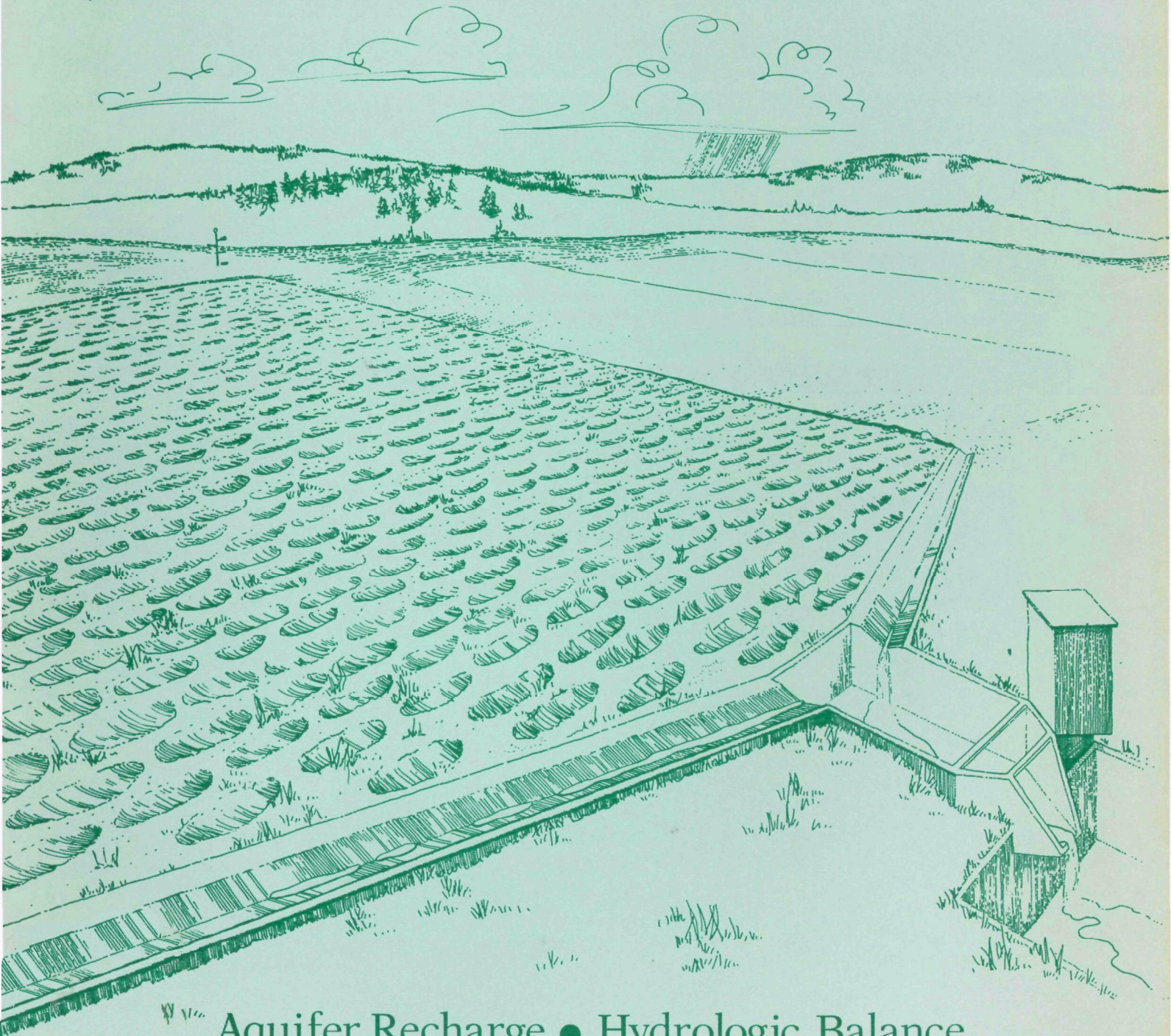


Effects of Surface Configuration in Water Pollution Control on Semiarid Mined Lands

Montana Agricultural Experiment Station

Montana State University, Bozeman

April 1977 Research Report 114



Aquifer Recharge • Hydrologic Balance
Erosion • Runoff Chemistry • Soil Water Flow

EFFECTS OF SURFACE CONFIGURATION IN WATER POLLUTION
CONTROL ON SEMIARID MINED LANDS

by

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Demonstration Grant Number R-803079-01-0

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DISCLAIMER

This report does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by either the U.S. Environmental Protection Agency or the Montana Agricultural Experiment Station.

ACKNOWLEDGEMENT

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ABSTRACT

A system of intensively monitored micro-watersheds was constructed to demonstrate the effects of several specific soil surface manipulation treatments on control of runoff, chemistry of runoff, soil water flow, aquifer characteristics and vegetation establishment at five active coal strip mine areas within the tri-state region of Montana, North Dakota and Wyoming. Surface treatments were chiseling and gouging with and without topsoiling practices, and dozer basins with topsoiling.

Without exception, topsoiled watersheds underwent less runoff than similar nontopsoiled watersheds. The total amount (depth) of surface runoff at the Montana and North Dakota Demonstrations was 1.63 cm for topsoil-dozer basins, 2.32 cm for topsoil-gouged, 4.76 cm for topsoil-chiseled, 13.74 cm for nontopsoil-gouged, and 16.70 cm for nontopsoil-chiseled.

Quantities of eroded soil material per treatment watershed resulting in gullies at the Montana Demonstration Areas were 2.7 m³ for topsoil-dozer basins, 8.1 m³ for topsoil-gouged, 23.7 m³ for nontopsoil-gouged, 26.4 m³ for topsoil-chiseled, and 43.1 m³ for nontopsoil-chiseled. Thus the fundamental principle of less runoff - less erosion was substantiated on these spoil watersheds.

The *in situ* hydrologic balance of the spoil biosphere was determined using weighing lysimeters and neutron probe techniques. Deep percolation characteristics were measured during precipitation periods. Most watersheds eventually lost this deep percolated water through the evapotranspiration process measured on a hydrologic year basis. A minority of watersheds underwent a net loss of 10 to 20 cm of water as deep percolation for the hydrologic year.

Levels of NO₃-N, Mg, Ca, soluble salts and most trace elements were found in low concentrations in watershed runoff water. Exceptions were Mn and Fe, where concentrations in runoff waters at all Demonstrations often exceeded federal standards for drinking water. Occasional samples contained Cd, Pb and PO₄-P levels which exceeded desirable standards.

Surface spoil hydrology and aquifer characteristics interrelationships are discussed, and the aquifer chemical quality presented. Manganese was the only trace element in the ground water which consistently exceeded federal standards for human consumption. A comparison of ground-water quality among the Demonstration Areas indicates that highest concentrations for most of the observed parameters were in the developing spoils aquifer at the North Dakota site.

This interim report is submitted in partial fulfillment of Contract No. R-803079-01-0 by the Montana Agricultural Experiment Station under the sponsorship of the U.S. Environmental Protection Agency. This report concentrates most directly on data collected during the period May, 1974 to May, 1976. Work is expected to be completed in September, 1978.

INTRODUCTION AND OBJECTIVES

The strippable coal deposits in the western states are located predominantly in arid areas of less than 35 cm of annual precipitation. Of the limited annual precipitation which reaches the soil surface, only minor amounts are stored in the soil. Over time drainage patterns have developed which rapidly and efficiently shed nearly all the free-standing surface water from an area, leaving water only in the small depressions such as those formed by the burrowing of rodents and imprints left by grazing animals. The efficient drainage topography combined with soils of extremely low infiltration rates and rapidly formed interconnecting patterns of rills and gullies results in the loss of significant amounts of water which, if stored in the soil, could have been utilized for plant growth. The generally smooth surfaced, recontoured terrain being left in the wake of strip mining normally provides no depressions for impeding the flow of water, but rapidly funnels sediment and nutrient laden excess runoff into the adjacent gullies and streams. During the winter months, snow is also blown from smooth, reshaped spoils surfaces and deposited in nearby gullies and areas where it may augment the needs of standing vegetation. Thus, large amounts of critically needed water falling on smooth surfaced recontoured terrain are being completely lost and rendered unavailable for plant establishment and development.

Conservation of much needed water may be increased by manipulation of a soil surface to increase infiltration and reduce runoff of precipitation. Range pitting and scarifying stable land surfaces have been relatively common agricultural practices in the West for decades. During the dust

bowl years, listering of the surface of bare and exposed fields was not unusual as a soil saltation and erosion control practice. However, the manipulation of the surface of drastically disturbed, unstable slopes such as strip mine spoils is innovative.

The potential of surface manipulation of mine spoils was first demonstrated in Montana in 1968 when the sharp ridges typical of old spoils were levelled off and large depressions made to trap winter snow and spring rains which were previously lost.

Research work in subsequent years has identified distinct advantages offered by several configurations. Treatments have recently been employed on extremely dry spoils in Arizona and New Mexico as well as in semiarid northern locations. The possibility of broad applicability of surface manipulation in reclamation of mine spoils was recognized in 1973 by the National Academy of Sciences in its report, Rehabilitation Potential of Western Coal Lands. Because of favorable response, the potentials, limitations and broad applicability of the process are now being demonstrated with funding from the U.S. Environmental Protection Agency (E.P.A.) at five locations in Montana, North Dakota and Wyoming.

Possible benefits of surface manipulation occur in two distinct phases of mine spoils reclamation efforts: (1) in lending temporary stability to loose steep slopes and reducing erosion while increasing infiltration and soil water content, and (2) in promoting a more rapid establishment of vegetative cover and the resulting permanent soil stability which acceptable reclamation of the land must achieve. Advantages in plant establishment with surface manipulation concern

the accumulation of moisture in sufficient quantity to promote early germination of seed, the lengthening of the growing season and the protection of seedlings from exposure.

This project is designed to demonstrate and evaluate the practicality of using three basic types of surface manipulation: deep chiseling, gouging and dozer basins. Deep chiseling is accomplished with a commercially available farm implement (Figure 1). The chisels are operated on the contour and controlled to form 30 centimeter deep continuous grooves on 30 centimeter centers.



Figure 1. The chiseling apparatus consists of a commercially available farm implement.

The gouging treatment is accomplished with a specially designed implement. The basic machine consists of the hydraulically raised and lowered frame of a chisel plow (Figures 2, 3). The chisels are removed and replaced with three equally spaced, vertically positioned discs of 64 centimeter diameter from an offset disc plow. As the surface manipulator is drawn forward by a tractor, the frame and discs of the implement are

alternately raised above ground and lowered into the terrain surface, thus forming elongated pits approximately 40 centimeters wide, 60 centimeters long and 15 centimeters deep. The gouges are applied along the contour of the shaped spoils.

Dozer basins were originally formed with a bulldozer blade set on angle to create basins approximately 6 meters long, 7.5 meters from center to center, and one meter deep. Field experience with the method showed that forming the basins with the front mounted bulldozer blade was a rather difficult and inefficient operation resulting in basins of varying size and form characteristics (Figure 4). In 1972 a new implement was designed and constructed to improve the technique of forming large basins (Figures 5, 6). This implement was mounted on the rear of a crawler tractor attached to the ripper mechanism.

These three types of surface manipulation techniques could have an appreciable influence upon spoil hydrology and ultimately upon reclamation. Therefore, the effects of these surface manipulation techniques in association with topsoiling practices are being evaluated according to the following major objectives:

- (1) to determine at each demonstration area the complete hydrology of the soil biosphere which includes the precipitation, evapotranspiration, runoff, soil moisture storage, and deep percolation components;
- (2) to determine at each demonstration area the chemistry of runoff water from spoil watersheds;
- (3) to determine at each demonstration area aquifer characteristics and chemistry of the ground water in the immediate vicinity of the Demonstrations;

(4) and to study at each demonstration area the geometry and life expectancy of surface manipulations and their suitability for stabilization and reclamation of large contiguous areas.

This initial report concerns soil and water aspects of surface manipulation techniques while revegetation results shall be presented in a later publication.

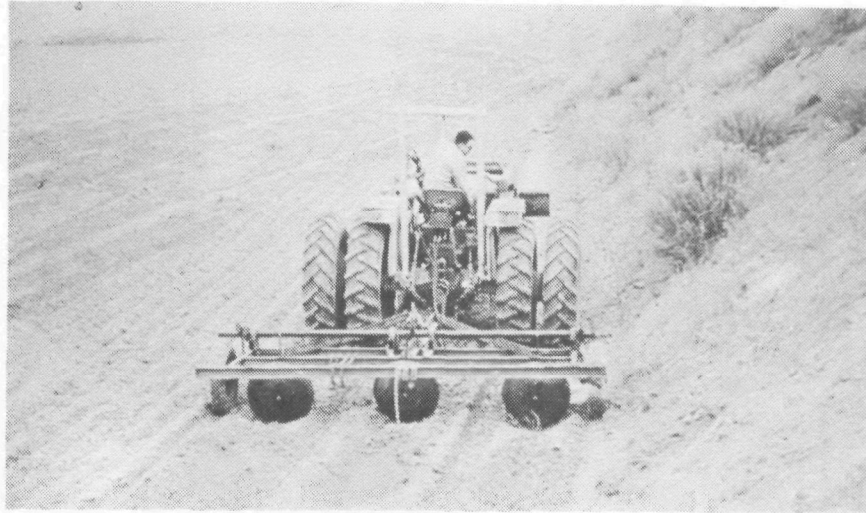


Figure 2. The gouging apparatus consists of three 64 cm diameter discs mounted on a tool bar frame.



Figure 3. This gouging surface manipulation treatment was constructed as the operator alternately raised and lowered the discs, thus forming elongated pits about 50 cm long. On the left deep chiseling treatment contrasts with the gouging treatment.

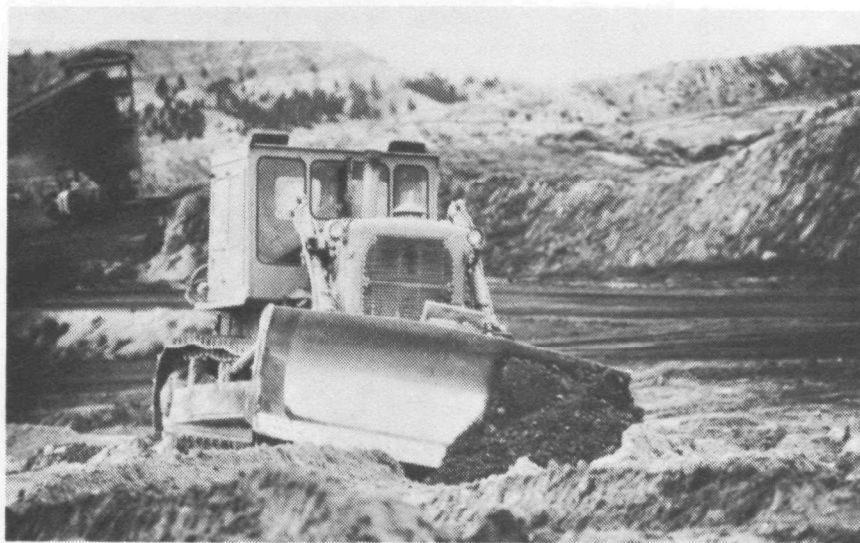


Figure 4. Dozer basins being constructed with the angled front blade of a crawler tractor.



Figure 5. The dozer basin blade was mounted in the ripper shank position of a crawler tractor.



Figure 6. This dozer basin surface manipulation treatment was constructed as the operator alternately raised and lowered the basin blade, thus forming elongated pits about 6 m long.

ORIENTATION AND DESIGN OF DEMONSTRATION AREAS

During 1975, demonstration areas were established at the Western Energy Company Rosebud Mine near Colstrip, Montana, Knife River Coal Company Mine near Savage, Montana, and the North American Coal Company Indian Head Mine near Beulah, North Dakota. In 1976, two additional demonstration areas were established at the Dave Johnston Mine near Glenrock, Wyoming, and at Arch Mineral Corporation Seminoe No. 1 Mine near Hanna, Wyoming (Figure 7). The approximate size of each demonstration was: Colstrip 30 ha, Savage 28 ha, Beulah 22 ha, Glenrock 16 ha, and Hanna 12 ha.

Construction at all five demonstration areas has been completed. The limited data collected to date at the Glenrock and Hanna areas will not be presented in this report and the discussions will be limited to the Colstrip, Savage, and Beulah demonstration areas.

Each study site was located in an area of different edaphic, topographic, and climatic characteristics. Specific sites were selected to enable maximum exclusion of confounding outside vectors such as excessive runoff, flooding and sedimentation. The types of drainage patterns, slope aspect, degree of slope, and uniformity of slope were all important considerations in final site selection. The contour of each drainage provides a bisecting drainage channel with opposing relatively uniform gradients and long slopes. The five treatments evaluated on shaped surface mined spoils were topsoil-gouged, nontopsoil-gouged, topsoil-chiseled,

DEMONSTRATION AREAS: ★

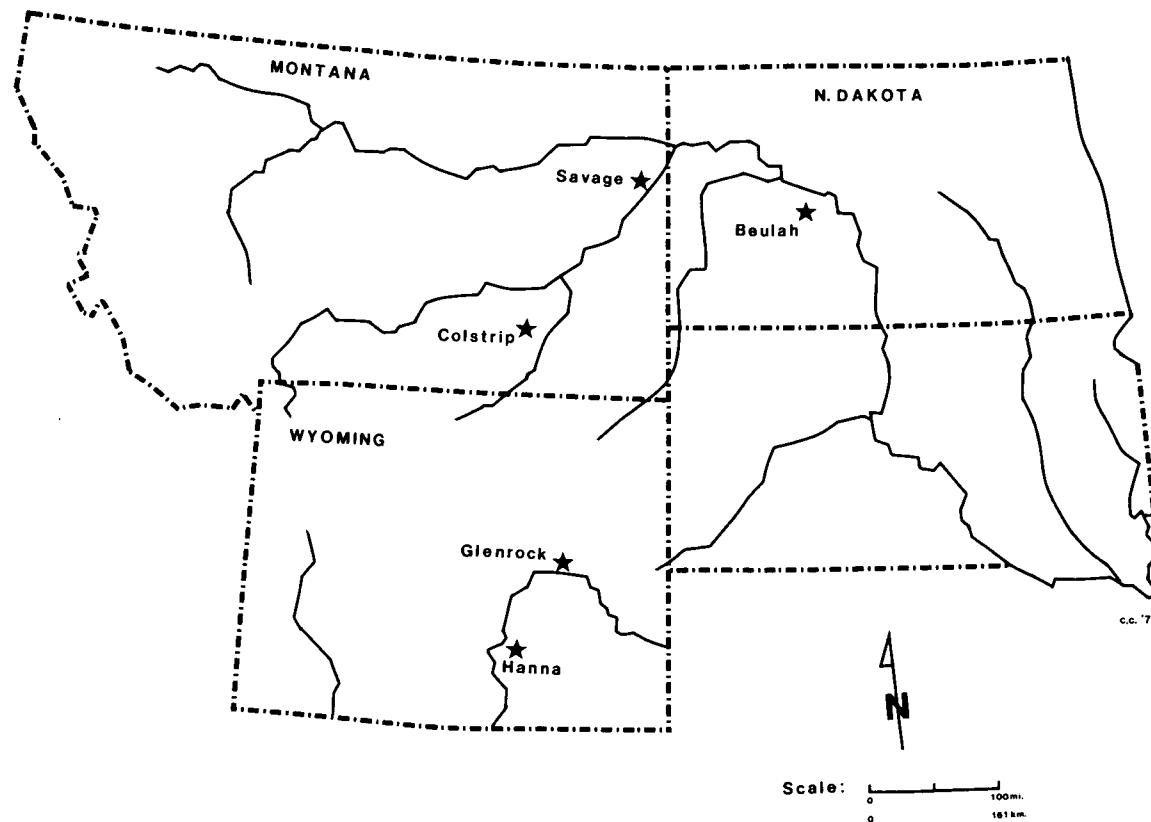


Figure 7. Location of the five Demonstration Areas in the states of Montana, North Dakota, and Wyoming.

nontopsoil-chiseled and topsoil-dozer basins. Chiseling on spoils, which demonstrated a minimum of surface reclamation, was considered the control against which all other treatments were compared.

To address the project objectives, two types of treatment areas were necessary. The more extensive of the two types includes the application of each of the five treatments within a large area consisting of two opposite exposures (Figures 8, 9, 10). More than 75 percent of each study consists of this type of treatment. Such a treatment area provides large contiguous areas for ground-water recharge, extensive areas for the development of wind and water erosion patterns, comparison of opposite exposures, and opportunity to evaluate equipment for efficiency and suitability for large scale treatment application.

A second intensive treatment arrangement was used in conjunction with the extensive application type. The second type consisted of five microwatershed treatment areas near each other with provisions for intensive continuous monitoring of the hydrologic budget of the spoil system (Figures 8, 9, 10). Five microwatersheds, with approximate dimensions of 60 m by 37 m (.206 ha) have been constructed at each study area (Figures 11, 12, 13). The upper end and two sides of each watershed are delineated with impervious asphalt impregnated strips of chopped strand fiberglass mat supported by rough sawed 5 cm by 10 cm lumber (Figures 14, 15). The lower boundary of each watershed consists of two runoff collection ditches (Figures 15, 16).

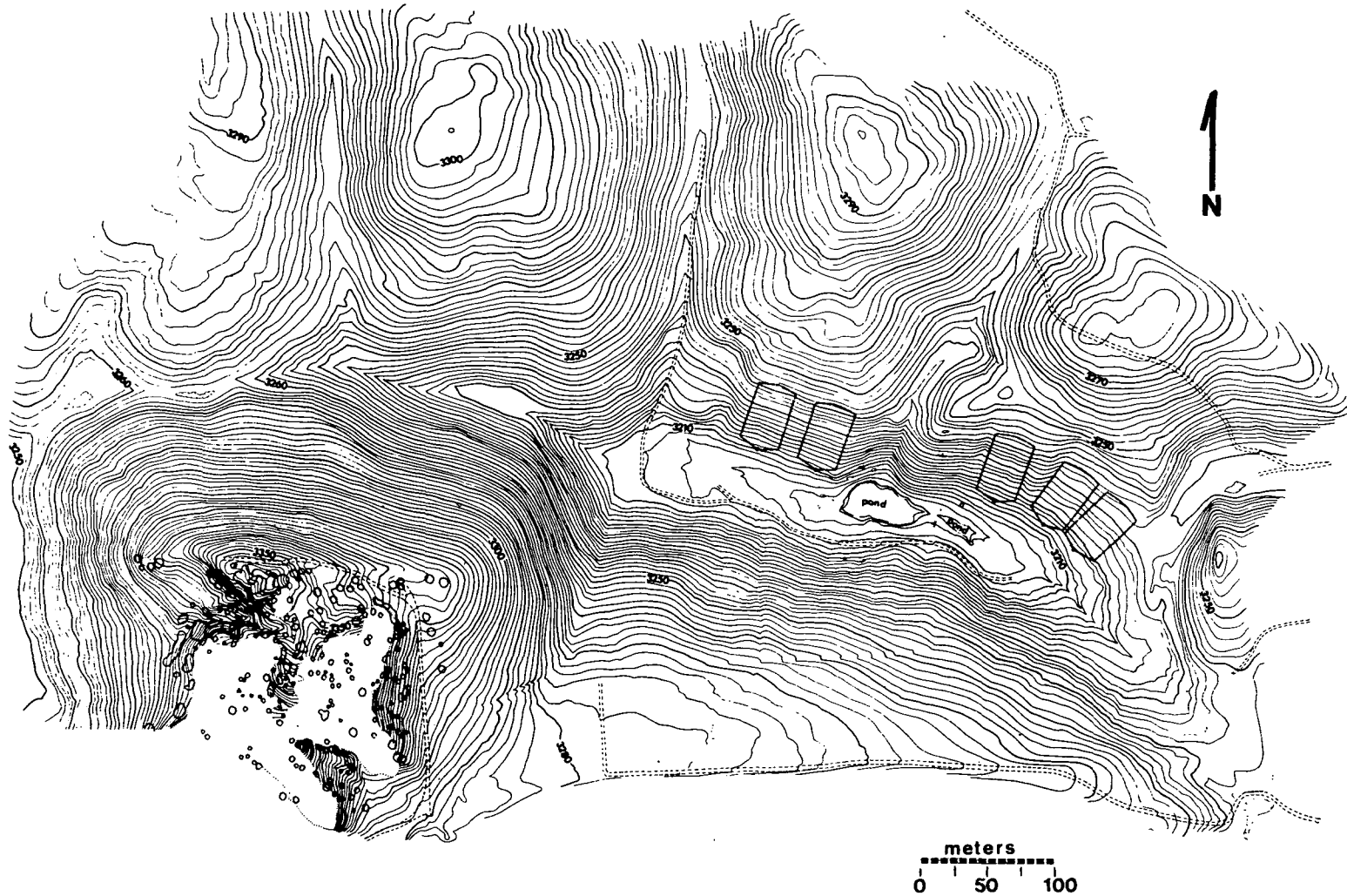


Figure 8. Topographic setting of the Colstrip Demonstration Area indicating microwatershed locations and companion slope of opposite exposure. See Figure 11 for more detailed analysis near microwatersheds.

