interpretation of data points in Figure VI-24 shows that the expected life of gully plug projects on loam soil would approximate 37 years.

From linear interpretation of data points in Figure VI-25, projected life expectancy of contour furrows approximates 30 years on sandy loam soil and 36 years on clay loam soil.

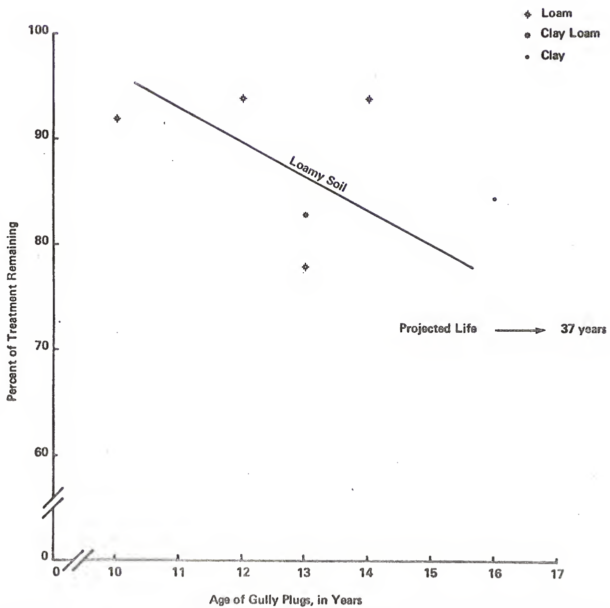


Figure VI-24. Decrease in the storage capacity of gully plug treatments as affected by time on various soil types.

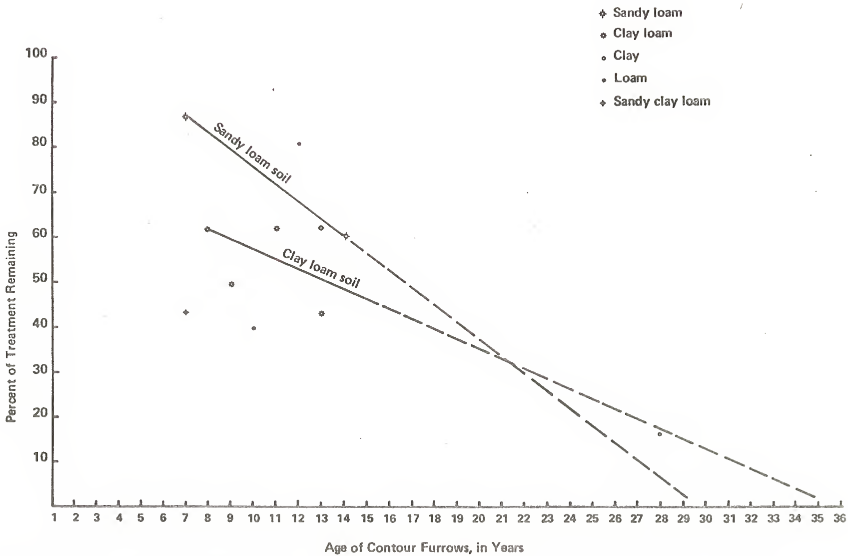


Figure VI-25. Decrease in storage capacity of contour furrow treatments as affected by time on various soil types.

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