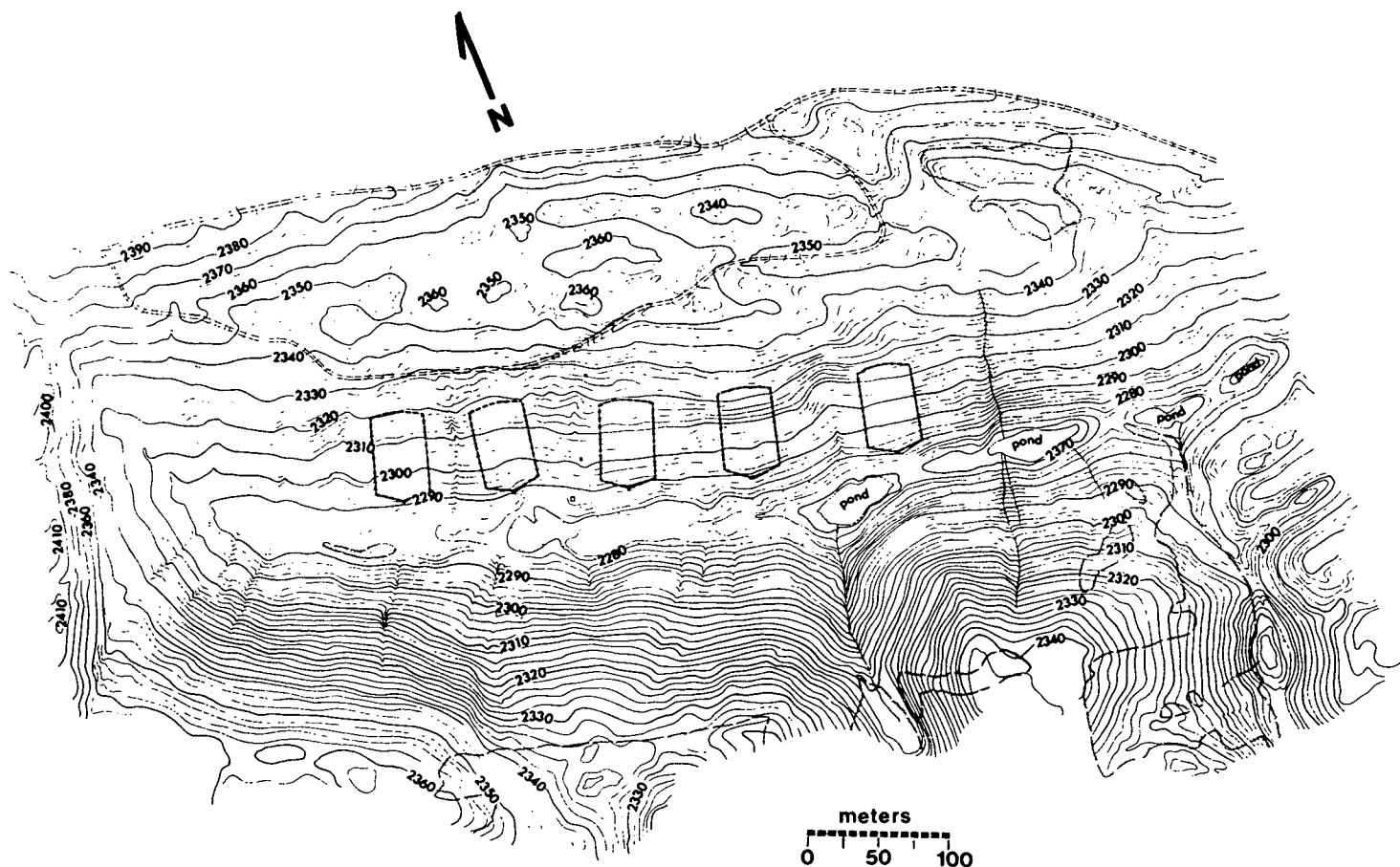


Figure 9. Topographic setting of the Savage Demonstration Area indicating microwatershed locations and companion slope of opposite exposure. See Figure 12 for more detailed analysis near microwatersheds.

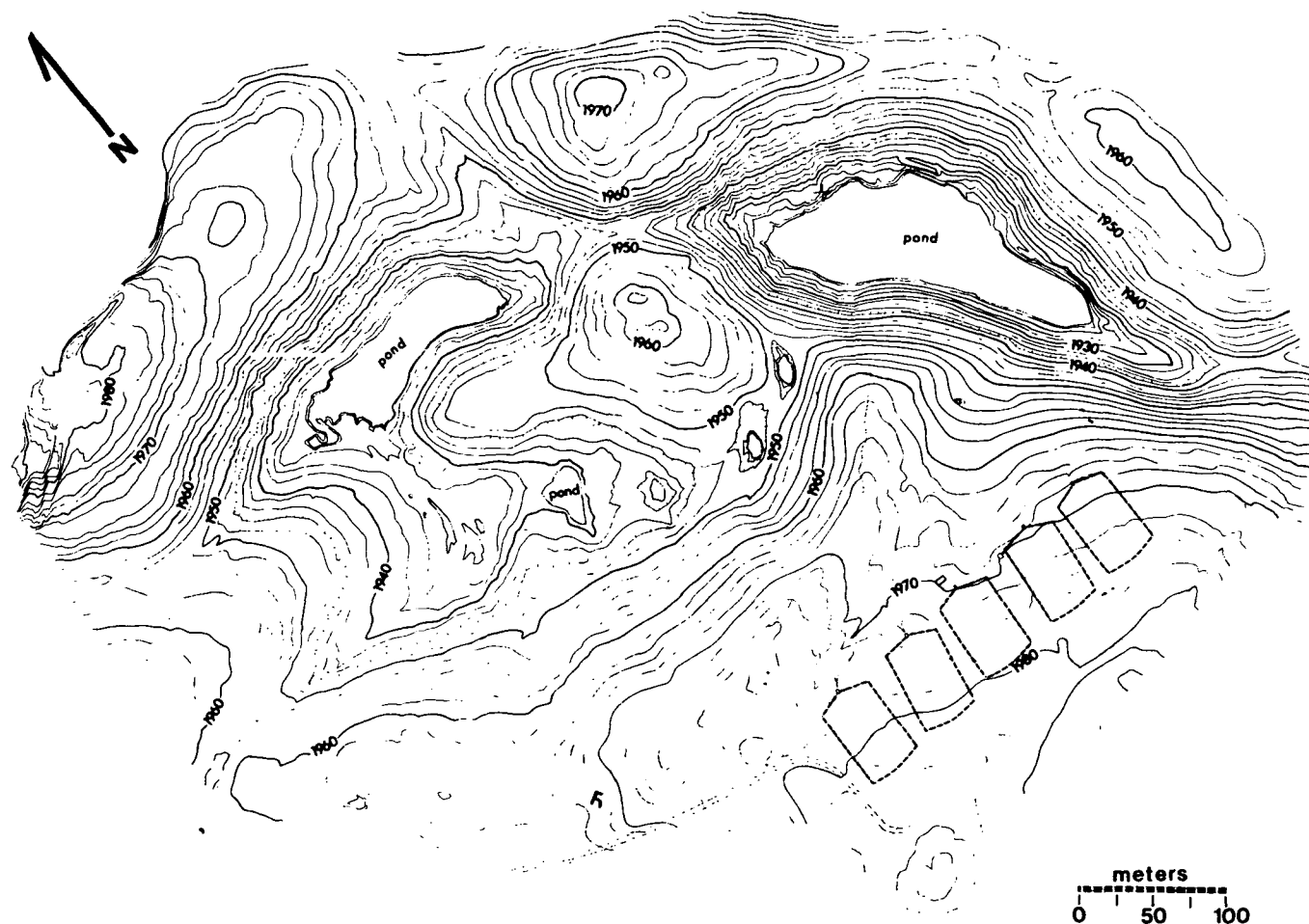


Figure 10. Topographic setting of the Beulah Demonstration Area indicating microwatershed locations and companion slope of opposite exposure. See Figure 13 for more detailed analysis near microwatersheds.

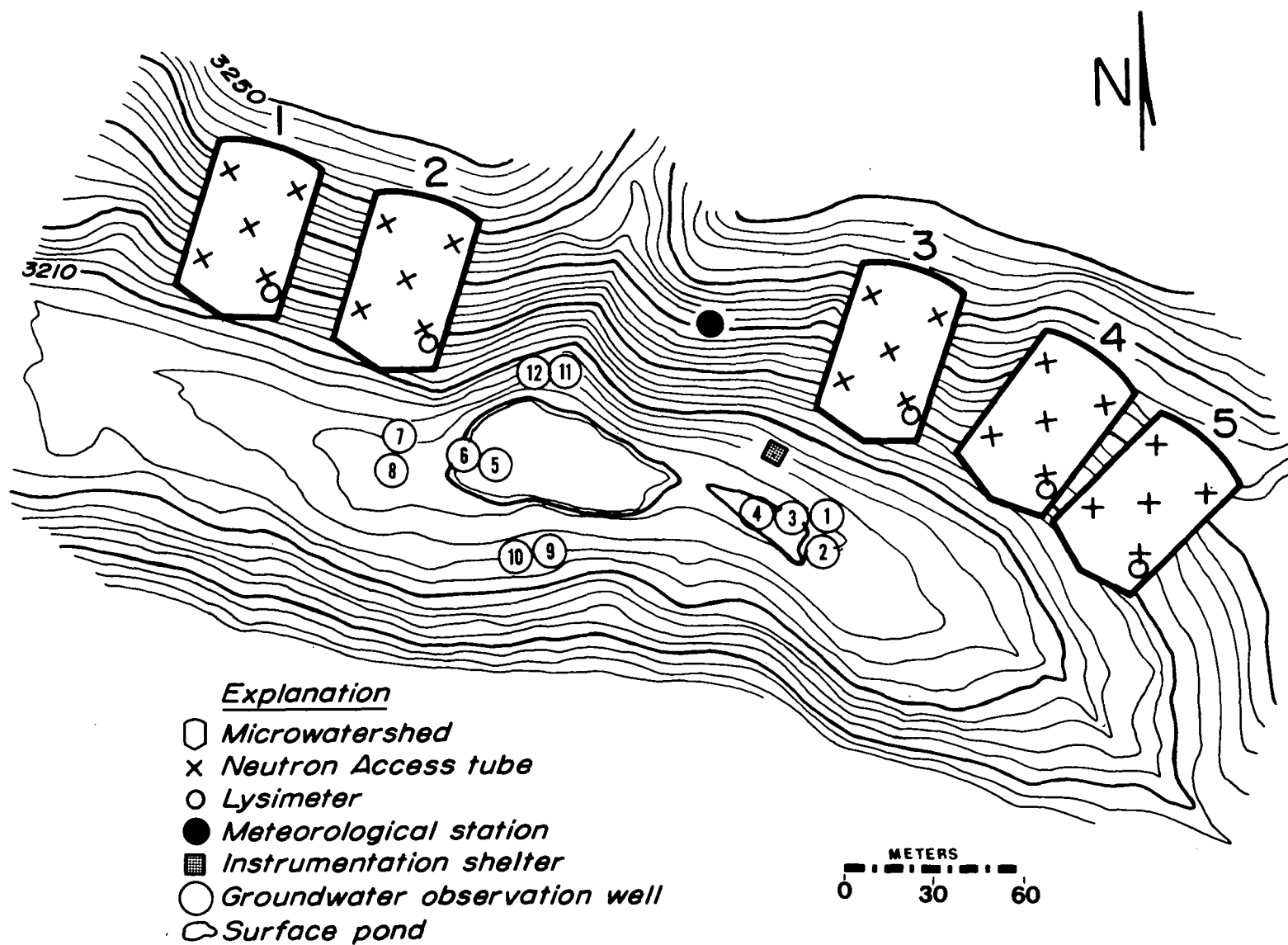


Figure 11. Orientation of instrumentation and groundwater observation wells at the Colstrip Demonstration. Microwatershed treatment assignments were; 1) topsoil-gouged, 2) topsoil-dozer basins, 3) topsoil-chiseled, 4) nontopsoil-gouged, and 5) nontopsoil-chiseled.

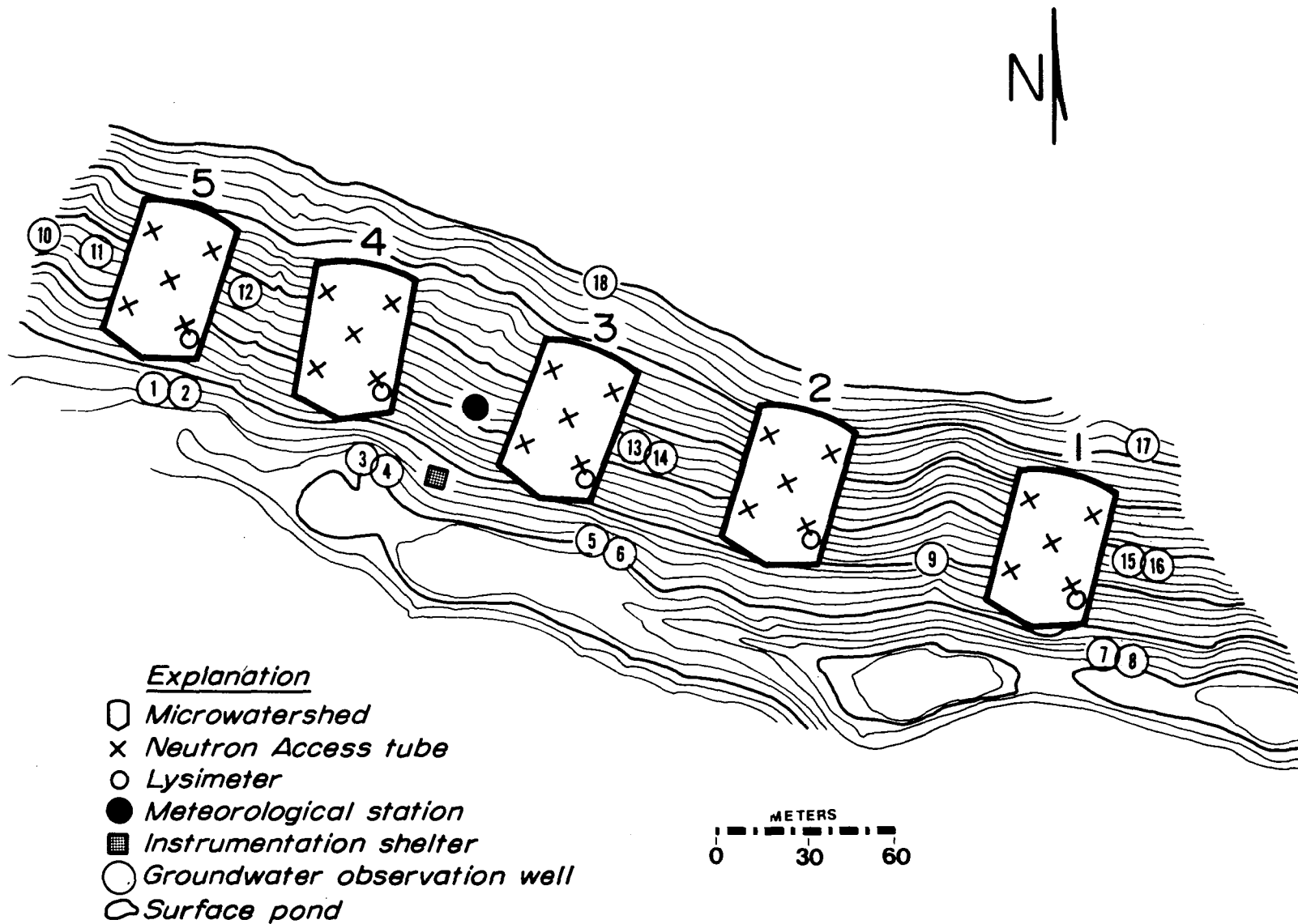


Figure 12. Orientation of instrumentation and groundwater observation wells at the Savage Demonstration. Microwatershed treatment assignments were; 1) topsoil-chiseled, 2) nontopsoil-gouged, 3) topsoil-gouged, 4) nontopsoil-chiseled, and 5) topsoil-dozer bairs.

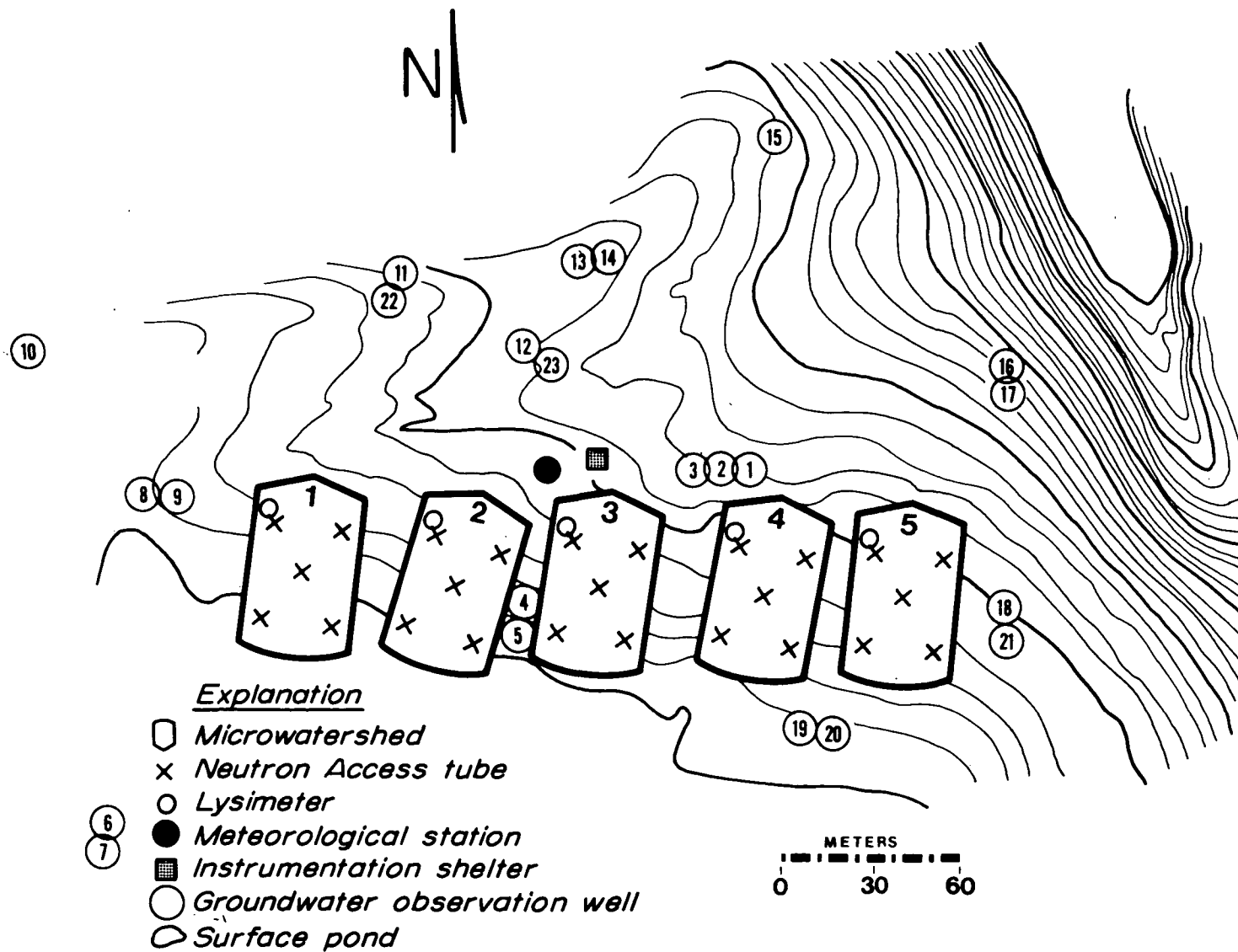


Figure 13. Orientation of instrumentation and groundwater observation wells at the Beulah Demonstration. Microwatershed treatment assignments were; 1) topsoil-chiseled, 2) nontopsoiled-gouged, 3) nontopsoiled-chiseled, 4) topsoiled-gouged, and 5) topsoiled-dozer basins.

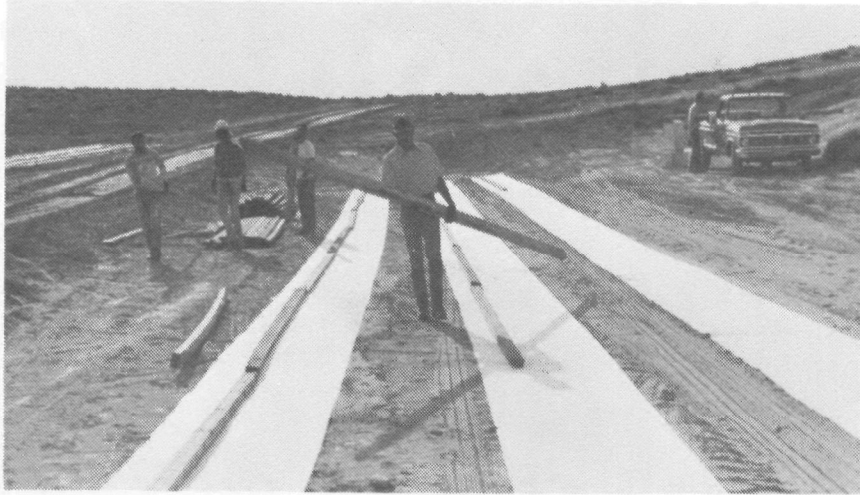


Figure 14. Asphalt impregnated strip of chopped strand fiberglass mat supported by lumber bounded each watershed. Above, the fiberglass mat is being prepared for asphalt treatment.

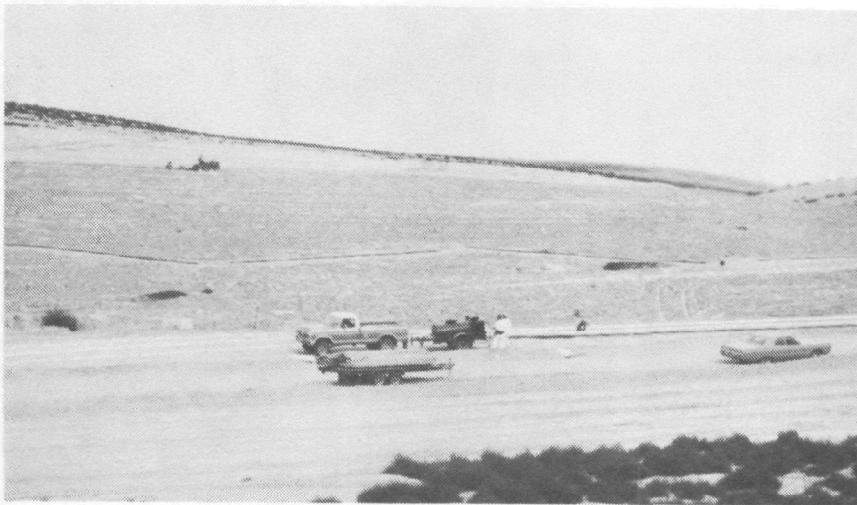


Figure 15. In foreground, barrier strips are being constructed by spraying heated liquid asphalt onto fiber mat. In the background, a ditch is prepared at the top of the watershed prior to installation of the asphalt fiberglass barrier.



Figure 16. At both Wyoming Demonstration Areas, sheet metal strips were substituted for the asphaltting technique. The two watersheds shown above have such metal strips at the top and bottom with sides yet to be completed.

At the lower edge of the microwatershed, at a point where the runoff collection ditches intersect, a concrete or metal flume collection box was positioned so as to collect water from the ditches. A 7.6 cm (3 inch) wide by 30.5 cm (12 inch) high Parshall measuring flume was bolted onto the lower end of the flume box (Figure 17).

Each flume was equipped with a stage recorder that was fitted with a gear driven potentiometric output device connected directly to one of the data recording channels in the instrument shelter via an underground wire in a plastic pipe.

An automatic water sampler was positioned adjacent to and connected to the lower throat section of the Parshall flume (Figures 17, 18).

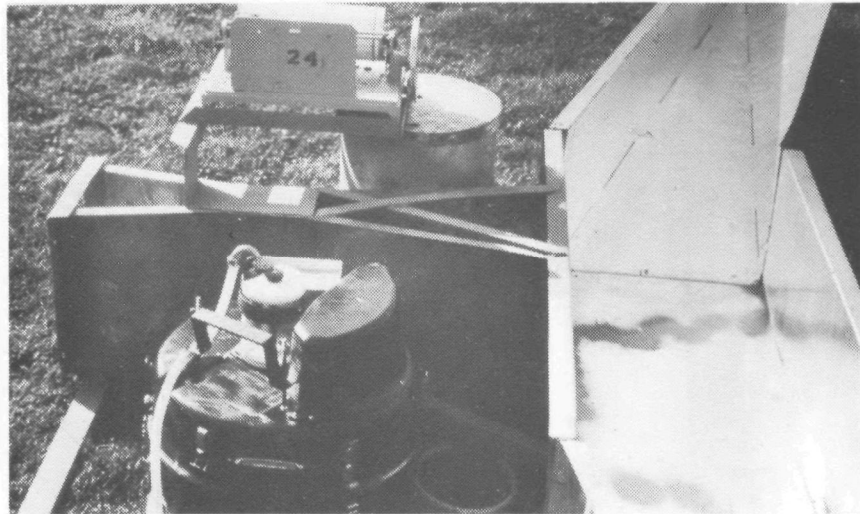


Figure 17. Metal flume collection box with attached Parshall flume, stage recorder and automatic water sampler. This design was positioned at the flume end of each watershed.

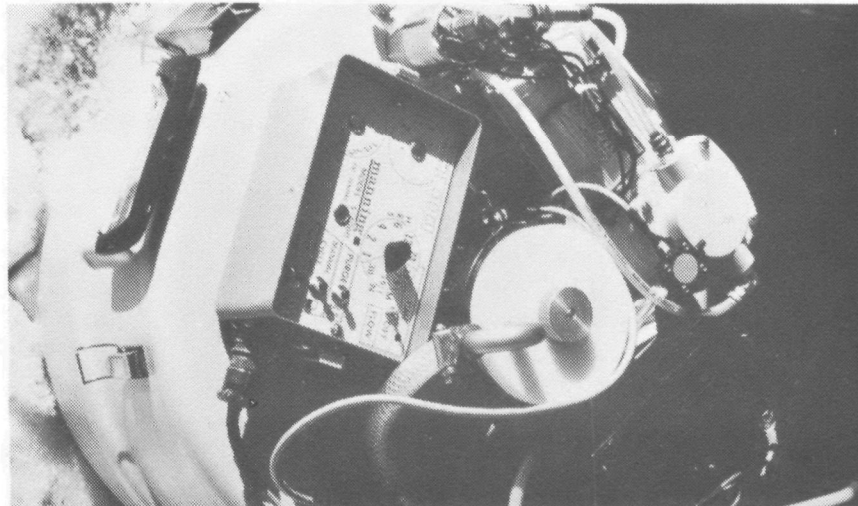


Figure 18. The automatic water sampler can collect up to 24 samples in a choice of timed increments from 2.7 minutes to once per day.

The cycle controlled sampler was capable of collecting up to 24-500 ml water samples at time intervals varying from 2.7 minutes to 24 hours. The sampler was controlled with an adjustable interrupt switch mounted on the companion stage recorder. The switch initiated a water sample collection cycle when a water flow of 5 cubic centimeters per second or greater occurred.

A completely enclosed and insulated instrument protection building was positioned at a central location within each of the Demonstration Areas. Each building was used to house all delicate data logging systems. Within approximately 30 m of each instrument building, a meteorological station was installed (Figures 19, 20). All the electrical output sensors were connected directly to the data acquisition system in the instrument shelter by way of sensor wires extending through buried plastic pipe. Each meteorological data recording station consisted of the following sensors:

1. integrated wind speed
2. wind direction
3. direct solar radiation
4. relative humidity
5. precipitation (intensity and duration)
6. barometric pressure
7. evaporation potential (type A pan)
8. air temperature at 2 meters
9. air temperature at 1 meter
10. soil temperature at four depths

Each system was monitored by a central data collection unit. This unit contains the circuitry to perform 32 channel switching, the analog to digital conversion, formatting, data recording, and employs a crystal-controlled clock for time data. All data collected and processed by the unit is stored on two-track, C-90 standard cassette tapes. These data stored on the tape are played back into computer storage files and computer programs were developed for data compiling and analysis.

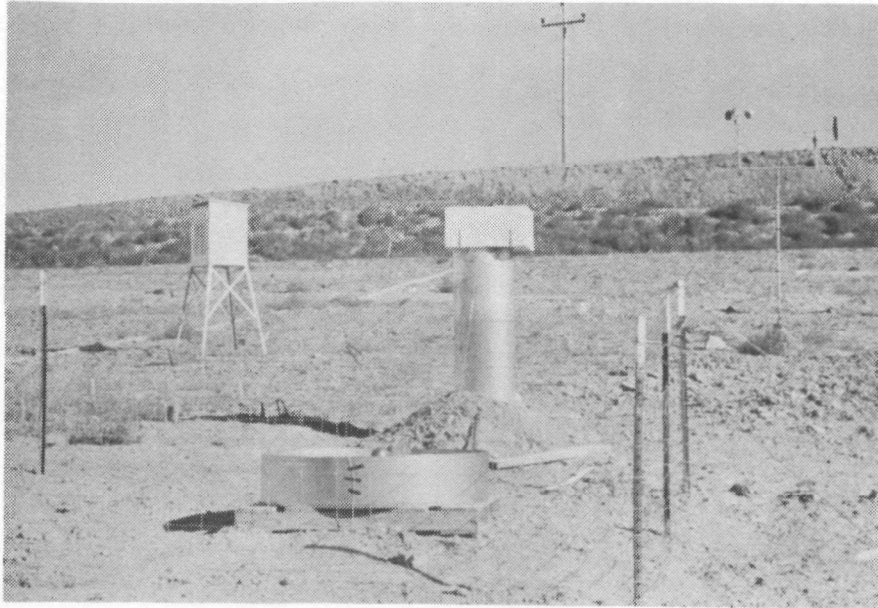


Figure 19. Typical meteorological station at the Demonstration Areas showing mast with sensors, evaporation pan with stilling well recorder and instrument shelter.

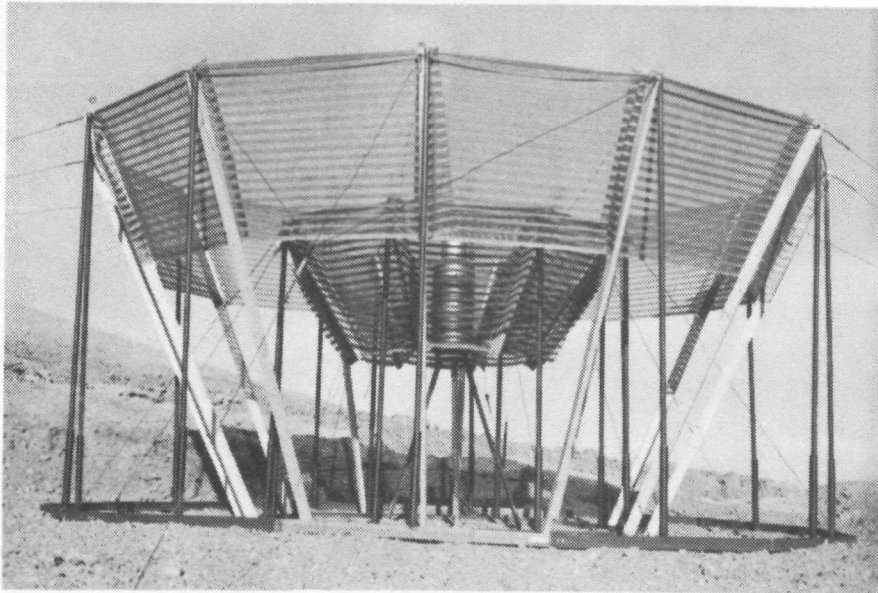


Figure 20. Wyoming windshield design with precipitation gauge was used at the two Wyoming Demonstration Areas.

Aquifer development, recharge and/or discharge was monitored at each Demonstration Area. Professional ground-water hydrologists were consulted in determining the final location and depths of observation wells at each study area (Figures 11, 12, 13). Wells were positioned and drilled so as to maximize the opportunity to monitor existing and developing aquifer fluctuations, determine hydraulic gradients and flow direction and monitor possible changes in water quality. Water levels within three wells at Savage and Beulah were monitored continuously with stage recorders. Water levels in other wells were measured periodically.

Weighing lysimeters averaging about 1360 Kg (3000 lbs.) in mass were utilized in each watershed to determine evapotranspirative patterns in spoils as a function of different treatments (Figures 11, 12, 13). Recent lysimetry developments have made it possible to construct intermediate size units by employing fluid bag transducers with manometer tube readout. Also, one lysimeter per demonstration area had an electrical output transducer connected to the data acquisition system. The reader is referred to Appendix I for a discussion on the development and testing of these lysimeters.

Five neutron access tubes (5.08 cm inside diameter aluminum pipe) were placed within the boundaries of each microwatershed to allow measurement of soil water content (Figures 11, 12, 13). Soil profile moisture was determined for each tube on a monthly basis using a neutron emission probe and sealer (Troxler).

WATERSHED SOIL, CHEMICAL, PHYSICAL, AND CLAY MINERALOGY ANALYSES

Introduction

Detailed knowledge of the soil, chemical and physical characteristics within watersheds aids in interpretation of data and observations on ground-water quality, runoff water quality, soil water movement and plant development. Also, an understanding of clay mineralogy is basic for predicting watershed behavior. Soils dominated by clay minerals tend to expand upon wetting, i.e. smectite (also known as montmorillonite). The soil particles become oriented in a manner which restricts infiltration-percolation processes. Conversely, in a soil dominated by clays that tend to hold their structure upon wetting, i.e. kaolinite and illite, the infiltration-percolation processes may be relatively rapid. Thus, the dominant types of clay minerals in the surface material of a mine spoil watershed may be a major factor affecting the amount of runoff and erosion.

Methodolgy

Each treatment watershed was core sampled to a depth of 275 cm at three diagonally oriented sites. Each core was divided into four increments of 0-30 cm, 30-90 cm, 90-150 cm, and 150-275 cm. These increments were analyzed for texture, organic matter, electrical conductivity, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, pH, exchangeable Ca-Mg-Na-K, B, Zn, Cu, Mn, Fe, Pb, Cd and Ni. Laboratory procedures are specified in Table 1.

In each watershed, five subsamples from the 0-15 cm soil depth were composited for mineralogy analysis. The particle size distribution was

Table 1. Guide used in Montana for rating soil material for use as a final plant growth medium cover for mined land. Lab procedures and Red Flag levels listed are used for soil analysis and interpretation in this report.

Sampling Scheme		Suspect Levels	Laboratory Procedure
Soil Survey 30 cm increment to 180 cm depth	Overburden 3 m increment		
saturation %	saturation %		U.S.D.A. Handbook 60, p. 84, method 2 & 3a.
mechanical analysis	mechanical analysis	clay>40%	A.S.A. Agronomy Monograph No. 9, method 43-5, p. 563-566.
conductivity	conductivity	>4mmhos/cm	U.S.D.A. Handbook 60, p. 88-89.
pH	pH	>8.3	U.S.D.A. Handbook 60, p. 102.
Ca	Ca		U.S.D.A. Handbook 60, p. 84, method 2 & 3a. Atomic Absorption Spectrophotometry.
Mg	Mg		Same as Ca.
Na	Na		Same as Ca.
SAR	SAR	>10	as meq/L $Na/[(Ca + Mg)/2]^{1/2}$
B	B	8 ppm	Hot water extraction with B free condenser tubes.
	NO ₃ -N	10 ppm	A.S.A. Agronomy Monograph No. 9, p. 1212, method 84-5.3.
	NH ₄ -N	10 ppm	Jackson, M.A. 1958. Soil chem. anal., Prentice Hall, Inc. p. 19, 194-195.
	Se	2 ppm	NaBH ₄ extraction, atomic absorption.
	Mo	0.3 ppm	A.S.A. Agronomy Monograph No. 9, p. 1054-1057, method 74-2.
	Hg	500 ppb	Gaseous hydride-hot water extraction. EPA. 1774. Meth. chem. anal. of water & wastes.
	Zn	40 ppm	DTPA Extractable. SSSAP, Vol. 35, No. 4, 1971, p. 600-602.
	Mn	60 ppm	Same as Zn.
	Cu	40 ppm	Same as Zn.
	Cd	1 ppm	Same as Zn.
	Pb	5 ppm	Same as Zn.
	Ni	1 ppm	Same as Zn.
	PO ₄ -P		NaHCO ₃ extraction. Olsen, S.R. 1954. U.S.D.A. Circular No. 939, March.

determined using the pipette method. Clay mineralogy analysis was performed with x-ray diffraction under supervision of Dr. M. Klages, Professor of Clay Mineralogy at Montana State University.

Results:

Table 1 presents a guide used in Montana for rating soil material for use as a surface plant growth medium cover on shaped mine spoils. The column titled "suspect levels" indicates the predetermined level of concentration at which an element may adversely influence plant growth and in some cases, water quality. It should be realized that these suspect levels are in a constant process of changing as our technology grows, and that some trace element suspect levels are not confirmed due to the lack of studies with consistent results. Tables 2 through 16 (pages 28-42) present data which quantifies the chemical and physical nature of the soil in microwatersheds located at the Colstrip, Savage and Beulah Demonstration Areas.

Tables 2 through 6 (pages 28-32) present soil analysis data from watersheds located at the Colstrip Demonstration Area. Trace elements were found to be in low to moderate concentrations. The area is neither saline or alkali in nature. Nitrates were at relatively high levels as compared to rangeland and there seemed to be nitrate accumulation at depths greater than 90 cm. Soil profile texture was predominately sandy loam.

Tables 7 through 11 (pages 33-37) present soil analyses data from watersheds located at the Savage Demonstration Area. Nitrates and

phosphates were present in relatively high concentrations as compared to native rangeland. Trace elements, major cations (Ca, Mg, Na, NH_4 , and K) and anions (NO_3 -N, PO_4 -P, SO_4 and B) were found consistently low to normal concentrations in all watersheds. The soil profile texture was predominantly a fine sandy loam but ranged from sand to clay, and contained a considerable amount of gravel.

Tables 12 through 16 describe the soil status of the five watersheds at the Beulah Demonstration Area. This site is saline in nature as most electrical conductivity analyses exceed the suspect level of 4 mmhos/cm. Sodium adsorption ratios (SAR) were not determined on these samples, however additional soil samples were collected from the 0-20 cm (8 inch) depth on each watershed. Analysis of these samples indicated the average SAR across all watersheds was 16.3, but ranged from 13.3 to 20.2. Thus the soil material at this Demonstration was saline and sodic in nature. The soil profile texture ranged from clay to loam but was predominately silty clay. Nitrate, ammonium, and phosphate levels were relatively high. All trace elements (Ni, C, Pb, Mn, Cu, Fe, and Zn) analyzed were found to be in moderate concentrations except nickel which generally exceeded 1.0 ppm. This level of nickel is considered excessive in Montana. What effect this has on plant production has not been determined at this Demonstration Area.

The above soil characteristics indicate that all Demonstrations Areas are individually unique, and differences between watersheds within an area are small. The North Dakota area was more salty in nature which may affect the plant-water balance and ultimately plant growth and production. This area was also characterized by an abundance of clayey textured soil material

Table 2. Soil analyses from 3 sampling sites in the nontopsoil-chiseled treated watershed located at the Colstrip, Montana, demonstration area. Samples were collected during the winter, 1975.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm	B ppm
1	0-30	8.9	< 0.15	0.18	0.95	3.38	16.37	1.75	0.13	88	1.38	SL	2.2	0.64	8.0	0.6	1.0	0.69	0.23	0.51	0.04
1	30-90	8.9	< 0.15	0.25	0.35	3.38	13.00	2.20	0.13	63	38.0	SL*	4.0	0.02	4.0	< 0.1	0.4	0.64	0.23	0.38	0.11
1	90-150	8.9	< 0.15	0.20	0.95	3.38	14.25	1.55	0.13	2.5	1.38	SL	2.2	0.86	4.0	0.1	0.4	1.19	0.23	0.38	0.17
1	150-275	8.4	< 0.15	0.53	11.10	6.75	13.37	2.00	0.13	2.5	115.0	L	0.8	2.16	16.2	1.5	1.8	0.80	0.23	0.77	0.03
2	0-30	8.7	2.73	0.22	0.95	3.38	12.50	1.75	0.13	88	9.1	SL	1.5	0.86	15.2	0.6	3.2	1.24	0.23	0.38	0.01
2	30-90	8.8	1.78	0.24	2.85	6.75	17.25	1.55	0.13	88	5.5	SL	1.5	0.20	7.2	0.1	0.4	0.80	0.23	0.38	0.02
2	90-150	8.6	1.87	0.52	8.55	3.38	11.25	2.20	0.13	2.5	15.4	L	1.1	0.20	7.2	0.1	0.4	0.80	0.23	0.25	0.01
2	150-275	8.5	< 0.15	0.84	54.75	27.01	9.52	1.75	0.13	88	24.2	L	0.8	0.50	11.9	0.4	2.8	0.97	0.23	0.38	0.04
3	0-30	8.5	< 0.15	0.78	6.50	3.38	9.52	1.75	< 0.13	88	>138	SL*	5.1	1.86	9.3	1.2	2.0	1.24	0.23	0.51	0.06
3	30-90	8.7	< 0.15	0.40	3.50	3.38	4.50	1.75	< 0.13	2.5	95.6	SL*	2.2	2.80	10.9	1.2	1.8	1.35	0.23	0.77	0.06
3	90-150	8.5	< 0.15	0.68	4.10	6.75	8.75	1.28	< 0.13	2.5	115.0	slL	1.5	2.50	12.2	1.8	2.4	1.63	0.23	0.64	--
3	150-275	8.6	< 0.15	0.70	3.50	6.75	4.50	1.55	< 0.13	2.5	98.3	SL*	2.0	3.10	11.9	1.0	2.0	1.46	0.23	0.64	0.07

*insufficient sample, hand texture

Table 3. Soil analyses from 3 sampling sites in the topsoil-chiseled treated watershed located at the Colstrip, Montana, demonstration area. Samples were collected during the winter, 1975.

Site	Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm	B ppm
1	0- 30	8.7	< 0.15	0.21	3.50	6.75	24.12	2.00	0.13	63	3.44	SL	5.1	0.02	3.8	< 0.1	1.2	0.69	0.35	0.38	0.15
1	30- 90	8.7	< 0.15	0.22	0.15	6.75	17.25	2.45	0.13	63	4.70	LS	1.5	0.02	7.8	< 0.1	1.2	0.69	0.23	0.51	0.27
1	90-150	8.9	< 0.15	0.16	0.95	6.75	19.00	2.68	0.13	63	25.20	LS	1.1	< 0.02	6.6	< 0.1	1.0	0.86	0.23	0.51	0.04
1	150-275	8.7	< 0.15	0.29	4.90	6.75	30.65	2.95	0.13	63	32.30	SL	4.8	0.36	9.2	< 0.1	2.0	0.80	0.23	0.51	0.29
2	0- 30	8.7	1.97	0.31	5.95	6.75	12.50	0.80	0.13	113	2.06	SL	4.8	0.02	3.8	< 0.1	1.4	0.58	0.23	0.38	0.15
2	30- 90	8.6	1.01	0.42	4.10	10.13	12.10	1.55	0.13	63	8.50	SL	1.5	0.42	7.5	0.4	1.4	0.80	0.23	0.38	0.01
2	90-150	8.5	1.30	0.86	12.85	3.38	9.12	1.55	0.13	63	25.20	SL	2.2	0.20	5.5	< 0.1	1.0	0.91	0.23	0.25	0.02
2	150-275	8.2	1.78	0.76	13.30	6.75	14.25	2.20	0.13	63	22.0	L	1.5	1.50	11.9	1.1	1.8	1.19	0.23	0.64	0.17
3	0- 30	8.6	< 0.15	0.28	7.95	3.38	13.87	2.20	0.13	88	1.38	SL	4.0	0.36	6.6	0.1	1.0	0.91	0.23	0.38	0.34
3	30- 90	7.8	0.92	0.82	10.90	13.51	17.25	2.45	0.13	63	>138	SL	1.1	0.20	10.2	0.1	2.4	0.80	0.23	0.38	0.38
3	90-150	8.2	0.15	0.68	13.30	3.38	11.25	1.75	0.25	2.5	>138	SL	3.5	1.58	10.0	0.6	2.8	1.19	0.23	0.38	0.16
3	150-275	8.3	1.30	0.62	13.30	6.75	14.60	2.00	0.25	88	>138	SL	0.8	0.14	13.8	< 0.1	1.8	1.30	0.23	0.38	0.09

Table 4. Soil analyses from 3 sampling sites in the nontopsoil-gouged treated watershed located at the Colstrip, Montana, demonstration area. Samples were collected during the winter, 1975.

Site	cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm	B ppm
1	0-30	8.6	<0.15	0.34	4.10	6.75	29.75	3.63	0.13	113	6.1	SL	5.1	0.28	7.8	0.2	1.2	0.80	0.23	0.38	0.21
1	30-90	8.5	<0.15	0.52	2.90	1.00	25.50	3.15	0.13	113	>138	SL	1.5	0.58	11.2	0.5	1.2	1.02	0.23	0.51	0.01
1	90-150	8.5	<0.15	0.46	10.00	1.00	25.88	2.95	0.13	63	>138	SL	1.5	0.72	15.5	0.6	2.0	0.97	0.35	0.64	0.09
1	150-275	8.4	<0.15	0.55	7.95	3.38	10.00	1.55	<0.13	63	>138	SL	2.5	0.86	10.9	0.4	1.8	0.97	0.23	0.38	0.10
2	0-30	8.7	<0.15	0.26	0.35	3.38	17.25	1.75	0.25	63	6.98	SL	3.2	1.00	13.8	0.5	2.8	1.19	0.23	0.38	0.01
2	30-90	8.9	1.11	0.22	0.95	13.61	14.25	1.75	0.25	63	8.50	SL	2.2	0.20	4.6	<0.1	2.8	0.80	0.23	0.25	0.01
2	90-150	8.8	2.93	0.33	4.90	6.75	9.12	1.55	0.25	63	9.90	SL	1.5	0.58	13.5	0.6	2.4	1.24	0.23	0.38	0.05
2	150-275	8.6	1.97	0.37	7.15	6.75	13.37	1.75	0.13	2.5	11.30	SL	1.1	1.08	15.8	0.9	3.6	1.52	0.23	0.64	0.13
3	0-30	8.9	<0.15	0.20	0.95	6.75	14.60	1.75	0.25	63	0.30		1.1	1.00	9.8	0.4	2.0	0.97	0.23	0.38	0.04
3	30-90	9.0	<0.15	0.24	0.95	3.38	18.05	2.45	0.25	63	0.30	SL	1.5	2.38	10.9	1.6	1.8	1.41	0.23	0.77	0.05
3	90-150	8.8	<0.15	0.34	4.10	3.38	19.75	2.45	0.13	63	56.40	SL*	1.5	2.16	13.3	1.7	2.8	1.08	0.23	0.90	0.07
3	150-275	8.7	<0.15	0.60	13.30	30.39	11.75	1.75	0.25	2.5	107.5	SL	0.8	0.28	10.0	<0.1	1.4	0.91	0.23	0.51	0.07

*insufficient sample, hand texture

Table 5. Soil analyses from 3 sampling sites in the topsoil-gouged treated watershed located at the Colstrip, Montana, demonstration area. Samples were collected during the winter, 1975.

Site	Gr Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/ 100 g	Mg meq/ 100 g	Na meq/ 100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm	B ppm
1	0- 30	8.3		0.26	4.1	6.75	27.12	2.45	0.25	113	9.1	SL	4.4	0.42	7.0	0.2	2.0	1.13	0.35	0.64	0.81
1	30- 90	8.3	< 0.15	0.40	3.5	3.38	19.75	2.95	< 0.13	63	>138	SL	0.8	0.86	15.8	0.8	1.4	1.02	0.35	0.64	0.19
1	90-150	8.4	< 0.15	0.56	15.55	6.75	20.62	2.95	0.13	63	>138	SL	1.1	0.92	14.1	0.6	2.4	1.52	0.35	0.64	0.41
1	150-275	8.2	< 0.15	0.64	16.35	10.13	16.37	2.45	0.13	63	>138	L	2.0	1.72	19.6	1.5	4.4	0.69	0.35	0.77	0.23
2	0- 30	8.7	< 0.15	0.23	1.55	<1.00	15.5	1.75	0.13	63	0.3	SL	3.5	0.58	9.8	0.5	1.2	0.97	0.23	0.38	0.29
2	30- 90	8.8	< 0.15	0.28	1.55	3.38	10.4	1.75	0.13	63	49.2	SL	0.8	0.78	10.0	0.4	1.8	1.02	0.23	0.38	0.24
2	90-150	8.2	1.59	0.56	12.55	10.13	8.25	2.00	0.13	63	>138	SL	2.5	1.28	13.8	0.8	2.8	1.02	0.23	0.64	0.49
2	150-275	8.5	< 0.15	0.44	10.60	3.38	13.87	2.45	0.13	63	>138	SL	2.2	1.20	12.2	0.4	2.0	0.86	0.23	0.51	0.23
3	0- 30	8.8	0.63	0.23	2.20	3.38	21.05	2.20	0.13	63	17.1	SL	2.5	1.00	12.2	0.2	3.6	1.02	0.23	0.64	0.01
3	30- 90	9.0	0.34	0.27	1.55	10.13	9.12	2.00	0.13	63	1.38	SL	1.1	1.36	15.5	< 0.1	3.6	1.30	0.23	0.64	0.02
3	90-150	8.5	< 0.15	0.42	8.55	10.13	14.60	2.43	0.13	88	61.1	SL	2.0	1.20	20.6	1.1	3.6	1.30	0.23	0.38	0.05
3	150-275	8.6	0.63	0.54	8.55	10.13	17.70	1.75	0.13	63	5.5	SL	4.0	0.36	11.9	0.4	1.4	0.69	0.23	0.38	0.03

Table 6. Soil analyses from 3 sampling sites in the topsoil-dozer basin treated watershed located at the Colstrip, Montana, demonstration area. Samples were collected during the winter, 1975.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm	B ppm
1	0- 30	8.6	< 0.15	0.31	10.6	3.38	12.1	1.55	0.13	88	5.5	SL	2.5	0.72	7.8	0.5	1.8	1.24	0.23	0.64	0.26
1	30- 90	8.4	0.25	0.52	7.15	10.13	10.0	2.00	0.18	88	115.0	SL	1.5	1.80	12.2	1.9	2.4	0.86	0.23	0.64	0.29
1	90-150	8.6	< 0.15	0.49	17.15	6.75	16.0	2.20	0.13	63	>138	SL	2.2	0.86	9.0	0.2	1.4	1.02	0.23	0.51	0.18
1	150-275	8.3	0.72	0.67	39.95	20.26	19.0	2.00	0.13	2.5	>138	SL	1.5	0.78	17.0	0.6	3.4	0.80	0.23	0.51	0.18
2	0- 30	8.7	< 0.15	0.22	4.10	10.13	16.37	1.75	0.13	88	6.1	SL	5.1	0.42	7.2	0.2	1.4	1.02	0.23	0.38	0.26
2	30- 90	8.7	1.11	0.56	8.55	13.51	17.25	2.20	0.13	63	>138	SL	7.2	0.78	18.4	0.6	4.8	0.75	0.23	0.38	0.01
2	90-150	8.8	< 0.15	0.44	2.85	3.38	15.50	2.20	0.13	63	122.9	SL	1.5	0.36	9.3	0.2	1.8	0.80	0.23	0.38	0.04
2	150-275	8.9	1.59	0.27	3.50	3.38	10.40	1.55	0.13	63	34.4	SL	2.5	0.36	7.2	0.2	1.2	0.86	0.23	0.38	0.12
3	0- 30	8.8	1.59	0.23	2.20	6.75	13.37	1.28	0.13	63	1.38	SL	2.5	0.42	16.6	0.4	1.4	0.80	0.23	0.64	0.15
3	30- 90	8.5	1.87	0.72	33.10	3.38	15.12	2.20	0.13	63	122.9	SL	2.5	0.72	17.6	0.8	3.4	1.13	0.23	0.64	0.06
3	90-150	8.4	0.82	0.64	17.15	3.38	9.12	1.55	0.13	63	31.1	SL	2.0	1.14	17.2	1.1	3.6	1.13	0.23	0.64	0.10
3	150-275	8.3	1.97	0.78	5.95	10.13	13.37	2.00	0.13	63	44.0	SL	1.1	0.92	15.5	1.0	3.4	1.13	0.23	0.64	0.23

Table 7. Soil analyses from 3 sampling sites in the nontopsoil-chiseled treated watershed located at the Savage, Montana, demonstration area. Samples were collected during the fall, 1975.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/ 100 g	Mg meq/ 100 g	Na meq/ 100 g	K ppm	SO ₄ ppm	Texture	P ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0-30	8.3	<.15	0.28	0.35	--	24.12	2.0	0.13	3	11.3	LFS	17.5	<0.02	5.2	0.1	1.8	<0.23	0.11	<0.12
1	30-90A	8.0	<.15	0.30	0.15	--	22.75	2.45	0.13	63	18.2	LFS	17.5	<0.02	5.2	0.1	1.8	<0.23	0.11	0.77
	30-90B	7.6	<.15	0.68	0.95	--	27.13	3.4	0.13	63	>138	FSL	29.5	<0.02	5.5	0.5	1.2	0.23	0.23	0.12
1	90-150	7.8	<.15	0.48	0.35	--	22.75	2.20	0.13	3	>138	LFS	12.5	<0.02	5.5	0.4	1.4	0.23	<0.11	<0.12
1	150-275	8.4	--	0.76	0.35	--	26.25	3.15	0.13	3	>138	LFS	12.5	0.28	8.4	1.4	1.4	0.23	0.35	0.12
2	0-30	8.2	0.15	0.73	4.9	--	28.5	4.3	0.13	88	--	SL+	47.5	<0.02	5.5	1.1	1.4	0.78	<0.11	0.12
2	30-90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	90-150	8.5	<.15	0.60	0.95	--	26.25	2.68	0.13	63	58.0	SL	14.5	0.20	5.5	1.0	1.4	0.50	<0.11	0.12
2	150-275	8.5	1.20	0.83	0.15	--	24.5	3.63	0.13	63	82.5	FSL	12.5	0.02	6.6	0.4	1.8	0.50	<0.11	0.12
3	0-30	8.1	0.63	0.76	2.85	--	26.25	5.25	0.13	63	13.8	SCL-	14.5	0.20	6.3	0.8	1.4	<0.23	0.11	<0.12
3	30-90	7.5	2.26	2.55	0.25	--	29.75	6.88	0.13	63	>138	SCL	14.5	0.08	14.4	0.8	1.8	<0.23	0.11	<0.12
3	90-150	7.7	0.92	1.68	0.35	--	28.5	5.43	0.13	63	>138	SL+	5.0	0.08	10.0	0.6	2.0	0.23	0.11	0.25
3	150-275	7.5	0.63	1.75	0.35	--	25.88	4.78	0.13	63	>138	SL-	7.7	0.02	7.8	0.6	1.8	0.50	<0.11	<0.12

-- No Sample

Table 8. Soil analyses from 3 sampling sites in the topsoil-chiseled treated watershed located at the Savage, Montana, demonstration area. Samples were collected during the fall, 1975.

Site	Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.2	< .15	1.09	2.85	5.10	31.5	4.78	0.50	150	2.75	L	12.5	0.28	<0.8	0.8	1.2	0.23	0.23	1.58
1	30- 90	8.4	< .15	0.92	0.35	3.40	31.5	3.63	0.13	150	>138	VFSL	12.5	<0.02	4.0	0.2	1.0	0.50	0.23	0.25
1	90-150	8.3	< .15	0.97	0.25	5.04	27.12	3.8	0.13	188	>138	VFSL	7.7	<0.02	2.6	0.2	0.4	0.23	<0.11	0.38
1	150-275	8.4	< .15	0.87	2.20	6.72	29.38	3.8	0.13	113	>138	FSL	7.7	<0.02	4.0	0.4	1.0	<0.23	<0.11	0.25
2	0- 30	8.2	< .15	1.64	1.55	5.04	31.5	5.7	0.13	188	>138	FSL	12.5	0.02	3.8	0.8	1.2	0.50	0.35	0.38
2	30- 90	8.2	< .15	1.96	0.35	6.72	29.75	6.15	0.13	113	>138	SIL	1.0	<0.02	2.8	0.5	1.4	0.23	0.11	0.25
2	90-150	8.3	< .15	1.38	0.15	3.36	30.65	5.7	0.13	113	>138	FSL	1.0	<0.02	3.9	0.2	1.2	<0.23	0.11	0.90
2	150-275	8.5	< .15	0.78	0.95	6.72	28.88	4.3	0.13	113	107.5	FSL	14.5	<0.02	3.2	0.5	1.0	<0.23	0.11	0.38
3	0- 30	8.6	< .15	0.58	0.35	3.36	26.25	3.4	0.13	88	73.7	FSL	5.0	<0.02	3.8	0.5	1.2	0.23	0.11	0.38
3	30- 90	8.4	0.53	0.72	1.25	6.72	32.0	5.9	0.13	150	0.30	SL	12.5	<0.02	6.0	0.8	1.4	0.50	0.23	0.20
3	90-150	8.4	< .15	1.17	0.35	3.36	29.38	4.3	0.13	88	>138	FSL	5.0	0.08	4.0	0.6	1.2	0.78	0.35	0.12
3	150-275	8.4	< .15	0.83	0.35	1.68	30.65	3.8	0.13	63	>138	FSL	12.5	0.02	3.8	1.0	1.8	<0.23	0.11	<0.12

Table 9. Soil analyses from 3 sampling sites in the nontopsoil-gouged treated watershed located at the Savage, Montana, demonstration area. Samples were collected during the fall, 1975.

Site	cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0-30	6.7	4.07	4.75	0.35	6.72	34.9	7.1	0.13	88	>138	SL	21.0	1.8	100.0	2.9	4.2	1.86	0.46	1.86
1	30-90	6.5	2.73	4.9	0.25	10.19	33.7	4.55	0.13	63	>138	SL	23.5	3.32	112.0	1.4	4.4	0.50	0.23	0.38
1	90-150	7.9	1.11	1.6	0.95	1.68	32.38	5.43	0.13	88	>138	FSL	12.5	0.92	13.3	1.7	2.4	0.23	0.23	0.90
1	150-275	8.4	<.15	1.11	0.35	5.04	29.75	4.55	0.13	63	>138	FSL	7.7	<0.02	2.6	0.5	0.4	<0.23	0.11	0.38
2	0-30	8.6	<.15	0.52	2.85	6.72	30.18	2.68	0.13	63	51.7	FSL	7.7	<0.02	2.6	0.2	1.2	<0.23	0.11	1.04
2	30-90	8.5	<.15	0.58	0.15	5.04	28.88	3.4	0.13	63	>138	FSL	7.7	<0.02	2.6	0.4	1.0	<0.23	0.11	0.38
2	90-150	8.3	<.15	1.28	0.15	1.68	28.0	2.68	0.13	63	>138	FSL	7.7	<0.02	2.6	0.2	1.0	<0.23	<0.11	0.20
2	150-275	8.2	<.15	1.23	0.15	3.37	28.5	2.95	0.13	63	>138	VFFL	7.7	<0.02	2.4	0.2	1.0	0.23	0.11	0.12
3	0-30	8.1	0.44	1.12	2.85	6.72	29.75	5.43	0.13	88	>138	SL+	12.5	0.72	7.0	1.8	1.4	1.59	0.23	0.38
3	30-90	8.0	0.72	2.25	0.15	5.04	32.0	6.88	0.13	113	>138	CL-	7.7	1.2	8.4	2.4	1.2	0.50	0.11	0.64
3	90-150	8.0	0.15	--	0.15	3.36	31.5	5.9	0.13	113	>138	L+	7.7	0.42	6.6	1.6	1.2	1.32	<0.11	0.38
3	150-275	8.1	<.15	1.32	0.35	6.72	31.5	5.25	0.13	88	>138	CL-	5.0	0.2	6.0	0.9	1.0	1.05	0.35	0.38

-- No Sample

Table 10. Soil analyses from 3 sampling sites in the topsoil-gouged treated watershed located at the Savage, Montana, demonstration area. Samples were collected during the fall, 1975.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.1	0.15	0.72	1.55	3.36	30.65	5.25	0.13	150	5.5	S+	12.5	0.08	7.0	1.0	2.0	< 0.23	0.35	0.38
1	30- 90	8.6	< .15	0.33	0.35	6.72	26.25	2.20	0.13	63	29.2	SL	5.0	< 0.02	4.0	0.2	1.2	0.78	0.23	0.25
1	90-150	8.5	< .15	0.45	0.15	1.68	28.5	2.45	0.13	63	93.0	FSL	5.0	< 0.02	3.9	0.2	1.2	< 0.23	0.11	0.12
1	150-275	8.3	< .15	0.99	0.25	5.04	25.88	4.3	0.13	63	138	LFS	5.0	< 0.02	3.2	0.4	1.4	< 0.23	0.23	0.38
2	0- 30	8.1	0.15	0.99	2.85	6.80	32.75	7.1	0.13	88	31.1	FSL	7.7	0.02	5.5	0.6	1.4	< 0.23	0.23	0.64
2	30- 90	7.7	< .15	0.96	0.15	3.40	31.05	5.0	0.13	88	>138	SL+	5.0	0.02	3.0	0.6	1.2	< 0.23	0.23	0.25
2	90-150	8.6	< .15	0.40	0.15	1.70	25.0	2.68	0.13	63	55.0	LFS	5.0	< 0.02	3.0	0.2	1.2	< 0.23	0.11	0.38
2	150-275	8.7	< .15	0.56	0.35	1.70	25.0	3.15	0.13	3	111.1	SL	2.5	< 0.02	2.8	0.2	1.4	0.78	< 0.11	0.12
3	0- 30	8.3	0.15	0.73	2.85	3.40	30.65	6.63	0.13	113	1.38	FSL	21.0	0.02	5.8	0.8	1.4	< 0.23	0.11	0.38
3	30- 90	7.9	1.20	0.92	0.15	5.10	29.75	5.9	0.13	113	>138	L-	29.5	0.14	7.5	0.6	1.4	< 0.23	< 0.11	0.12
3	90-150	8.3	< .15	1.09	0.15	1.70	29.75	6.15	0.13	88	>138	L+	12.5	0.08	5.8	0.8	1.2	0.78	0.58	0.38
3	150-275	8.3	< .15	1.56	0.15	--	26.25	6.15	0.13	88	>138	FSL	17.5	< 0.02	5.5	0.6	1.0	< 0.23	0.11	0.38

-- No Sample

Table 11. Soil analyses from 3 sampling sites in the topsoil-dozer basin treated watershed located at the Savage, Montana, demonstration area. Samples were collected during the fall, 1975.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100 g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	7.8	< .15	1.05	5.25	--	26.7	4.13	0.13	113	9.9	FSL+	14.5	0.14	5.8	0.20	2.0	< 0.23	0.11	0.12
1	30- 90	7.9	< .15	0.73	0.95	--	26.7	4.3	0.13	113	>138	LFS	12.5	< 0.02	7.0	0.10	2.0	1.05	0.23	< 0.12
1	90-150	8.1	< .15	1.40	0.35	--	27.12	4.3	0.13	88	>138	SL	12.5	< 0.02	6.6	0.9	1.2	1.05	< 0.11	1.04
1	150-275	8.4	< .15	1.08	0.95	--	24.5	3.63	0.13	3	>138	SL	7.7	< 0.02	2.6	0.4	1.0	< 0.23	0.11	0.12
2	0- 30	8.1	1.97	1.26	35.3	--	34.12	6.15	0.13	150	7.4	CL-	21.0	0.14	18.4	1.0	0.40	< 0.23	0.35	1.58
2	30- 90	8.5	< .15	0.50	7.15	--	25.0	2.95	0.13	63	0.3	LFS	7.7	< 0.02	3.2	0.4	1.0	0.50	0.11	0.25
2	90-150	8.5	< .15	0.48	3.5	--	22.38	2.45	0.13	63	12.9	LFS	7.7	0.08	6.3	0.8	1.4	< 0.23	0.23	0.12
2	150-275	8.6	< .15	0.53	0.15	--	22.75	2.0	0.13	3	36.6	LFS	7.7	< 0.02	4.9	0.2	1.0	< 0.23	0.23	< 0.12
3	0- 30	7.8	0.25	2.09	12.55	--	30.65	5.9	0.13	88	>138	L+	41.5	0.64	7.8	1.1	2.8	< 0.23	0.35	0.38
3	30- 90	7.9	0.63	2.33	1.55	--	29.75	5.43	0.13	63	127.1	SCL	12.5	0.5	7.0	1.2	2.0	0.23	0.35	0.38
3	90-150	7.9	< .15	2.61	2.2	--	28.5	5.0	0.13	63	115.0	SL	7.7	0.72	7.8	1.1	2.0	0.50	0.23	0.38
3	150-275	7.9	0.15	2.63	0.15	--	30.65	6.4	0.13	88	>138	L+	7.7	0.42	7.8	1.2	3.4	0.23	0.11	0.25

Table 12. Soil analyses from 3 sampling sites in the nontopsoil-chiseled treatment at the Beulah, North Dakota demonstration area. Samples were collected during the spring of 1975 immediately following treatment installation.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	B ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0-30	9.1	-0.15	4.3	10.6	11.76	20.25	7.1	10.05	238	+137.5	0.47	Sic1-M-	5.0	5.8	93.0	4.9	7.4	1.05	0.11	1.72
1	30-90	9.0	-0.15	4.36	0.35	15.12	18.5	6.88	10.5	213	+137.5	0.46	Sic1-M-	5.0	3.6	90.0	4.4	7.4	2.4	0.11	3.43
1	90-150	9.0	0.15	4.39	3.50	16.80	21.5	9.38	8.03	238	+137.5	0.34	Sic1-M-	5.0	5.86	98.0	4.6	5.8	2.67	0.11	2.28
1	150-275	8.8	0.72	4.63	11.95	8.40	22.38	7.55	8.88	213	+137.5	0.44	Sic1-M-	5.0	4.2	78.0	5.8	6.4	1.59	0.23	3.00
2	0-30	8.1	2.16	6.76	5.95	3.36	21.65	10.55	7.68	213	+137.5	0.43	Sic1-M-	12.5	4.18	112.0	5.9	2.0	2.67	0.23	3.87
2	30-90	8.9	0.53	4.78	7.15	20.16	21.5	7.1	8.7	213	+137.5	0.13	Sic1-M0	7.7	5.64	122.0	4.6	10.2	1.32	0.35	3.00
2	90-150	8.6	1.87	3.18	4.9	33.60	19.75	7.33	11.15	300	+137.5	0.52	Sic-M-	5.0	12.0	102.0	7.1	13.4	3.76	0.35	6.56
2	150-275	8.9	2.26	4.63	7.95	15.12	22.75	8.7	9.93	238	+137.5	0.52	Sic1-M	5.0	2.8	100.0	6.4	7.4	2.4	4.17	0.35
3	0-30	8.1	2.06	6.82	7.95	3.36	21.87	9.88	7.25	213	--	0.56	--	7.7	4.18	102.0	6.6	1.8	1.86	0.23	4.62
3	30-90	8.6	1.11	5.74	8.55	5.04	21.87	8.7	8.88	213	+137.5	0.81	Sic1-M-	5.0	5.0	98.0	4.9	4.8	1.86	0.23	3.87
3	90-150	8.8	0.44	5.02	7.95	35.28	21.87	8.7	12.38	275	+137.5	0.58	Sic1-M-	7.7	3.6	100.0	7.0	8.2	2.4	0.23	3.87
3	150-275	8.7	0.92	4.96	8.55	13.44	21.87	7.55	9.28	238	+137.5	0.42	Sic1 M-	7.7	5.92	90.0	4.9	6.2	1.05	0.35	3.43

-- No Sample

Table 13. Soil analyses from 3 sampling sites in the topsoil-chiseled treatment at the Beulah, North Dakota demonstration area. Samples were collected during the spring of 1975 immediately following treatment installation.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	B ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.0	3.12	2.0	13.3	3.36	32.0	7.78	0.13	188	--	--	--	17.5	0.50	46.0	1.5	3.4	1.05	0.11	1.72
1	30- 90	8.8	1.68	4.9	17.15	11.76	22.38	7.78	7.05	213	+137.5	1.04	CL-	14.5	4.2	98.0	5.6	6.7	1.59	0.23	3.43
1	90-150	9.0	0.82	4.66	7.15	28.56	24.1	8.0	10.05	238	+137.5	0.42	Sic1-	7.7	5.8	122.0	5.3	7.6	2.13	0.23	3.43
1	150-275	9.1	0.63	4.36	7.95	18.48	23.25	8.0	8.25	213	+137.5	0.36	Sic1-	7.7	5.0	78.0	6.2	7.6	2.13	0.23	3.29
2	0- 30	8.5	1.49	3.26	13.3	3.36	23.25	8.0	0.70	238	+137.5	0.30	L	7.7	1.5	55.0	2.0	3.4	1.32	0.11	1.58
2	30- 90	9.0	0.34	4.93	5.25	13.44	21.87	7.8	9.28	213	+137.5	0.55	Sic1-	12.5	3.6	115.0	6.4	7.6	1.86	0.23	4.32
2	90-150	8.9	1.01	4.74	4.9	16.80	21.5	7.55	9.5	213	+137.5	0.41	Sic1-	5.0	31.6	98.0	6.5	8.0	1.86	0.11	3.43
2	150-275	8.7	9.15	5.2	9.15	11.76	23.6	9.15	8.5	275	+137.5	0.52	S11+	12.5	5.8	98.0	7.6	5.8	2.95	0.23	4.62
3	0- 30	8.1	2.73	1.44	10.6	10.50	25.5	7.8	0.13	213	73.7	--	--	12.5	0.64	46.0	1.7	3.6	0.5	-0.11	1.44
3	30- 90	8.7	0.44	5.2	8.55	21.84	24.12	7.8	7.25	275	+137.5	0.69	Sic1-	12.5	5.92	93.0	4.9	5.2	3.22	0.23	4.02
3	90-150	8.8	1.59	4.06	7.95	13.44	23.75	8.2	6.68	238	+137.5	0.58	Sic1-	5.0	3.6	98.0	5.0	4.8	1.59	0.23	4.91
3	150-275	8.8	0.44	4.9	5.25	15.12	21.87	8.48	7.05	213	+137.5	0.47	Sic1-	7.7	5.8	93.0	5.8	4.0	3.22	0.35	4.76

-- no sample

Table 14. Soil analyses from 3 sampling sites in the nontopsoil-gouged treatment at the Beulah, North Dakota demonstration area. Samples were collected during the spring of 1973 immediately following treatment installation.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	B ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.6	1.11	5.2	11.95	21.84	23.25	8.2	9.5	275	+137.5	0.33	Sic1-	17.5	5.5	102.0	7.4	6.2	1.32	0.35	3.43
1	30- 90	8.8	1.59	4.66	12.55	5.04	23.25	8.48	10.9	300	+137.5	0.49	Sic1-	7.7	5.0	109.0	8.8	8.9	1.86	0.23	3.87
1	90-150	8.7	0.34	5.14	13.3	16.80	22.75	8.2	10.5	275	+137.5	0.66	Sic1-	12.5	10.0	109.0	8.2	8.0	2.13	0.35	2.57
1	150-275	8.0	3.31	6.14	10.6	13.44	25.0	9.15	11.15	300	+137.5	1.28	Sic1+	7.7	10.8	125.0	9.2	10.0	3.76	0.23	7.44
2	0- 30	8.0	1.39	5.56	7.95	1.68	19.4	10.33	5.2	213	+137.5	0.76	CL	14.5	3.02	84.0	4.4	3.2	0.78	0.11	3.14
2	30- 90	8.5	2.64	5.2	7.15	10.08	24.12	8.48	11.15	238	+137.5	1.66	--	12.5	19.4	133.0	7.6	8.6	2.4	0.23	4.32
2	90-150	8.2	3.79	6.16	7.95	10.08	23.25	8.7	11.75	350	+137.5	0.80	Sic1	14.5	13.6	141.0	9.8	14.8	3.49	0.46	5.06
2	150-275	8.4	3.59	6.13	14.1	6.72	4.15	7.33	11.5	300	--	--	--	12.5	18.0	98.0	9.7	8.0	6.2	0.46	11.70
3	0- 30	7.9	2.54	7.6	7.15	8.40	28.15	11.0	7.68	213	+137.5	0.94	--	21.0	5.28	133.0	6.8	2.0	1.59	0.23	4.76
3	30- 90	8.9	1.20	5.05	10.0	1.68	21.87	7.78	10.5	300	--	0.60	Sic1-	7.7	13.6	66.0	7.3	5.4	3.22	0.70	1.31
3	90-150	9.0	-0.15	4.6	1.55	33.60	20.62	6.63	10.75	213	+137.5	1.38	Sic1-	7.7	3.6	102.0	5.9	8.9	3.49	0.23	3.14
3	150-275	8.0	0.72	4.63	7.15	20.16	20.62	9.15	8.03	238	+137.5	0.53	Sic1-	1.0	6.4	92.0	5.9	5.4	2.40	0.11	4.91

-- No Sample

Table 15. Soil analyses from 3 sampling sites in the topsoil-gouged treatment at the Beulah, North Dakota demonstration area. Samples were collected during the spring of 1975 immediately following treatment installation.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	B ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.1	2.45	2.02	4.9	5.04	21.87	8.0	0.13	213	+137.5	0.40	CL	14.5	0.50	58.0	1.5	3.4	0.78	0.11	1.17
1	30- 90	7.9	2.45	6.1	17.95	6.72	21.05	10.55	4.18	213	+137.5	0.48	CL	12.5	2.6	109.0	3.6	1.4	1.32	0.11	2.57
1	90-150	7.7	2.93	7.57	11.95	10.08	26.25	12.38	5.8	188	+137.5	0.53	CL	7.7	4.4	152.0	4.1	1.4	1.05	0.11	4.62
1	150-275	8.4	0.44	5.38	11.10	6.72	24.12	10.55	6.45	213	+137.5	0.38	CL	5.0	4.76	78.0	4.6	2.8	1.86	0.11	3.73
2	0- 30	8.1	2.35	1.58	7.15	26.88	19.4	7.1	0.13	150	+137.5	0.40	CL	12.5	0.58	63.0	1.4	8.0	1.32	0.11	1.17
2	30- 90	8.7	0.63	4.63	10.6	5.04	20.25	8.93	7.5	188	+137.5	0.49	CL	5.0	4.4	90.0	4.6	4.0	1.86	0.35	3.73
2	90-150	8.2	1.11	6.02	11.95	25.20	23.6	10.55	7.5	213	+137.5	0.70	CL	7.7	3.6	100.0	4.4	1.8	1.59	0.11	3.14
2	150-275	7.3	2.16	6.76	9.15	8.40	21.05	11.25	7.15	213	+137.5	0.83	CL	23.5	3.4	215.0	5.0	2.8	2.4	0.23	3.29
3	0- 30	8.2	1.39	1.44	4.1	3.36	16.37	6.4	0.13	213	111.1	0.39	L+	12.5	0.92	55.0	2.0	4.0	1.32	0.11	1.58
3	30- 90	8.3	1.11	5.32	5.95	5.04	20.62	11.25	7.5	213	+137.5	0.50	Sic1	7.7	3.6	70.0	5.3	2.4	1.32	0.11	2.71
3	90-150	8.0	0.82	4.48	5.25	10.08	21.05	12.38	4.0	213	+137.5	0.35	Sic1+	21.0	2.94	72.0	5.0	0.4	1.32	0.23	2.57
3	150-275	7.9	1.97	7.84	9.15	25.20	25.5	12.38	5.8	213	+137.5	0.57	Sic1+	14.5	3.68	72.0	4.8	1.4	1.86	0.11	3.43

Table 16. Soil analyses from 3 sampling sites in the topsoil-dozer basin treatment at the Beulah, North Dakota demonstration area. Samples were collected during the spring of 1975 immediately following treatment installation.

Site	Cm Depth	pH	Organic Matter %	Electrical Conductivity mmhos/cm	NO ₃ -N ppm	NH ₄ -N ppm	Ca meq/100g	Mg meq/100 g	Na meq/100 g	K ppm	SO ₄ ppm	B ppm	Texture	PO ₄ -P ppm	Zn ppm	Fe ppm	Cu ppm	Mn ppm	Pb ppm	Cd ppm	Ni ppm
1	0- 30	8.3	0.72	3.05	5.25	5.04	17.7	8.0	2.25	213	--	0.31	--	12.5	0.78	32.0	2.4	1.4	1.05	-0.11	0.77
1	30- 90	8.2	-0.15	6.4	12.55	3.36	24.5	13.13	7.5	238	+137.50	0.27	Sic1	12.5	0.92	55.0	2.8	1.2	1.05	-0.11	1.31
1	90-150	7.9	1.87	6.4	7.15	5.04	27.12	12.88	5.8	213	+137.5	0.43	CL	7.7	2.3	70.0	3.6	2.0	0.5	0.23	2.14
1	150-275	7.7	3.31	5.8	5.25	6.72	27.12	13.55	5.63	275	+137.5	0.78	CL	12.5	2.08	92.0	4.1	2.0	1.86	0.11	2.42
2	0- 30	8.0	1.68	7.84	37.6	6.72	25.5	11.0	8.03	238	+137.5	0.49	CL	12.5	4.04	84.0	5.7	2.0	1.86	0.23	3.29
2	30- 90	8.0	0.63	6.49	14.9	10.08	27.72	11.5	6.45	213	+137.5	0.47	CL	12.5	1.80	49.0	3.6	1.4	1.05	0.23	1.72
2	90-150	8.1	0.82	6.34	11.1	5.04	26.7	11.65	7.05	213	+137.5	0.24	CL	23.5	1.20	44.0	2.9	2.0	1.86	-0.11	0.64
2	150-275	8.4	0.63	5.74	11.95	5.04	23.25	11.65	6.45	213	+137.5	0.23	L	23.5	1.44	49.0	2.8	2.0	1.05	0.11	1.31
3	0- 30	8.0	2.16	1.16	4.9	-0.50	21.5	7.1	0.13	213	--	0.33	L	14.5	0.28	46.0	1.2	4.0	1.32	-0.11	1.17
3	30- 90	8.5	2.16	5.2	99.15	28.56	22.38	7.55	11.28	275	+137.5	0.42	Sic1-	12.5	4.84	80.0	6.1	5.4	0.78	0.23	2.85
3	90-150	7.6	2.73	6.43	3.5	-0.50	24.5	10.05	7.25	213	+137.5	0.86	CL	17.5	2.50	66.0	3.6	2.8	1.32	0.11	1.58
3	150-275	7.8	0.82	5.5	2.85	6.72	20.62	11.25	4.53	213	+137.5	0.28	Sil	14.5	1.20	52.0	2.9	1.2	1.05	0.11	0.90

-- No Sample

as compared to the two areas in Montana. This heavy texture has created a number of problems associated with watershed installation, operation, and maintenance. Slumping has occurred which caused alteration of surface flow gradients in several watersheds. Consequently, surface flow water collection facilities were rendered useless until modified. Also, numerous large and small, extremely deep holes (termed "piping") have developed on these watersheds. Remedial tactics in plugging these holes with bentonite and straw have been successful.

Table 17 presents results of the particle size analyses of the surface 15 cm of soil in each watershed. The Colstrip site was found to

Table 17. Particle size analyses of the surface 15 cm of soil in each treatment watershed at the Colstrip, Savage and Beulah Demonstration Areas. Samples were collected during the summer of 1975.

Watershed Treatment	% Sand	% Silt	% Clay	Textural Class
<u>Colstrip</u>				
nontopsoil-gouged	68	21	11	sandy loam
topsoil-gouged	74	14	12	sandy loam
nontopsoil-chiseled	67	23	10	sandy loam
topsoil-chiseled	78	11	11	sandy loam
topsoil-dozer basin	59	29	12	sandy loam
<u>Savage</u>				
nontopsoil-gouged	51	34	15	loam
topsoil-gouged	57	27	16	sandy loam
nontopsoil-chiseled	56	26	18	sandy loam
topsoil-chiseled	37	39	24	loam
topsoil-dozer basin	41	34	25	loam
<u>Beulah</u>				
nontopsoil-gouged	11	49	40	silty clay loam
topsoil-gouged	64	20	16	sandy loam
nontopsoil-chiseled	17	46	37	silt clay loam
topsoil-chiseled	58	23	19	sandy loam
topsoil-dozer basin	55	25	20	sandy loam

be typically a sandy loam while the Savage site was loam and sandy loam in texture. At the Beulah site the topsoil was a sandy loam texture with spoils material a silt clay loam texture. Therefore, the effect of surface manipulation is being evaluated on the variety of textural classes from sandy at Colstrip to clayey at Beulah.

Table 18 presents results of the clay mineralogy analyses. It should be pointed out that clay mineralogy determinations by any technique are

Table 18. Clay mineralogy analyses for the Colstrip, Savage and Beulah Demonstration Areas. Samples were collected during the summer of 1975 from the surface 15 cm of each treatment watershed.

Watershed Treatment	Type and Predominance* of Clay Mineral					
	Smectite	Illite	Kaolinite	Quartz	Chlorite	Vermiculite
<u>Colstrip</u>						
nontopsoil-gougued	low-mod	low-mod	mod	0	low	trace
topsoil-gougued	low	mod	mod	0	low	0
nontopsoil-chiseled	mod	low	low-mod	trace	tr-low	low
topsoil-chiseled	0	mod	mod	0		0
topsoil-dozer basin	low	mod	mod	0	low	0
<u>Savage</u>						
nontopsoil-gougued	mod	mod	low	0	low	trace
topsoil-gougued	mod-high	low-mod	low	trace	low	0
nontopsoil-chiseled	mod	mod	low	0	low	0
topsoil-chiseled	mod-high	low-mod	low	trace	low	0
topsoil-dozer basin	mod-high	low-mod	low	trace	low	0
<u>Beulah</u>						
nontopsoil-gougued	high	low	tr-low	0	low	0
topsoil-gougued	mod-high	mod	low	0	low	0
nontopsoil-chiseled	high	low	trace	tr-low	low	0
topsoil-chiseled	mod-high	low	tr-low	0	low	0
topsoil-dozer basin	high	low	tr-low	0	low	0

* very high = 75-100%
high = 50-75%
moderate = 25-50%
low = 5-25%
trace = less than 5%

qualitative in nature, thus exact numbers are not derived. Watersheds at the Colstrip Demonstration are dominated by nonexpanding clays, i.e. illite and kaolinite. Expanding smectite clay was also present in quantities as high as 50%, but the dominance of illite and kaolinite would permit little swelling effect in this spoil system. The demonstration areas at both Savage and Beulah are dominated by smectite clay.

Therefore, if all three demonstrations had identical slope and were similar in all other respects, the runoff would be expected to be greater at the Savage and Beulah watersheds as compared to the Colstrip watersheds. This could be attributed to the swelling of the smectite clays upon wetting at both Savage and Beulah, thus reducing the infiltration-percolation rates and increasing runoff.

The surface 15 centimeters of soil at the Savage Demonstration Area was dominated by expanding clay, i.e. smectite. The nature of this clay in the soil system tends to close the water conducting pores upon wetting. Figure 23 (page 49) demonstrates this principle as the infiltration rate decreased rapidly with time for all treatments. The Beulah Demonstration Area was also dominated by expanding clays, but as shown in Figure 24 (page 50) the infiltration rates did not decrease rapidly with time as compared to the results noted at the Savage Demonstration Area. One possible explanation for this observation was that the salt concentration in the bulk soil solution was higher in concentration than that in the overlapping diffuse layers of the clay particles, as described by Gouy (1910) diffuse layer theory. By osmosis mechanisms, this would mean water could not readily flow between clay particles and cause this clay to expand, thereby decrease infiltration. Soil analyses from this site indicated saline conditions, so this is a potential mechanism to explain our observations.

WATERSHED INFILTRATION CHARACTERISTICS

Introduction

Infiltration is the process by which water enters the soil through the surface. The rate of this process is of prime concern in watershed studies because infiltration rate on slopes with little vegetation is an important factor in determining runoff and erosion characteristics. The infiltration rates were determined at the Colstrip, Savage and Beulah Demonstrations on three types of surface manipulation treatments.

Methodology

The infiltrometer apparatus is shown in Figure 21. Meeuwig (21)

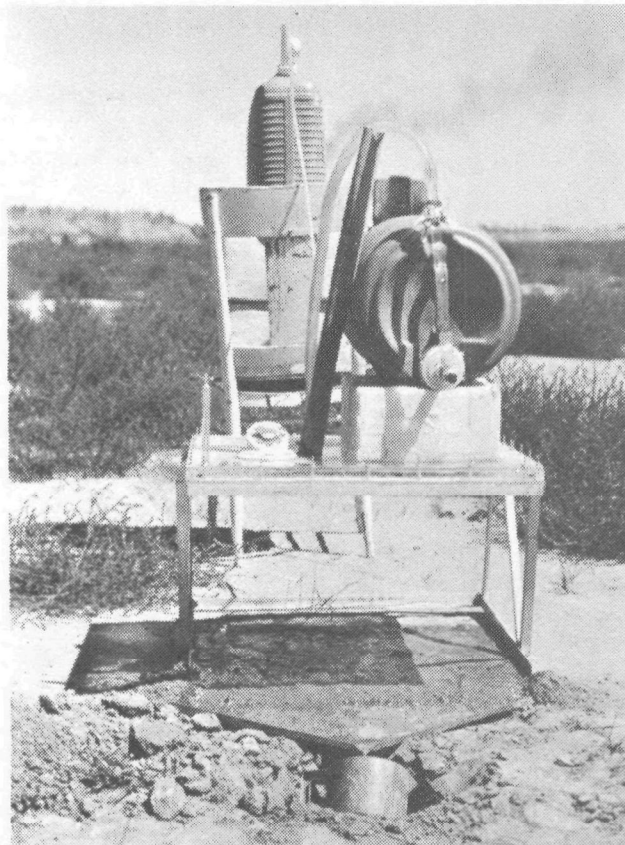


Figure 21. Infiltration apparatus in operation showing runoff into a cup.

described construction of this apparatus. Basically the device consists of a plexiglass water reservoir which delivers a raindrop effect onto the soil surface through 517 capillary tubes. A flowmeter registers the water application rate while soil surface runoff is funneled into a measuring cup. The infiltrometer encompasses a $.31 \text{ m}^2$ sample area. Simulated rainfall was applied at a rate of 15 cm/hr and readings were made every 2.5 minutes during a 30 minute test. The high rate of water application simulated a severe rainstorm in volume of water applied, but not in raindrop collision force.

No infiltration measurements were made on watersheds with the gouge treatment. The spacing and size of these gouges compared to the infiltrometer dimensions invalidated the technique. No complications arose on watersheds that were chiseled and topsoil-chiseled. The infiltrometer was set up in the bottom of dozer basins rather than between the basins.

Results

Figures 22, 23 and 24 describe the infiltration characteristics at the three Demonstration Areas. The surface 15 cm of soil at the Colstrip Demonstration was dominated by non-expanding clays, i.e. kaolinite and illite (see Clay Mineralogy section in this report). When this clay type is present, the infiltration rate tends to remain rapid with time since these clays swell little upon wetting, thus the water conducting pores remain open. Figure 22 substantiates this principle as the infiltration rates remained relatively rapid throughout the 30 minute test in the chiseled watersheds. The topsoiled-dozer basin watershed infiltration rate

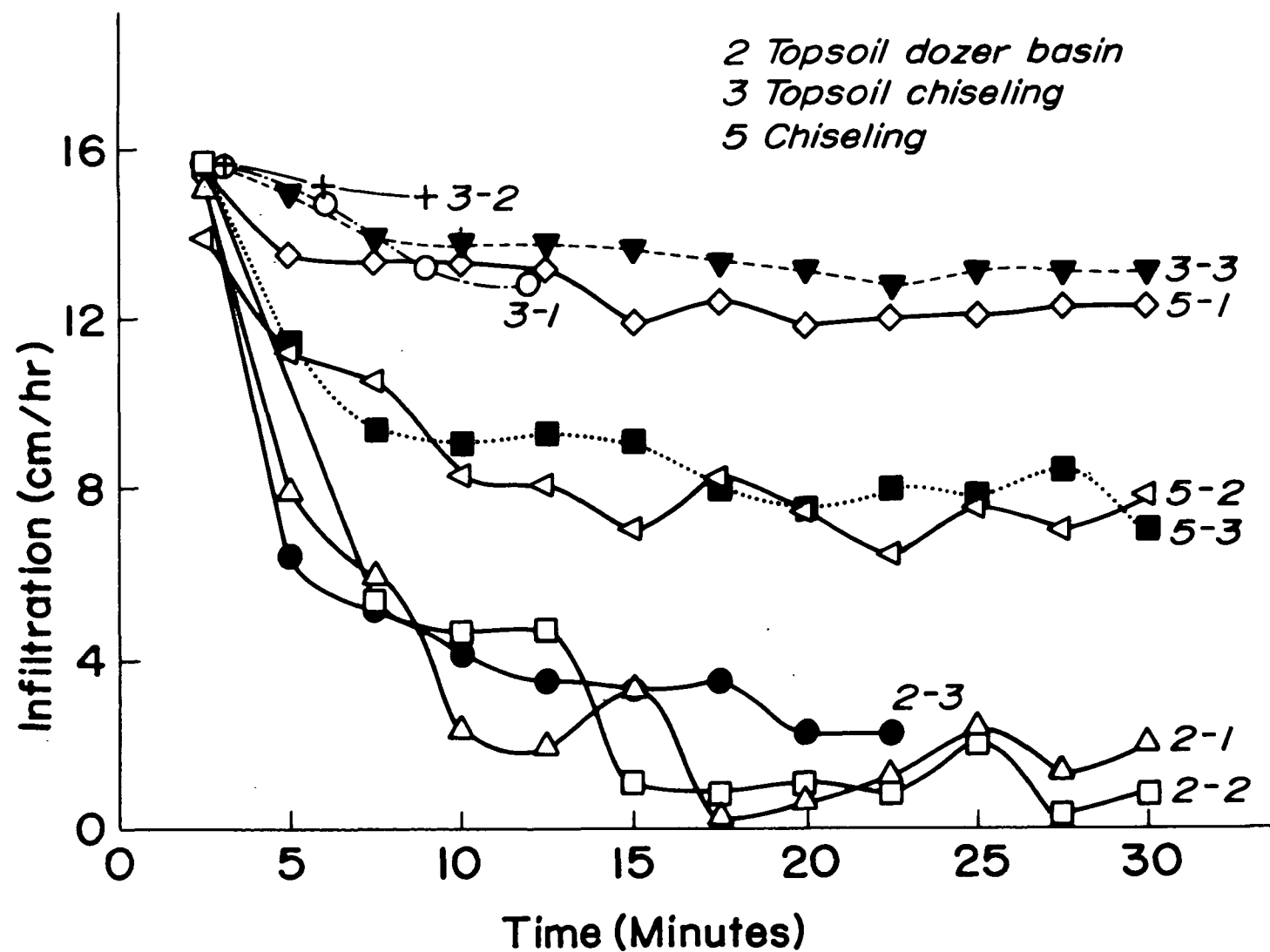


Figure 22. Infiltration rates as a function of three surface manipulation treatments at the Colstrip Demonstration Area during August, 1975. The first identification digit represents treatment while the second denotes replication.

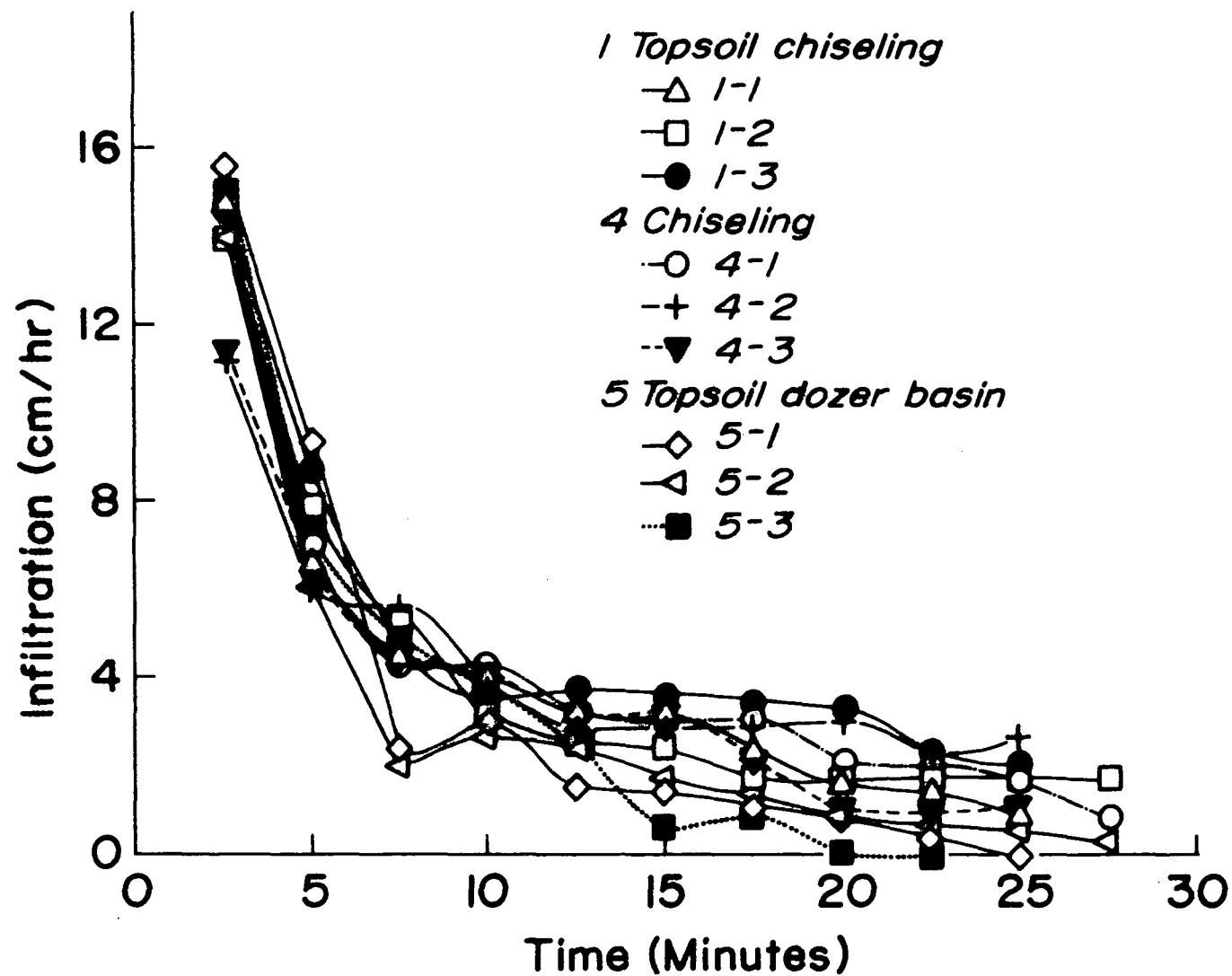


Figure 23. Infiltration rates as a function of three surface manipulation treatments at the Savage Demonstration Area during August, 1975. The first identification digit represents treatment while the second denotes replication.

1 Topsoil chiseling
 3 Chiseling
 5 Topsoil dozer basin

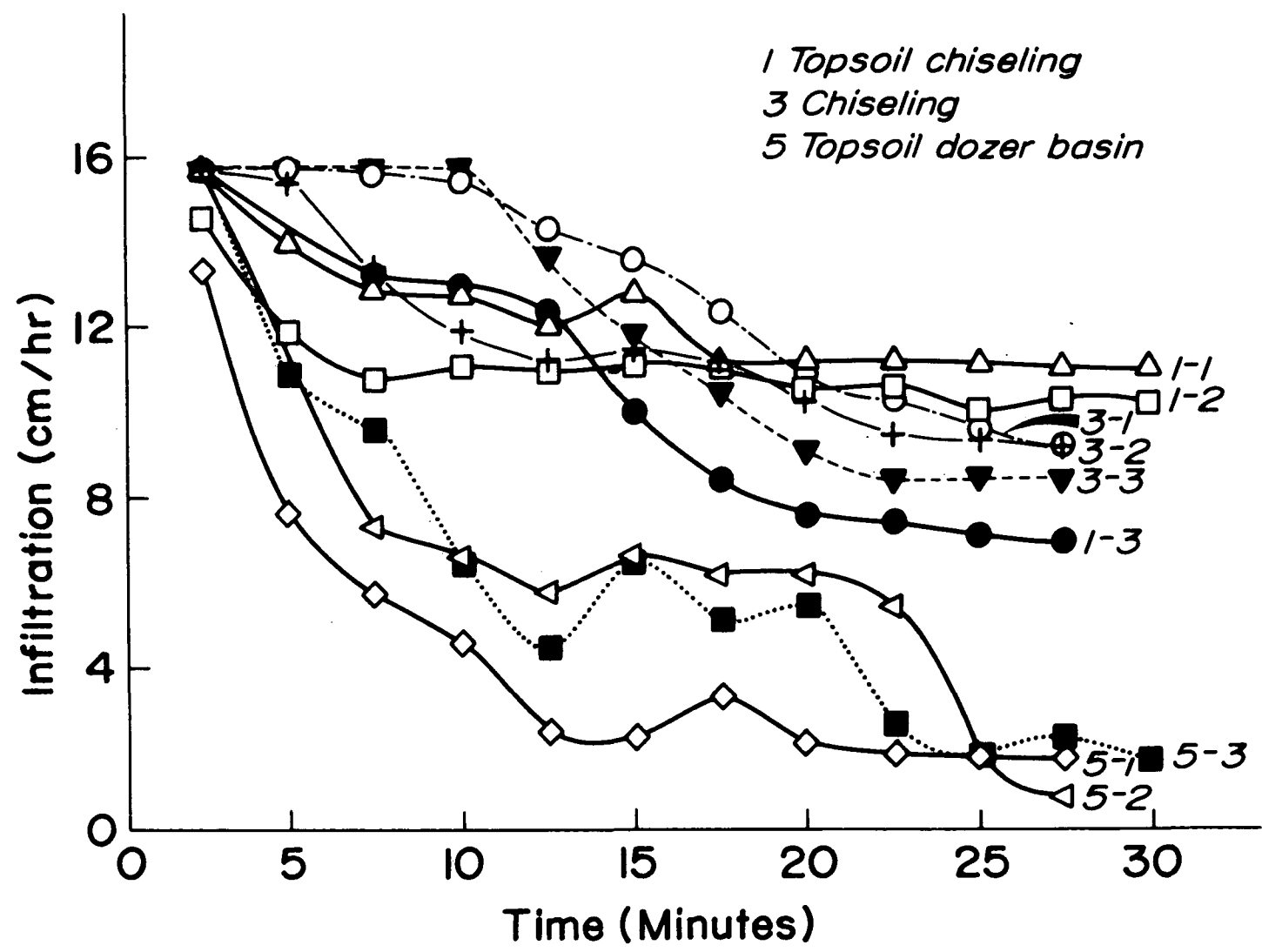


Figure 24. Infiltration rates as a function of three surface manipulation treatments at the Beulah Demonstration Area during August, 1975. The first identification digit represents treatment while the second denotes replication.

decreased with time, but the rate of decrease was considered moderate. Although the watershed with dozer basins was topsoiled, the base of these basins lies below the topsoil layer. Therefore, the comparatively lower infiltration rate measured in the bottom of these dozer basins was, in part, due to no topsoil. The watershed that was topsoiled and chiseled had the greatest infiltration rate at the Colstrip Demonstration.

Figure 23 shows the infiltration rate over time for three surface treatments at the Savage Demonstration. As previously discussed, the dominant clay mineral located in the surface soil at this demonstration was smectite. Therefore, a rapidly decreasing infiltration rate during a precipitation event could have been expected, since substantial swelling of the soil particles would probably occur resulting in closure of soil water conducting pores. Figure 23 demonstrates this phenomenon. A rapid decrease in infiltration rate was measured in these watersheds, regardless of surface modification type or the presence of topsoil. Since there was little difference in infiltration rates between watersheds, a valid comparison of runoff as a function of surface manipulation treatment depression volumes is possible at this Demonstration Area.

Figure 24 shows the infiltration rate over time for three surface treatments at the Beulah Demonstration. The surface clay mineralogy at this demonstration was dominated by smectite, and the physical analysis indicated a high percentage of clay was present. Also the soil material at this site contains relatively high concentrations of sodium. These characteristics would generally result in a soil with extremely low infiltration rates. However, data in Figure 24 demonstrate that during

a 30-minute test the infiltration rates did not in all cases decrease substantially. The infiltration rate of the dozer basin treatment was low after 30 minutes, but neither chiseling treatment underwent a substantial decrease with time. The soil surface on these watersheds exhibited considerable cracking due to the forces of swelling and shrinking. On such surface the infiltration rate may initially be high as water is transmitted through the cracks, but the infiltration rate would probably decline rapidly with time as the cracks closed due to swelling. Therefore, if the infiltration test on these chiseled watersheds would have been conducted longer than 30 minutes, it is highly probable that the rate of infiltration would have approached zero. The foregoing prediction was substantiated through field observations completed several days following an intense precipitation event which revealed large quantities of water remaining ponded in depressions formed in nontopsoiled treatments.

WATERSHED SURFACE STABILITY AND EROSION CHARACTERISTICS

Introduction

Several severe rainstorms occurred during the spring of 1975 at the Colstrip, Savage and Beulah Demonstration Areas. At that time the surface manipulation treatments had not been installed at the Beulah area, and watershed boundary and surface flow diversion installations had not been completed at the other two areas. Consequently, during these storms the watershed areas upslope from the microwatersheds contributed extra runoff across the surface manipulation treatments. Following these rains many gully systems were present, but the degree of severity varied between treatments.

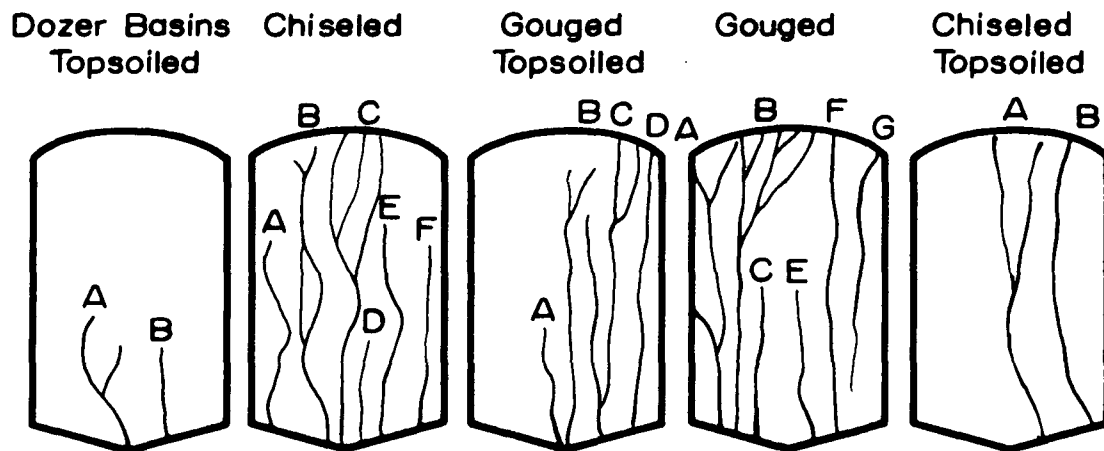
Methodology

Sketches were made of the gully patterns in each watershed and the volume of these gullies were determined by on-site measurements.

Results

Figure 25 illustrates the gully formation patterns across watersheds located at the Colstrip and Savage Demonstration Areas. The volume of each gully, identified by an alphabetic letter, is shown in Table 19. These data show that compared to all treatments, watersheds with top-soil-dozer basins were most effective in reducing erosion processes which led to gully formation. Topsoiled watersheds with the gouged

Savage Demonstration



Colstrip Demonstration

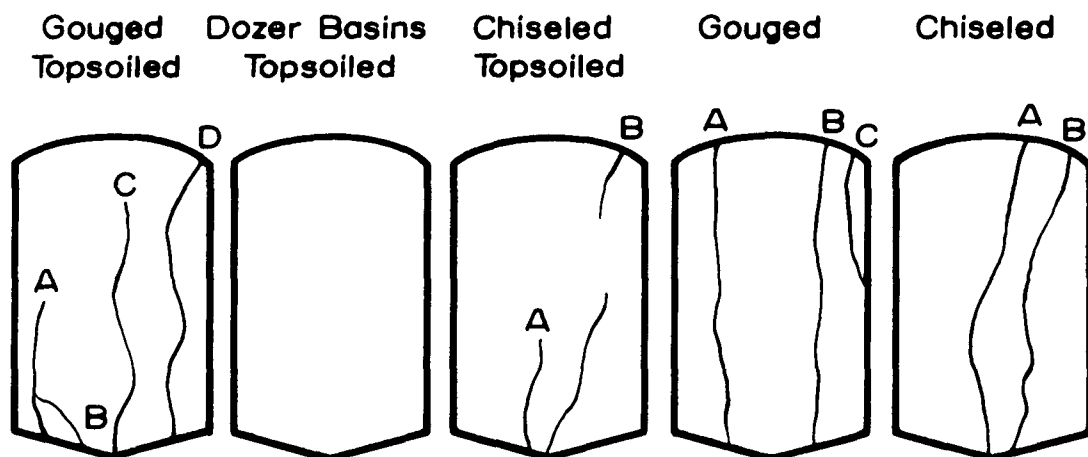


Figure 25. Gully formation patterns across watersheds located at the Colstrip and Savage Demonstrations. Data were collected during August 1975.

Table 19. Volume of individual gullies as illustrated in Figure 25.

Watershed Treatment	Gully Volume (m ³)						Total
	A	B	C	D	E	F	
<u>Savage Demonstration</u>							
nontopsoil-gouged	6.20	2.40	0.30	0.30	3.40	1.40	14.00
topsoil-gouged	0.05	2.20	3.20	1.40			6.85
nontopsoil-chiseled	1.00	14.70	11.30	0.40	5.00	4.10	36.50
topsoil-chiseled	12.7	8.0					20.70
topsoil-dozer basins	0.60	2.10					2.70
<u>Colstrip Demonstration</u>							
nontopsoil-gouged	8.10	1.00	0.60				9.7
topsoil-gouged	0.20	.06	0.40	0.60			1.26
nontopsoil-chiseled	3.90	2.70					6.6
topsoil-chiseled	0.50	5.20					5.70
topsoil-dozer basins							NONE

treatment were more effective in controlling erosion as compared to nontopsoil-gouged, topsoil-chiseled and nontopsoil-chiseled watersheds. These data demonstrate that topsoiling had the effect of reducing erosion. Both the gouged and chiseled watersheds with topsoil underwent less gully formation as compared to nontopsoil-gouged and chiseled watersheds.

SURFACE MANIPULATION DEPRESSION WATER CAPACITY AND SEDIMENTATION CHARACTERISTICS

Introduction

The main objective of surface manipulation treatment is the reduction of surface runoff and associated sedimentation. Depressions that are created must have a sufficiently long life to reduce erosion while vegetation is being established.

The capacity of basins to hold surface runoff is of prime importance. Depression capacity is defined as that volume of water that may be held in the basins without overflow occurring. Infiltration is prevented in the field measurement of depression capacity. Therefore, in reality, infiltration is expected to increase the depression water capacity of all surface treatments.

Methodology

Surface detention capacity of each treatment was determined at all three Demonstration Areas during the summer of 1975 and again during the summer of 1976. A light weight plastic sheet was placed over a chiseled area and a wooden frame, 1 m² in dimension, was placed over the plastic. As water was applied onto the sheet the weight adjusted the plastic to conform with the soil surface. Excess water was allowed to drain, and that detained was measured in a graduated cylinder. This measurement was replicated three times in each chiseled watershed and data were extrapolated to a per unit hectare basis.

A similar procedure was used on watersheds with gouged and dozer basin surface manipulations. Here, a single gouge or dozer

basin was lined with a plastic sheet and then filled to capacity with water, and the water volume was measured. This test was replicated three times and the data extrapolated to a per unit hectare basis. In order to determine sedimentation characteristics in each treatment, the associated loss of water storage capacity with time was determined.

Results

The density of surface depressions varies considerably from treatment to treatment (Table 20). Chiseling as a treatment is not

Table 20. Mean surface density of depressions created by surface manipulation techniques at the Colstrip, Savage and Beulah Demonstration Areas.

Treatment	Depressions per unit area (ha)
	<u>Colstrip Demonstration</u>
topsoil-gouged	7,815
nontopsoil-gouged	4,775
topsoil-dozer basin	1,220
	<u>Savage Demonstration</u>
topsoil-gouged	6,230
nontopsoil-gouged	5,646
topsoil-dozer basin	825
	<u>Beulah Demonstration</u>
topsoil-gouged	5,325
nontopsoil-gouged	4,025
topsoil-dozer basin	375

intermittent across an area, but consists of closely spaced, continuous channels which are placed on the contour. As a treatment, chiseling can be considered more easily to have a capacity to hold water than to have a density. The spacing of channels is controlled

by the distance between chisels on the chisel plow. The density of a surface manipulation treatment varies from several hundred to thousands of depressions per hectare. Even with the most dense gouging treatments, not all of the land surface will be actively entrapping precipitation.

The detention capacity of the surface manipulation treatments evaluated was greatest for dozer basins, intermediate for gouging, and least for chiseling (Table 21). A considerable amount of variation

Table 21. The average water depression capacity on mine spoil watersheds as a function of five treatments at the Colstrip, Savage and Beulah Demonstration Areas.

Treatments	Surface Water Holding Capacity (L/Ha x 10 ³)		
	Colstrip	Savage	Beulah
	<u>Before Sedimentation*</u>		
nontopsoil-chiseled	--	--	122.2
topsoil-chiseled	--	--	176.4
nontopsoil-gouged	24.7	38.2	133.8
topsoil-gouged	68.2	25.6	189.5
topsoil-dozer basin	522.9	128.8	--
	<u>July, 1975</u>		
nontopsoil-chiseled	186.5	37.9	--
topsoil-chiseled	81.4	0.0	--
nontopsoil-gouged	11.3	0.7	--
topsoil-gouged	52.8	0.0	--
topsoil-dozer basin	516.4	125.3	--
	<u>June, 1976</u>		
nontopsoil-chiseled	29.1	0.4	27.2
topsoil-chiseled	3.7	0.3	30.9
nontopsoil-gouged	1.4	5.1	113.5
topsoil-gouged	7.4	2.2	198.7
topsoil-dozer basin	295.8	207.9	--

* The Colstrip and Savage Demonstration Areas were measured during April, 1975 and the Beulah Area in August, 1975.

-- Data not collected.

was observed between field sites and topsoiled and non-topsoiled areas. The depression capacity of topsoiled surface treatments was greater on the average than the same treatments on non-topsoiled areas. This may have been the result of larger gouged and dozer basins being constructed in the softer topsoiled areas.

The capacity of a surface treatment to hold water is of little value if the treatment is not long lasting. The rate of sedimentation of basins in a period of time should give an indication of life expectancy. The rate of sedimentation of the surface treatments between April, 1975 and June, 1976 was measured (Table 22) by the

Table 22. Estimated rate of sedimentation and life expectancy of 5 surface manipulation treatments constructed at the Colstrip, Savage, and Beulah Demonstration Areas.

Treatment	Detention Capacity Decrease per Year (%)	Minimum Effective Life of Depression (yrs.)
<u>Colstrip Demonstration</u>		
nontopsoil-chiseled	92	< 2
topsoil-chiseled	85	< 2
nontopsoil-gouged	96	< 2
topsoil-gouged	94	< 2
topsoil-dozer basin	47	> 5
<u>Savage Demonstration</u>		
nontopsoil-chiseled	100.	< 1
topsoil-chiseled	100.	< 1
nontopsoil-gouged	100.	< 1
topsoil-gouged	100.	< 1
topsoil-dozer basin	---	---
<u>Beulah Demonstration</u>		
nontopsoil-chiseled	85	< 2
topsoil-chiseled	90	< 2
nontopsoil-gouged	17	> 5
topsoil-gouged	0	> 5
topsoil-dozer basin	---	---

--- Missing data

methods previously described. It is apparent from these data that additional measurements will be necessary to better quantify this sedimentation process. There are some data discrepancies where the detention capacity for a treatment increased over time. This error originates from not conducting sedimentation measurements at the same locations on these watersheds. Apparently the sedimentation process is variable across each watershed. Permanent markers have been installed in order to perform these measurements at the same location over a period of time.

THE CHEMISTRY OF RUNOFF FROM SPOILS

Introduction

Major streams draining intensive agricultural areas have been monitored for water quality for at least 30 years (3, 14, 27, 37). These data indicate no significant change in water quality even though fertilizer use has increased severalfold in these areas. However, other researchers who have studied runoff from agricultural lands on a smaller scale have measured excessive concentrations of elements, particularly $\text{NO}_3\text{-N}$ (23, 24, 35, 5). Therefore, in addition to trace element concerns, the quality of runoff waters from spoils is of importance since moderate to near maximum rates of fertilizer may be used on newly seeded spoils for vegetation establishment to gain surface stability in the shortest time possible.

The physical, chemical and biological effects of sediment in water makes it a primary hazard to water quality. Wadleigh (33) estimated that four billion tons of sediment wash into the United States' waterways each year and each ton contains 0.9 Kg of N and 0.6 Kg of P.

It has been well established (15,22,30) that sediment contains higher concentrations of nutrients than the soil that remains. For example, in Wisconsin (19) investigators found that eroded material contained 2.7 times as much N, 3.4 times as much P, and 19.3 times as much exchangeable K as the soil that remained. It could be assumed this same phenomenon would apply to most anions and cations. Little fertilizer P leaches through the soil or runs off as inorganic PO_4 in solution, but it can wash off as phosphorus absorbed in sediment (17, 29, 31).

Sediment acts as a scavenger with the ability to absorb or desorb elements on its chemically active surface (11, 20). Therefore, sediment as a pollutant has a two-fold detrimental effect on the environment. It depletes the land resource from which it came and often impairs the quality of the water resource in which it is deposited.

Methodology

At the flume of each watershed, a portable, automated water sampler was installed to collect samples during each runoff event. Each unit was set to collect a sample at the event initiation and at equal time increments until the event ended or the 24-bottle capacity was filled. The sampler was designed with a high velocity fluid transport system to help prevent settling out of suspended solids. Thus, a rather representative sediment sample can be attained.

Sample preservation prior to laboratory analysis was as outlined by the Environmental Protection Agency (8). Table 23 describes the preservation methodology. The H_2SO_4 acts as a bacterial inhibitor, the HNO_3 prevents metal precipitation, and refrigeration acts as a bacterial inhibitor. All water sample containers underwent a cleansing process before use which included scrubbing with soap, rinsing several times with tap water, rinsing with a dilute HCl solution and finally rinsing several times with distilled water. Specific procedures used in the analysis of water samples are summarized in Table 24.

Table 23. Water sample preservation treatment and corresponding analyses performed. All samples were refrigerated upon treatment.

Preservation Treatment	Analysis Performed
None	pH, electrical conductance, settleable matter, SO_4 , CO_3 , HCO_3 , PO_4 -P, B
H_2SO_4 to pH < 2	NO_3 -N
HNO_3 to pH < 2	Se, Ca, Mg, Na, K, Mn, Cu, Zn, Pb, Cd, Fe (Dissolved metals)

Table 24. Summary of laboratory procedures used for runoff water analyses.

Element	Procedure *+
Pb, Cd, Cu, Fe, Zn, Mg, Mn, Ca, Na, K	Atomic Absorption Spectroscopy
Se	Gaseous Hydride Method
Settleable Matter	Imhoff Cone
pH	Electrode
Conductivity	Conductance Bridge - Meter
HCO_3 , CO_3	Titration
Sulfate	Turbidimetric
PO_4 -P	Persulfate digestion--colorimetric
Boron	Curcumin Method
Nitrate-N	Cd reduction

*All procedures were from "Methods for Chemical Analysis of Water and Wastes." EPA (8).

+All metal analyses are dissolved metals. EPA specifications state water samples for dissolved metal analyses should be filtered (.45 micron) soon as possible to remove sediment material. This operation was performed in the lab at Montana State University which was generally several days after the sample had been collected at the field sites. Current plans are to filter future samples in the field.

Results and Discussion

The purpose of this section is to evaluate the quality of runoff waters from spoils. In order to do this, surface water quality not associated with spoils must be considered, that is, baseline water quality characteristics should be determined. Thus, a discussion follows which indicates what the literature considers acceptable levels of water quality.

On a national basis, federal agencies have published water quality criteria for various uses (Tables 25, 26). Although these standards

Table 25. Drinking water standards of the U.S. Public Health Service^{1/}

Substances	Recommended Limits of Concentrations mg/l	Mandatory Limits of Concentrations mg/l
Arsenic (As)	0.01	0.05
Barium (Ba)	-	1.0
Cadmium (Cd)	-	0.01
Chloride (Cl)	250.0	-
Chromium (Cr ⁺⁶)	-	0.05
Copper	1.0	-
Cyanide (Cn)	0.01	0.2
Fluoride (F)	0.6-1.7	-
Iron (Fe)	0.3	-
Lead (Pb)	-	0.05
Manganese (Mn)	0.05	-
Nitrate (NO ₃)	45.0	-
Phenols	0.001	-
Selenium (Se)	-	0.01
Silver (Ag)	-	0.05
Sulfate (SO ₄)	250.0	-
Total dissolved solids (TDS)	500.0	-
Zinc (Zn)	5.0	-

^{1/}United States Public Health Service standards, 1962.
Public Health Service Publication 956.

Table 26. Recommended ^{2/} surface water criteria for public water supplies, including agricultural irrigation.

Constituent or Characteristic	Permissible Criteria mg/l	Desirable Criteria mg/l
Ammonia	0.5(as N)	< 0.01
Arsenic	0.05	Absent
Barium	1.0	Absent
Boron	1.0	Absent
Cadmium	0.01	Absent
Chloride	250.0	< 25
Chromium (Cr ⁺⁶)	0.05	Absent
Copper	1.0	Virtually absent
Iron (filterable)	0.3	Virtually absent
Lead	0.05	Absent
Manganese (filterable)	0.05	Absent
Nitrates plus nitrites	10 (as N)	Virtually absent
pH (range)	6.0-8.5	Absent
Selenium	0.01	Absent
Silver	0.05	Absent
Sulfate	250.0	< 50
Total dissolved solids (filterable residue)	500.0	< 200
Zinc	5.0	Virtually absent

^{2/} Report of the Committee on Water Quality Criteria, F.W.P.C.A., U.S. Department of Interior, 1968.

are widely quoted for water quality, they are not directly applicable to every situation. In some sections of the United States, such as eastern Montana, the quality of water available from domestic supplies and some municipal supplies does not meet the following standards in one or more respects. Nevertheless, people in such areas have used these waters for lifetimes or generations.

To further orient the discussion on runoff water quality from spoils, surface water quality records from eastern Montana are presented. The U.S. Department of Interior Geological Survey (32)

has collected surface water quality records in Montana for many years. Two of these years, 1964 and 1972, are presented in Table 27. These two years were chosen because they represent a time span and contained the most complete and intensive data from the twelve sites discussed (compared to adjacent years). Although neither Tables 25 and 26 nor Table 27 present the complete list of macro and trace elements, a general overview is attained. In instances where these tables can be compared, the surface waters of eastern Montana do not, on the average, contain element concentrations in excess of national standards.

Tables 28, 29, and 30 present runoff chemistry data from the surface manipulation spoil watersheds at the Colstrip, Savage and Beulah Demonstrations. Three sample bottles were generally required to obtain a complete chemical analysis due to the need for the different preservation treatments (Table 23). As a result, analyses for a single runoff event on a calendar date, shown in Tables 28-30, usually represent a combination of samples which may have been obtained several hours or several days apart. This technique could result in chemical relationships which appear contradictory within the complete analysis, such as ionic balance or the ratio between dissolved solids and specific conductance. It is felt, however, that the technique is adequate for establishing and monitoring baseline chemical characteristics. The following paragraphs discuss the chemical characteristics of runoff from mine spoils at the three Demonstration areas.

Concentrations of the major cations (calcium, magnesium, and sodium) are not particularly high at any of the Demonstration Areas. The concentrations, in general, are consistent with values for other surface waters in southeastern Montana (Table 27). There was some indication that sodium values may have increased during the spring and summer of 1976. However, due to sample contamination and analytical problems, this trend could not be confirmed. Average values for the major anions (bicarbonate and sulfate) were generally within the range of values shown in Table 27.

Concentrations of $\text{PO}_4\text{-P}$ ranging from .02 to .05 ppm have been reported (1, 31) as minimal for supporting algal blooms. Applying this criterion, the $\text{PO}_4\text{-P}$ levels measured in these runoff samples frequently attained or exceeded this concentration. However, it should not be concluded that this $\text{PO}_4\text{-P}$ runoff phenomenon is peculiar only to spoil systems. For example, about 161 km (100 mi) from Colstrip in the irrigated Yellowstone Valley, a three-year study (7) included measurements of $\text{PO}_4\text{-P}$ concentrations in runoff waters from fertilized crop land. Here concentrations ranged from .15 to 1.0 ppm, which is generally higher than the levels measured at all three spoil watershed sites.

The sodium absorption ratio (SAR) is defined by Equation 1 where

$$\text{SAR} = \text{Na} / \left(\frac{\text{Ca} + \text{Mg}}{2} \right)^{\frac{1}{2}} \quad \text{Eq. 1}$$

the concentrations are in milliequivalents per liter. The SAR concept is important regarding the suitability of waters for agricultural irrigation. The sodium content of a soil system can increase when irrigation water is applied with $\text{SAR} > 15$. This is an undesirable process which could result

in the development of a soil with sodic characteristics. Such soils have poor physical conditions, very low infiltration rates and can create difficulties associated with soil-plant water relations. The SAR levels in runoff waters at all three Demonstration Areas were somewhat sporadic with time. In addition, problems with the sodium analysis limited the amount of SAR data available for review. Hopefully, as this study matures, these SAR data will develop a pattern.

Most trace elements were found in low concentrations in runoff waters at all three Demonstrations. Manganese and iron were the only consistent exceptions. Concentrations of these elements in runoff waters at all Demonstrations often exceeded federal standards for drinking water, but were probably acceptable for irrigation purposes. Both lead and cadmium were found in generally acceptable concentrations at all Demonstrations with only occasional samples exceeding drinking water standards. Selenium concentrations in runoff waters were found to be consistently low, and this laboratory determination was eventually discontinued. Both copper and zinc were present in low concentrations at all three Demonstrations. There were few distinguishable characters between Demonstration Areas and between treatments in terms of the chemistry of runoff waters. Although there are some exceptions to the above statements, more data are needed to substantiate these relationships.

Data in Tables 28, 29, and 30 are arranged sequentially by date and runoff event. One might anticipate that the chemistry of the runoff would change during an event, and certainly differences in the sediment load could be expected. At present these data do not demonstrate such trends.

There do not appear to be trends in these runoff data as a function of surface manipulation treatments. However, the point should be made that these data are presented in terms of concentrations and the concentration multiplied by the runoff volume is the nutrient load leaving the watershed. Different volumes of runoff as a function of the surface manipulation were measured, and are discussed in another section of this report (Hydrologic Balance of the Spoil Biosphere); thus, the surface treatments have an indirect effect on the amount of actual chemical load that was leaving spoils as runoff.

Table 27. Surface water quality records⁺ in southeastern Montana during 1972 and 1964.

STATION* NUMBER	CHEMICAL ANALYSIS (ppm)												SAR	SPECIFIC CONDUCTANCE (mmhos/cm)	pH
	Fe	Mn	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ + NO ₂	P	CO ₃	HCO ₃			
1972															
1	.021	.015	17.9	5.56	14.6	3.42	25.3	6.9	.05	.065	0	86.2	.72	.208	7.7
2	.033	--	34	11.2	21.5	3.02	63.3	5.8	.19	--	0	136.7	.82	.348	7.8
3	.025	.020	68.9	22.6	71.2	3.24	254	12.4	--	--	0	177.7	1.9	.789	7.9
4	--	--	65.6	21.8	54	--	238	9.6	.28	.093	--	--	1.6	.766	8.0
5	.0181	.0125	58.1	23.6	20.9	1.71	112	1.5	.07	.03	0	224	.61	.542	8.0
6	.0139	.020	57	33.8	48.9	2.7	190	3.2	.08	.04	0	236	1.2	.716	8.1
7	.0236	--	69.2	23.7	71.8	3.6	252	9.5	.26	--	2.7	188	1.9	.815	8.1
8	.0141	.0145	46.8	16.1	46.3	3.3	144	8.0	.34	.07	.58	156	1.4	.555	7.8
9	.1383	--	66.8	41.3	31.7	3.1	182	3.8	--	--	.58	233	.76	.706	8.1
10	.0308	--	60.7	41.2	68.7	5.2	235	4.0	.14	--	0	269	1.7	.860	7.9
11	--	.0167	126.6	52.7	180.4	--	582		.33	.03	--	--	3.38	1.640	7.8
12	.0291	.0109	53.5	21	63.3	3.9	198	11.6	.20	.03	0	183	1.84	.700	7.9
1964															
2	.0012		40.7	11.5	27.3	3.2	78.7	5.9	.72		0	145	.94	.407	7.4
3	.0066		77.4	25.8	90.9	3.6	294.1	13.5	1.04		0	195	2.16	.920	7.6
7	.012		79	24.6	90.7	3.3	308.3	10.1	.98		0	204	2.26	.957	7.7
10	.006		66.2	48.4	67.3	4.3	237.7	5.0	.26		0	272	1.58	.862	7.8
12	.015		53	22.3	63.9	3.9	205.9	10.0	3.04		0	180	1.65	.718	7.8

⁺All values are averages taken from tables presented in Water Quality Records in Montana, 1964 and 1972. U.S. Dept. of the Interior Geological Survey.

*Station	Location
1	Yellowstone River near Livingston, MT
2	Yellowstone River at Billings, MT
3	Bighorn River at Kane, WY
4	Bighorn River near Hardin, MT
5	Little Bighorn River below Pass Creek near Wyola, MT
6	Little Bighorn River near Hardin, MT
7	Bighorn River at Bighorn, MT
8	Yellowstone River near Miles City, MT
9	Tongue River at State Line near Decker, MT
10	Tongue River at Miles City, MT
11	Powder River at Moorhead, MT
12	Yellowstone River near Sidney, MT

Table 28. Chemical analyses of runoff water from mine spoil watersheds subjected to different surface manipulation treatments located at the Western Energy Mine near Colstrip, Montana.

	pH (Laboratory) (*Field)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	Potassium (K)	Boron (B)	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	SAR	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Selenium (Se)	Lead (Pb)	Cadmium (Cd)	Iron (Fe)	Specific Conductance	Settleable Matter	
Date of Collection		mg/l											µg/l								µmhos/ cm	ml/1/ hr
TOPSOIL GOUGED																						
10/30/75	8.3	213	0	127	.01	.15	4	-	5.0	37.0	130	5.30	298	44	95	3	145	0	24	520	5.3	
06/29/76	6.6*	223	0	11.5	0	.03	-	.17	50.4	301	-	-	1500	59	380	-	<10	<4	12500	320	30.0	
06/29/76	7.1	92	0	11.4	0	.01	-	.03	11.2	57.0	-	-	229	19	18	-	<10	<4	930	140	6.8	
06/29/76	7.0	94	0	6.9	.18	0	-	.03	16.6	81.5	-	-	294	24	50	-	<10	<4	1775	130	2.9	
06/29/76	6.9*	107	0	11.3	.16	.05	-	.06	11.0	50.5	-	-	338	30	150	-	<10	<4	980	170	5.1	
06/29/76	6.9*	75	0	12.9	0	.08	-	.06	11.4	54.0	-	-	214	31	285	-	<10	<4	1195	140	1.7	
07/14/76	6.7*	-	-	-	-	-	-	-	71.9	336	-	-	1564	90	661	-	15	11	13560	-	-	
TOPSOIL DOZER BASINS																						
10/30/75	8.4	213	0	135	.33	.36	6	-	13.0	37.0	110	3.96	380	17	435	5	55	0	33	600	10.0	
05/05/76	7.9	69	0	4.6	.16	.01	-	-	3.0	38.3	-	-	30	<1	43	-	<10	<5	<20	<100	-	
05/12/76	7.0	48	0	19.9	1.92	0	-	-	11.2	84.0	-	-	590	81	422	-	<10	9	2900	<100	-	
05/28/76	6.7*	123	0	4.4	-	.02	-	.08	-	-	-	-	-	-	-	-	-	-	-	180	20.2	
06/15/76	7.2	128	0	6.1	-	.02	-	.07	-	-	-	-	-	-	-	-	-	-	-	220	-	
TOPSOIL CHISELED																						
02/09/76	8.5	147	-	9.8	.24	.04	-	-	7.6	11.3	<1	-	101	22	8	2	0	0	549	180	50.0	
02/09/76	8.6	154	-	15.6	.80	0	-	-	7.1	12.0	<1	-	33	11	0	1	0	0	295	170	52.0	
02/09/76	8.3	161	0	19.5	1.28	0	-	-	7.8	15.0	<1	-	5	15	0	1	0	0	173	200	52.0	
02/09/76	8.2	183	0	11.3	.20	0	-	-	7.4	12.7	<1	-	72	11	0	<1	0	7	275	170	48.0	
02/09/76	8.5	268	-	19.7	1.15	0	-	-	8.1	10.8	<1	-	20	16	0	1	22	3	294	170	92.0	
02/09/76	8.3	268	0	24.1	.94	0	-	-	9.8	19.4	<1	-	25	16	61	<1	5	3	429	210	62.0	
04/28/76	7.2	105	0	8.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	190	-	
05/05/76	7.6	102	0	7.1	.10	.02	-	-	2.8	38.0	-	-	119	4	38	-	12	<5	<20	180	-	
05/05/76	7.7	74	0	4.8	.07	.01	-	-	2.5	40.0	-	-	74	8	21	-	18	<5	<20	<100	-	
05/05/76	7.7	51	0	4.2	.16	.01	-	-	3.3	44.5	-	-	24	<1	10	-	15	<5	<20	<100	-	
05/05/76	7.3	40	0	3.7	.13	.03	-	-	3.0	33.8	-	-	15	3	8	-	10	<5	<20	<100	-	
05/05/76	7.9	46	0	3.5	.15	.01	-	-	1.5	27.5	-	-	<1	<1	5	-	14	<5	<20	<100	-	
05/05/76	7.8	40	0	9.3	.04	.02	-	-	1.8	33.3	-	-	33	<1	7	-	20	<5	<20	<100	-	
05/12/76	7.4	37	0	8.4	1.62	0	-	-	4.1	48.0	-	-	155	46	200	-	15	8	208	<100	-	
05/12/76	7.5	43	0	10.6	6.61	0	-	-	2.8	27.6	-	-	90	41	71	-	20	7	61	<100	3.2	
05/28/76	6.6*	153	0	4.1	.14	0	-	.05	3.4	45.0	-	-	32	42	<10	-	<10	<4	106	170	36.1	
06/15/76	7.2	129	0	5.5	-	.01	-	.07	-	-	-	-	-	-	-	-	<4	-	-	170	24.1	
NONTOPSOILED GOUGED																						
02/09/76	7.6	107	0	19.6	.11	0	-	-	9.8	4.2	2.0	.12	113	19	80	<1	0	8	362	180	1.8	
02/09/76	7.8	95	0	17.2	.13	0	-	-	6.6	8.8	<1	-	75	13	20	1	35	1	450	150	1.8	
02/09/76	7.6	93	0	52.8	.28	.01	-	-	7.1	7.6	<1	-	40	15	17	1	0	0	393	160	1.2	
02/09/76	8.8	102	-	8.8	.16	0	-	-	7.4	6.1	<1	-	31	12	0	1	10	0	195	140	1.8	
02/09/76	9.1	89	-	8.6	.99	0	-	-	7.4	4.9	<1	-	15	10	0	1	5	2	110	140	2.0	
02/09/76	8.7	97	-	9.6	.26	0	-	-	7.4	5.1	<1	-	27	11	41	<1	0	0	103	150	1.3	
02/09/76	8.8	157	-	10.3	4.54	0	-	-	7.6	12.5	<1	-	133	15	20	1	0	0	1622	140	3.4	
02/09/76	8.4	153	0	11.0	.35	0	-	-	7.6	7.4	<1	-	32	10	0	<1	0	0	263	150	3.3	
05/05/76	7.6	57	0	7.1	.16	.02	-	-	4.5	31.5	-	-	165	<1	19	-	<10	<5	<20	150	-	
05/05/76	8.0	57	0	5.0	.12	.01	-	-	4.5	27.5	-	-	90	5	22	-	<10	<5	<20	<100	-	
05/05/76	7.0	63	0	9.4	.02	.55	0	-	4.6	11.3	-	-	46	<1	17	-	<10	6	<20	<100	-	
05/12/76	7.5	58	0	9.1	2.55	0	-	-	6.0	19.9	-	-	205	58	605	-	20	12	1520	<100	4.5	
NONTOPSOILED CHISELED																						
02/09/76	8.9	107	-	26.1	.17	0	-	-	17.2	9.8	<1	-	133	22	15	1	10	0	716	200	2.0	
02/09/76	7.8	89	0	15.1	.43	0	-	-	7.6	4.4	<1	-	17	14	0	<1	0	0	131	140	1.9	
02/09/76	8.0	-	0	16.0	.53	0	-	-	7.5	7.4	<1	-	20	19	10	<1	0	0	145	150	4.1	
05/05/76	7.6	55	0	6.8	.16	.01	-	-	5.3	27.0	-	-	164	12	10	-	15	8	<20	<100	-	
05/05/76	7.7	53	0	6.3	.18	.01	-	-	5.0	24.8	-	-	177	4	54	-	17	7	<20	<100	-	
05/05/76	7.9	55	0	10.1	.13	.01	-	-	6.8	27.8	-	-	150	12	133	-	21	<5	<20	<100	-	
05/05/76	7.7	49	0	7.5	.15	.01	-	-	5.5	24.5	-	-	98	4	12	-	<10	<5	<20	<100	-	
05/05/76	7.4	68	0	10.8	.07	.03	-	-	4.3	12.5	-	-	64	5	11	-	<10	<5	<20	<100	-	
05/05/76	7.4	48	0	8.1	.08	.03	-	-	6.0	29.8	-	-	185	6	14	-	<10	<5	60	<100	-	
05/12/76	7.4	55	0	25.6	2.61	0	-	-	6.9	16.1	-	-	100	52	74	-	40	8	170	115	2.9	
05/28/76	6.6*	147	0	27.1	.82	.01	-	.10	9.0	24.0	-	-	87	57	<10	-	<10	<4	100	200	9.3	
05/28/76	6.6*	89	0	6.0	.57	.16	-	.04	4.6	11.5	-	-	23	51	<10	-	<10	<4	88	160	5.4	

¹ Suspected contamination or analytical problem for Na after 3/25/76.

Table 29. Chemical analyses of runoff water from mine spoil watersheds subjected to different surface manipulation treatments located at the Knife River Mine near Savage, Montana.

	pH(Laboratory) (*Field)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	Potassium (K)	Boron (B)	Magnesium (Mg.)	Calcium (Ca)	Sodium(**) (Na)	SAR	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Selenium (Se)	Lead (Pb)	Cadmium (Cd)	Iron (Fe)	Specific Conductance	Settleable Matter					
Date of Collection	mg/l												μg/l												μmhos/ cm	ml/l/ hr
TOPSOIL GOUGED																										
06/02/76 x	8.0*	86	0	7.9	1.89	.01	-	.09	<5	15	-	-	59	4	10	-	29	8	47	<100	65.9.					
06/02/76	6.9*	-	-	-	-	-	-	-	15.0	30	-	-	50	22	36	-	11	10	45	220	-					
06/07/76	7.0*	107	0	6.7	-	.09	-	.07	12.8	45	-	-	100	16	<10	-	<10	<4	<10	180	25.3					
06/13/76	6.7*	146	0	21.8	-	.31	-	.12	-	-	-	-	-	-	-	-	-	-	-	260	20.0					
TOPSOIL DOZER BASINS																										
02/09/76	8.1	280	0	42.0	1.70	0	-	-	7.4	25	3.5	.20	37	32	20	<1	12	0	133	200	9.2					
02/09/76	8.2	149	0	41.5	5.73	0	-	-	8.1	33	1.0	.04	41	18	10	1	0	0	85	200	14.0					
02/09/76	8.1	234	0	39.8	2.94	0	-	-	7.5	23	1.0	.05	20	18	82	1	0	0	55	210	9.2					
03/25/76	6.9*	92	0	21.1	<.01	.01	-	-	3.8	20	3.0	.20	0	12	36	1	<5	10	550	140	4.1					
06/02/76	6.9*	116	0	9.3	1.66	.44	-	.10	<5	31	-	-	78	9	20	-	<5	4	55	240	14.0					
06/02/76	7.0*	115	0	7.9	1.05	.03	-	.08	<5	28	-	-	39	8	18	-	18	7	47	170	11.4					
06/03/76	6.7*	96	0	-	1.64	.05	-	.09	<5	17	-	-	48	<2	10	-	<5	10	48	190	3.6					
06/03/76	7.2*	99	0	7.6	1.80	.01	-	.09	<5	35	-	-	49	8	10	-	<5	9	52	180	6.7					
06/03/76	6.8*	108	0	30.9	1.20	.01	-	.12	<5	25	-	-	49	6	148	-	<5	11	48	220	36.9					
06/07/76	7.1*	76	0	7.4	.11	.74	-	.04	4.0	23	-	-	40	21	<10	-	<10	<4	42	140	7.9					
06/07/76	7.4*	113	0	4.0	.33	.22	-	.04	4.8	34	-	-	18	22	<10	-	<10	<4	<10	<100	16.9					
06/07/76	7.4*	82	0	4.8	-	.26	-	.05	5.8	40	-	-	30	24	<10	-	<10	<4	<10	120	7.9					
06/13/76	6.6*	101	0	35.7	-	1.18	-	.06	4.5	34	-	-	120	27	<10	-	<10	<4	<10	220	8.0					
08/09/76	7.2*	168	0	9.8	-	.11	-	.05	7.0	50	-	-	510	<20	26	-	20	10	922	240	7.3					
08/09/76	7.2*	183	0	9.4	-	.12	-	.05	-	-	-	-	-	-	-	-	-	-	-	260	-					
TOPSOIL CHISELED																										
03/25/76	7.0*	168	0	-	-	.02	-	-	7.5	50	7.2	.25	210	32	968	-	<5	8	430	160	4.2					
06/02/76	7.0*	112	0	10.7	.50	.32	-	.09	5.0	23	-	-	217	15	48	-	8	5	23	200	3.9					
06/02/76	7.0*	115	0	7.0	-	.03	-	.05	5.0	19	-	-	59	15	18	-	13	4	31	190	32.9					
06/07/76	7.1*	98	0	4.9	-	.10	-	.09	6.0	39	-	-	49	15	10	-	<10	<4	10	160	26.7					
08/09/76	7.4*	223	0	6.0	-	.06	-	.14	19.0	61	-	-	165	<20	106	-	42	16	900	270	14.3					
NONTOPSOIL GOUGED																										
02/09/76	8.1	96	0	21.9	1.09	0	-	-	4.2	15	1.0	.06	24	18	37	<1	10	0	298	140	3.9					
02/09/76	7.9	93	0	23.3	2.73	0	-	-	3.2	15	0.0	.00	20	16	44	<1	0	0	100	140	5.3					
02/09/76	8.1	-	0	23.6	.97	0	-	-	4.9	18	2.0	.11	18	16	11	1	0	0	61	150	8.9					
02/17/76	-	-	-	9.8	.31	0	-	-	3.8	15	1.0	.06	0	14	10	2	0	5	82	140	-					
03/25/76	7.1*	153	0	48.1	.06	0	-	-	5.3	23	-	-	20	14	117	3	<5	10	529	180	3.2					
03/25/76	7.6*	164	0	-	-	.01	-	-	5.8	33	-	-	40	22	135	2	<5	10	130	220	-					
03/25/76	7.2*	73	0	65.0	.01	.02	-	-	5.5	25	-	-	10	13	132	2	<5	12	230	170	1.0					
06/02/76	7.0*	107	0	15.7	-	.07	-	.12	10.0	30	-	-	67	11	14	-	15	5	25	220	58.2					
06/02/76x	8.0*	86	0	7.9	1.89	.01	-	.09	<5	15	-	-	59	4	10	-	29	8	47	<100	65.9.					
06/07/76	7.0*	74	0	4.6	-	.03	-	.13	-	50	-	-	79	14	<10	-	<10	<4	25	<100	11.4					
07/01/76	7.3*	-	-	-	-	-	-	-	11.0	50	-	-	155	72	<10	-	<10	10	238	-	-					
08/09/76	6.6*	316	0	3.6	-	.05	-	.24	16.8	75	-	-	600	<20	135	-	30	10	4550	480	25.7					
08/09/76	7.2*	296	0	8.9	-	.18	-	.28	11.3	98	-	-	750	<20	120	-	25	11	6000	530	-					
08/13/76	7.2*	200	0	3.6	-	.11	-	-	60.0	94	-	-	925	<20	506	-	35	33	9950	250	7.4					
NONTOPSOIL CHISELED																										
06/02/76x	8.0*	-	-	-	1.42	-	-	-	5.0	32	-	-	69	8	15	-	<5	9	46	-	54.1					
06/02/76	6.8*	116	0	7.3	3.42	.14	-	.12	5.0	26	-	-	363	9	10	-	29	6	38	220	18.3					
08/09/76	6.8*	339	0	5.0	-	.12	-	.13	14.3	54	-	-	700	<20	105	-	20	11	4300	570	14.3					
08/09/76	7.2*	168	0	7.5	-	.05	-	.10	8.7	50	-	-	470	<20	25	-	15	7	844	210	10.0					

x = grab sample

** Suspected contamination or analytical problems for Na after 3/25/76.

Table 30. Chemical analyses of runoff water from mine spoil watersheds subjected to different surface manipulation treatments located at the Indian Head Mine near Beulah, North Dakota.

Date of Collection	pH (Laboratory) (*Field)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	Potassium (K)	Boron (B)	Magnesium (Mg)	Calcium (Ca)	Sodium ¹ (Na)	SAR	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Selenium (Se)	Lead (Pb)	Cadmium (Cd)	Iron (Fe)	Specific Conductance	Settleable Matter	
		mg/l												µg/l							µmhos/cm	ml/1/hr
TOPSOIL GOUGED																						
02/28/76	-	-	-	7.3	.12	.03	-	-	4.0	12	4.6	.3	39	2	58	1	5	0	91	<100	-	
06/07/76	7.7*	-	-	-	-	-	-	-	3.0	16	-	-	175	41	40	-	40	5	78	-	-	
06/07/76	7.8*	-	-	-	-	-	-	-	2.6	12	-	-	42	40	<10	-	<10	5	40	-	-	
TOPSOIL DOZER BASINS																						
09/30/75	-	-	-	84.0	-	-	3.3	-	13.5	9	159	7.8	20	28	<5	2	<5	<1	140	-	-	
02/14/76	-	293	0	29.1	.40	0	-	-	4.5	15	14	.8	81	4	70	1	5	5	79	200	-	
NONTOPSOIL GOUGED																						
02/28/76	-	-	-	18.6	.04	-	-	-	9.0	40	-	-	410	91	182	2	30	0	179	220	-	
NONTOPSOILED CHISELED																						
09/30/75	-	-	-	113	-	-	6.2	-	10.0	13	158	8.0	10	42	<5	.8	<5	<1	40	-	.02	
02/28/76	7.9	118	0	82.6	<.01	0	-	-	34.5	105	17	.4	3210	200	688	1	68	0	83500	238	24.3	
02/28/76	8.0	73	0	21.2	0	0	-	-	11.5	36	14	.5	1560	118	362	2	28	0	42800	140	10.6	
02/28/76	7.9	74	0	57.8	0	0	-	-	11.0	29	22	.9	1410	84	580	2	25	3	38000	198	12.0	
02/28/76	8.0	56	0	-	<.01	0	-	-	10.5	32	24	1.0	1505	87	298	2	33	2	41000	105	4.9	
03/25/76	6.7*	85	0	15.5	<.01	0	-	-	2.5	15	-	-	82	14	202	2	<5	13	380	160	13.9	
06/12/76	8.0*	-	-	-	-	-	-	-	28.2	98	-	-	1556	72	20	-	10	6	20	-	-	
06/12/76	8.8*	-	-	-	-	-	-	-	30.6	82	-	-	388	41	10	-	10	6	20	-	-	

¹ Suspected contamination or analytical problems for Na after 3/25/76.

SOIL HYDROLOGICAL CYCLE

Introduction

Five surface manipulation treatments were designed to capture and retain precipitation on the slopes of shaped mine spoils. The value of each treatment is dependent upon its erosion control characteristics and upon the quantity of water stored for beneficial effects such as vegetation development. Also, the concern exists that these treatments may retain greater than normal precipitation, which could initiate deep leaching effects. This chapter presents data which describe the soil water characteristics over time in each watershed.

Methodology

Intensive soil moisture content evaluations were completed within each of the previously described treatment watersheds. In each watershed five 5 cm inside diameter aluminum neutron access tubes, each extending approximately to the 250 cm soil depth, were monitored on a monthly basis. The soil moisture determinations were completed with the neutron scattering method at 15- to 30- cm increments. A Troxler gauge was used with a 100 millicurie Americium-Beryllium source emitting high speed neutrons. Soil moisture data are presented as the volumetric water content, and one mean value per depth of the five tubes in each watershed is presented with the standard deviation of the mean.

Soil water desorption characteristics for these watersheds were determined at the 0.0, .3, and 15 bar pressure levels using standard pressure plate apparatus (Appendix E). Three cores in increments of 30 cm taken in each watershed were composited for analysis. All soil samples

were air dried and passed through a 2.0 mm sieve. Following pressure plate analysis, the resulting water content at each pressure was multiplied by the corresponding soil bulk density to convert from water content on a weight basis to water content on a volume basis.

Bulk density profiles were determined in each watershed (Appendix C). At the Colstrip and Savage Demonstrations this determination was made using a Troxler depth density gauge with a 3.0 millicurie Radium-226 source emitting gamma radiation. This gauge was lowered down one neutron access tube in each watershed at 15- to 30- cm increments. This gauge measured the wet soil density in g/cm^3 . The moisture content of this same soil profile was determined with a Troxler soil moisture gauge. The dry soil bulk density was then calculated by subtraction.

Results

Figures 26, 27, and 28 summarize the soil hydrologic cycle recorded at the Colstrip, Savage and Beulah Demonstrations. Due to consistent soil moisture trends and the need for legible figures, some monthly readings are excluded. However, all monthly readings are presented in Appendix B. As shown in these appendix tables, the five tubes in each watershed were averaged by depths and standard deviations of these means were determined. Sometimes the number of tubes (n) was less than five, indicating a tube could not be used on that date due to a temporary blockage. The standard deviation of the mean ($S_{\bar{x}}$) between tubes within a watershed ranged between about 3 to 13 percent water by volume. Most of this variation was attributed to actual field moisture variations due largely to soil textural differences around each tube. Although not shown in these appendix tables, the standard deviation of the mean for the error mean

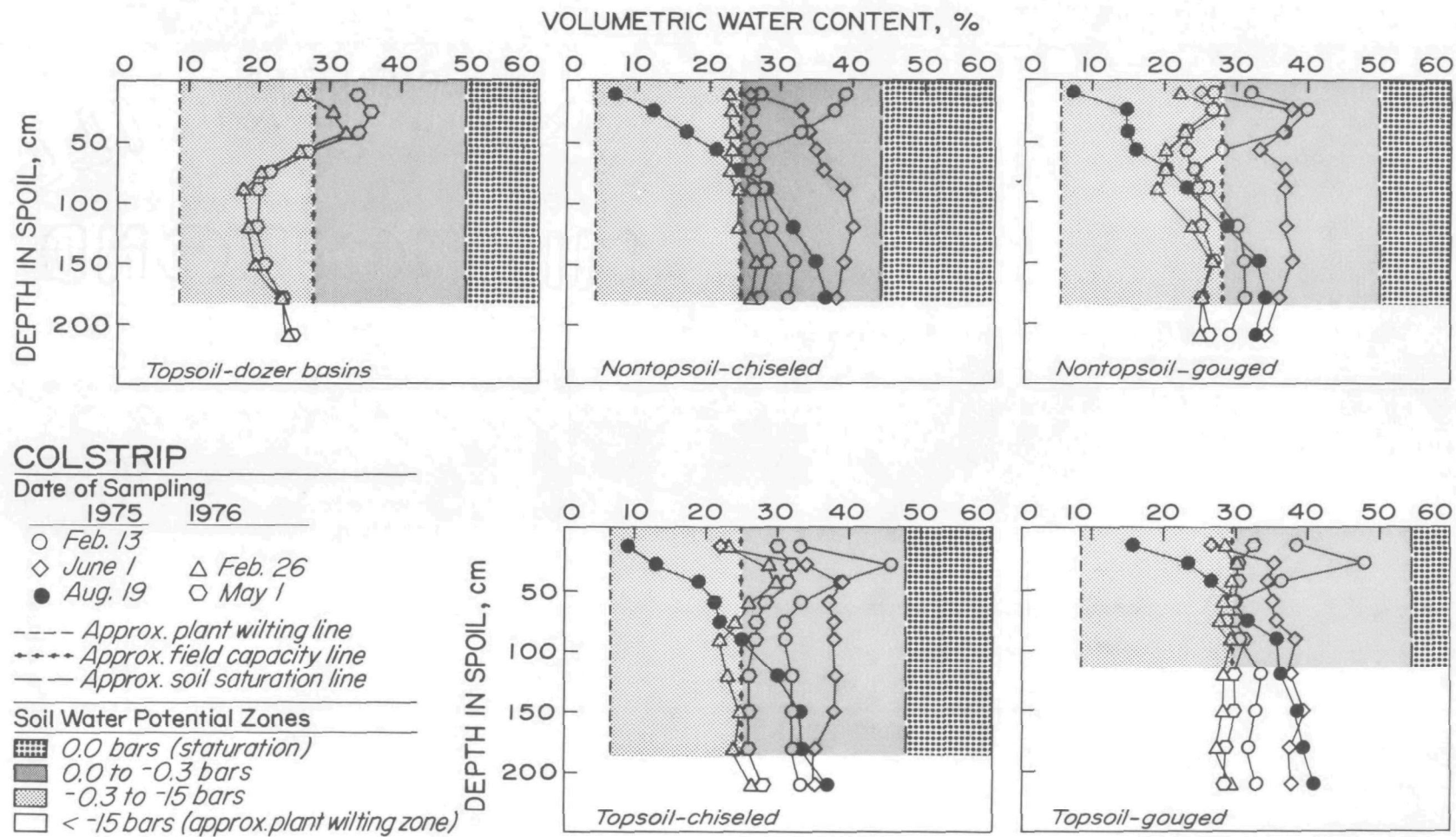


Figure 26. Soil profile water distribution over time as a function of surface manipulation treatments at the Colstrip Demonstration.

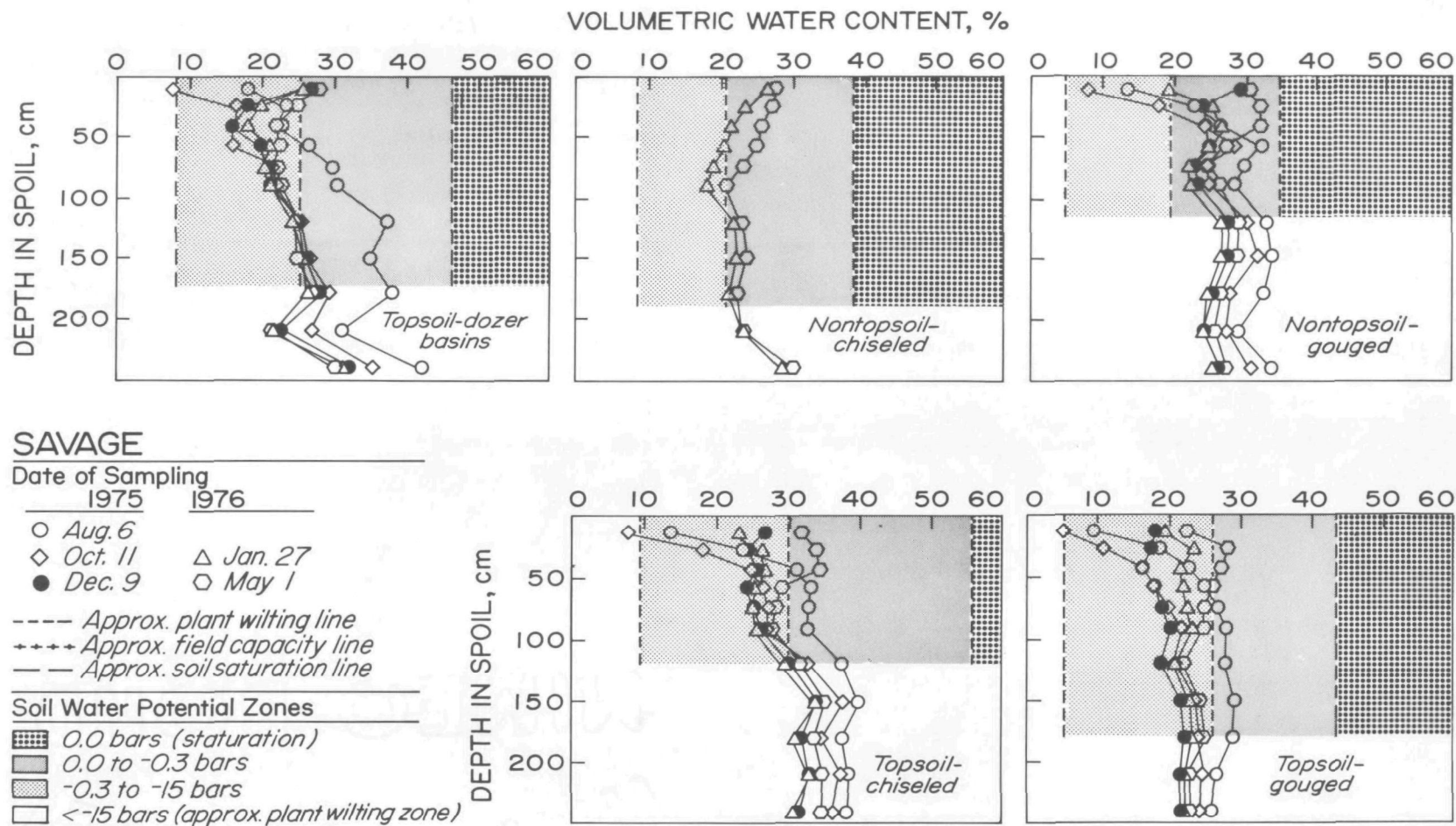


Figure 27. Soil profile water distribution over time as a function of surface manipulation treatments located at the Savage Demonstration.

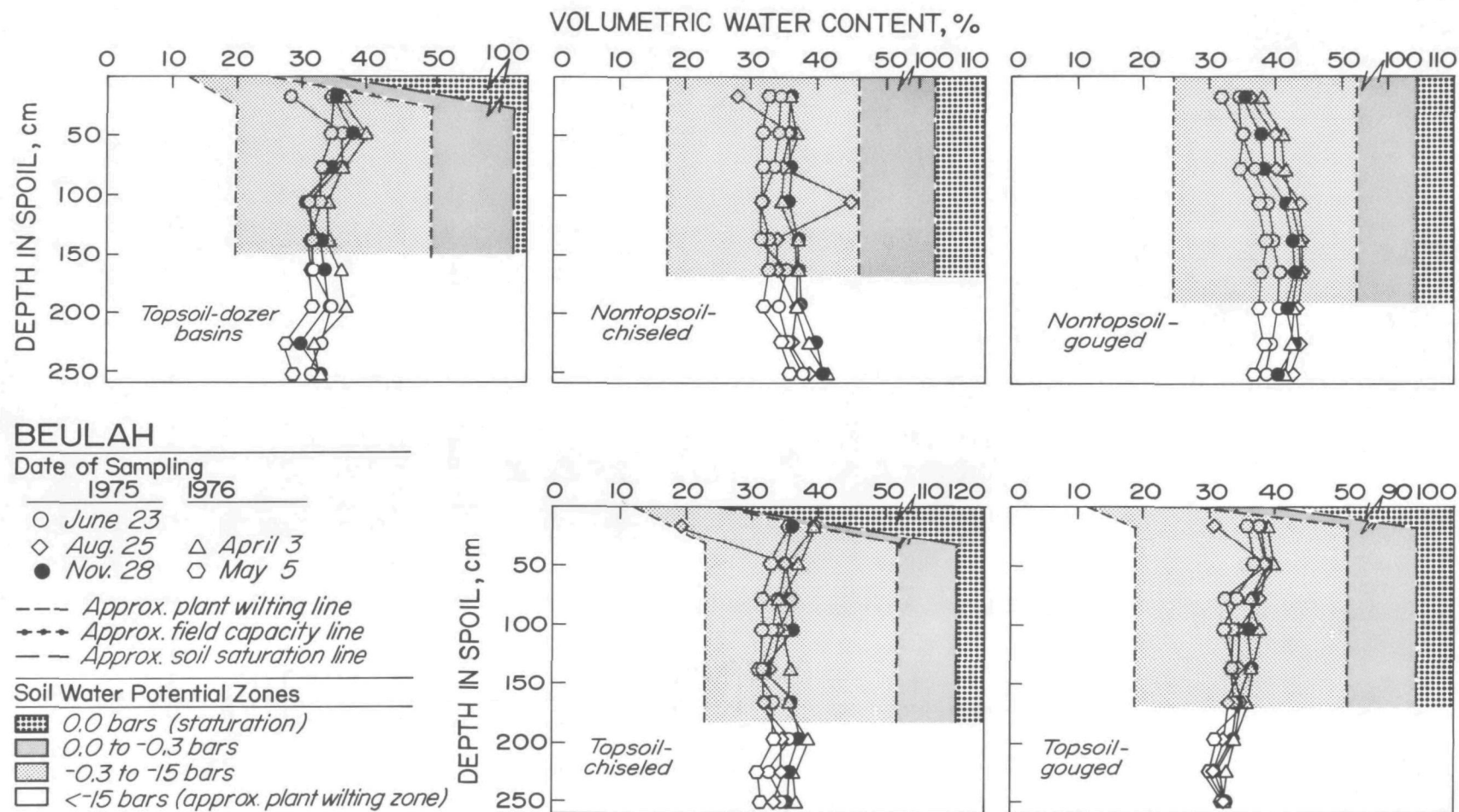


Figure 28. Soil profile water distribution over time as a function of surface manipulation treatments located at the Beulah Demonstration.

square term was consistently less than 1.0 percent, indicating the operator and instrument error was very small.

The approximate plant wilting, field capacity, and soil saturation lines shown in Figures 26, 27 and 28 define how much water the soil material will contain at soil water potentials of -15.0, -0.3 and 0.0 bars, respectively. Saturation (0.0 bars) is that point at which a soil will no longer absorb water, meaning all the air spaces in the soil matrix are filled with water. When a soil has been near saturation and then the gravitational water has been drained away, it is said to be at field capacity (-0.3 bars). If we were to use many types of plants from many types of climatological regimes and determined at what soil water potential they will permanently wilt, their average would be near -15 bars, and the percentage of water in the soil when this permanent wilting occurs is the wilting point. The authors realize the technical limitations of these terms (i.e., wilting point), but also recognize their usefulness in describing these data to the reader. Further, in our attempt to determine the desorption characteristics it was realized a certain amount of error was derived by using samples passed through a 2 mm sieve. The hydraulic boundary conditions which characterize the field situation are extremely difficult to reproduce for a soil sample removed from the profile. It has been suggested by some scientists to use undisturbed core soil material in this desorption analysis rather than sieving the soil, thereby retaining some of the physical characteristics such as porosity. Although this could decrease error and would be an advisable procedure to follow in the future, the complex problem of reproducing the hydraulic boundary conditions surrounding the soil core in its profile environment must still be faced.

Soil water can be subjected to several different energy forms. These different forms of energy direct the flow of soil water and dictate plant uptake of water from the soil. A detailed discussion of these energy factors is complex and not necessary for this report. Let it suffice to say that soil water potential, which is a numerically negative value, is the criterion for this energy and composed largely of gravitational, matric, osmotic, and pneumatic potentials (Equation 1).

$$\Psi_t = \Psi_g + \Psi_m + \Psi_o + \Psi_p \quad \text{Eq. 1}$$

where Ψ_t = total soil water potential

Ψ_g = gravitational potential; attraction of water towards the earth's center

Ψ_m = matric potential; adsorption forces between solid surfaces and water, including cohesive forces between water molecules

Ψ_o = osmotic potential; attraction between ions and water molecules

Ψ_p = pneumatic potential; forces arising from unequal pressures in gas phase

For a plant root to absorb water from the soil, it must have an energy, or plant potential (Ψ_p), lower (more negative) than the soil water potential (Ψ_t). Even though the plant attains a $\Psi_p < \Psi_t$, it may wilt if its roots cannot physically conduct sufficient water to meet biological and transpirational demands.

The boundary soil water potential lines in Figures 26, 27 and 28 were determined from soil desorption work in the laboratory (Appendix E). It should be noted that this technique determines the matric potential (Ψ_m) component of the total potential (Ψ_t), discussed previously in Equation 1,

which is a close approximation of Ψ_t , since the osmotic potential (Ψ_o), pneumatic potential (Ψ_p), and gravitational potential (Ψ_g) would probably be small in comparison.

Figure 26 presents soil water data from the Colstrip Demonstration area during the period February, 1975, to May, 1976. Instrumentation problems associated with the topsoil-dozer basin treatment did not permit collection of soil water data until late 1975. Only during August, 1975, was soil near the surface so dry that permanent wilting of vegetation would likely occur. This was characteristic of all watersheds, although the topsoil-gouged treatment remained at a somewhat higher moisture level during this severe dry period. Watershed soil profiles lost considerable water from June through August. For example, the nontopsoil-chiseled watershed lost during this period 20.5 cm of water within the soil zone zero to 225 cm deep. This water was lost by the evapotranspiration process and additionally by possible drainage deeper than 225 cm. The dominant plant species during the 1975 summer was Russian thistle (*Salsola kali*), while the first year growth of yellow sweetclover (*Melilotus officinalis*) was apparent. Annual and perennial grasses were found to be sparse. In Montana, Baker (2) measured the water use efficiency of a monoculture Russian thistle crop. He determined that this species had a very high water use efficiency requiring only 200 g of water to produce each gram of dry matter. It was also found that, compared to a bare soil check plot, this species used about 34 cm of water from a soil profile 2.5 m deep during the entire growing season. The level of soil water loss observed in these spoil watersheds due to evapotranspiration is thus not surprising.

General moisture characteristics shared by all treatments showed that above 50 cm, the soil moisture was maximum in February, 1975, while below 50 cm, the soil moisture was maximum in June, 1975. Also the profile water content was at a higher level in 1975 than at the equivalent date in 1976. The high level of moisture in the upper 50 cm of the profile during February may result from unsaturated flow from substrata towards the frozen surface. This phenomenon has been observed by researchers (36, 9) in the northern United States in many types of soils. The mechanism of this flow is still not resolved, but it has been in part attributed to soil temperature gradients.

This upward flow occurs as either liquid or vapor flow, or both, and is a characteristic which may be important in reclamation. If this upward flow occurs largely in the vapor phase then salt movement towards the surface is not a factor. However, if this flow is largely in the liquid phase, the magnitude of these flows appear sufficient to translocate salt towards the surface. This is a phenomenon that will require further research.

The profiles beneath the topsoil-gouged and topsoil-chiseled treatments were usually at a somewhat higher moisture level during the year than their counterparts without topsoil. This suggests that topsoil may tend to increase the infiltration rate. However, this difference was small, about 5 percent, and could be due to soil textural differences between watersheds. A profile high in silt or clay content would characteristically contain more water.

The effects of surface manipulation treatments on detention and storage of water were best demonstrated during the 1976 spring moisture recharge period (i.e., the period of February through May, 1976, Figure 26).

Snowmelt and precipitation were considerable. During this period the topsoil-dozer basin treatment underwent a profile recharge equivalent to 13.0 cm of water while the other treatments underwent a recharge of 8.0 cm for topsoil-chiseled, 7.5 cm for nontopsoil-chiseled, 5.0 cm for topsoil-gouged and 4.5 cm for nontopsoil-gouged(May not included). These data show that topsoiling in both the chiseled and gouged treatments resulted in greater profile water recharge compared to the nontopsoil counterparts. The topsoil-dozer basin treatment had a much greater surface water detention capacity compared to other treatments which resulted in maximum storage of precipitation.

These data from the Colstrip Demonstration indicate soil water in the unsaturated state was flowing below the 250 cm depth, a deep leaching effect. This can be deduced by the large increases in profile water during certain months (i.e., June), and these increases were just as prevalent at the 250 cm depth as they were near the surface. The quantity of water leaching past the 250 cm depth may have been substantial since the soil water content in most of the profile when the leaching occurred exceeded field capacity. The destination of this deep flow could be the saturated ground-water region at the base of the mine pit. Once this water flows below the 250 cm depth, it is out of the direct influence of water use by roots and evaporation, and the likelihood of its continued flow downward is great. This topic is further discussed in the next chapter of this report.

Figure 27 presents soil water data from the Savage Demonstration during period August, 1975, to May, 1976. Instrumentation problems associated with the nontopsoil-chiseled treatment did not permit collection of

soil water data until late 1975. The topsoil-chiseled treatment stored the greatest amount of soil profile water during the measurement period. Compared to all watersheds, the nontopsoil-chiseled treatment stored the least soil profile water, and at any one time contained on the average about 8% less water than the topsoil-chiseled treatment. This comparison would suggest topsoiling had the beneficial effect of permitting more surface water to enter the profile. However, it should be recalled from an earlier discussion of infiltration rates on these watersheds that no large differences in infiltration were evident between the topsoil-chiseled and nontopsoil-chiseled treatments.

A comparison between the gouged treatments indicates the nontopsoiled treatment contained on the average about 5% more soil water than the topsoiled treatment. This was true both near the surface and at lower depths. The soil profile water for the topsoil-dozer basin treatment demonstrated characteristics similar to the nontopsoil-chiseled and nontopsoil-gouged treatments.

It should be realized in the above discussion, which indicated different levels of soil water content between watersheds, that these soil differences could be due to textural variation as well as to surface manipulation treatments. Review of an earlier section in this report shows these watersheds were predominantly fine sandy loam in texture but varied from sand to clay. If a watershed contained slightly more silt or clay, it is conceivable that the water holding capacity of the profile would be characteristically higher, perhaps by as much as 5% to 10%. Future studies will evaluate the influence of soil texture at each sampling site.

The monthly profile patterns of recharge and discharge in Figure 27 were very similar between surface treatments. In the root zone, the highest level of soil moisture was present in May, 1976 in all watersheds, and the topsoil-chiseled treatment ranked the highest. A high soil moisture content near the surface during this time of the year is important for successful vegetation establishment. Sufficient soil water in the top 30 cm of the profile is critical for survival of both seedlings and second year plant growth. The driest period near the surface occurred in early October, 1975, when all treatments contained less than 9% soil water. This level of soil moisture in predominantly sandy loam soils would place most plants under extreme water stress. At the deeper depths, soil moisture was at a maximum in August, 1975. Apparently percolating water from spring precipitation was sufficient to cause substantial late summer recharge from the 50 cm to 250 cm soil depth. The 0 cm to 50 cm zone was quite dry in late summer due to the low precipitation during August coupled with the high evapotranspiration demands associated with warm temperatures.

Differences between these surface treatments at the Savage Demonstration were demonstrated most clearly during the 1976 spring recharge period (i.e., the period February, 1976, to May, 1976, Figure 27). This was a time when snowmelt and precipitation would test the effectiveness of surface manipulation to the full extent. During this period the topsoil-gouged treatment underwent a recharge of 8.0 cm of water in its profile compared to 6.5 cm for the nontopsoil-gouged, 5.0 cm for the topsoil-chiseled, 4.5 cm for the nontopsoil-chiseled and 3.5 cm for topsoil-dozer basin treatments. These data show that gouging was an efficient means of storing precipitation, and topsoiling provided an added water storage advantage over nontopsoiling practices.

If measurements had been made beyond the 250 cm depth, the soil profile recharge may have been considerably greater than that indicated by the above values. The above data indicate that considerable water movement past this depth occurred between dates of measurement, and this water was never really quantitatively defined. The amount of leaching past the 250 cm depth could have been substantial since, as at the Colstrip Demonstration, the soil water content in most of the profile (when leaching occurred) was more moist than the estimated field capacity (-0.3 bars).

Figure 28 presents soil water data from the Beulah Demonstration during the period June, 1975, to May, 1976. Soil moisture content near the surface never dropped below the -15 bar line. This is not to say that the surface 1.0 cm to 2.0 cm of soil did not dry out, since severe crust formation was a strong characteristic of these soils. However, immediately below the crust, the soil contained sufficient moisture to sustain plant growth.

The soil texture at this demonstration was predominantly silty clay, but ranged from loam to clay. The topsoil-gouged watershed was noticeably higher in clay content compared to the other watersheds, which is the reason soil moisture in this watershed varied little in the entire profile during the year. These data in Figure 28 demonstrate that very little profile recharge occurred during the year. This was probably due to the heavy texture of these soils, which would tend to lower permeability rates. Likewise, discharge of soil water in the profile was minimal due to the high porosity of heavy textured soils which allows the retention of large amounts of water.

The pattern of these data suggests the occurrence of some downward flow beyond the 250 cm soil depth. However, the amount of this flow was small since the water content of the profile ranged between field capacity and wilting point, probably near a soil water potential of -5 to -8 bars. Thus, very little water was available for the translocation of salts by leaching.

Differences between these surface treatments at the Beulah Demonstration were demonstrated most clearly during the 1976 spring period, i.e., the period February 1976, through April, 1976 (Figure 28). During this period the accumulation of snow melted and an additional 6.6 cm of precipitation was measured. The nontopsoil-chiseled treatment profile lost 8.0 cm of water, nontopsoil-gouged lost 6.5 cm, topsoil-gouged lost 5.5 cm, topsoil-chiseled lost 5.2 cm, and the topsoil-dozer basin treatment neither lost nor gained water in its profile. These data indicate a trend where topsoiled watersheds conserved soil water better than nontopsoiled watersheds, and dozer-basins conserved water better than either chiseling or gouging. However, none of the watersheds underwent a profile recharge during a climatologically wet portion of the year. This silty-clay spoil material, dominated by smectite clay that was saline and sodic in nature, epitomizes the combination of soil characteristics most difficult to reclaim in Western areas. Apparently little infiltration of precipitation can occur in this spoil material. Topsoiling may enhance infiltration, but the spoil material below acts as a barrier to water recharge of the deep profile. These data suggest that in heavy clay soils which are saline-sodic in nature, relief of compaction and chemical amendments may be necessary corollary procedures in association with topsoiling and surface depression techniques in order to attain successful reclamation.

Conclusion

Surface manipulation treatments will have varying degrees of success across different geographic locations when soil profile water recharge is the main concern. This variation is due to several important factors affecting the relationship between profile recharge and surface treatment, including depression volume, depression stability, soil texture, soil compaction and slope.

Results show the creation of soil surface depressions alone will not assure the recharge of soil profile water. At this time, these data indicate that an optimum combination of sufficient topsoil and long life-large capacity depressions constructed in permeable soil with terrain not too steep for the type of depressions will result in maximum water recharge rates.

Data collected at the Beulah Demonstration show that large stable depressions (dozer basins) as well as gouges were not able to substantially increase levels of soil profile water recharge. Large volumes of water were captured by the depressions, but the compact clayey soil restricted infiltration. The ponded water was eventually lost through evaporation. As a result, it was observed that concentrations of sodium and other soluble salt were deposited around the perimeter of each depression.

At the Cosltrip Demonstration, it was shown that dozer basins caused large increases in soil profile recharge. Further, it was observed that water detained in the depressions entered the soil profile in less than 24 hours. Unlike those at the Colstrip Demonstration, the dozer basins at the Savage Demonstration were constructed with the front blade of a smaller

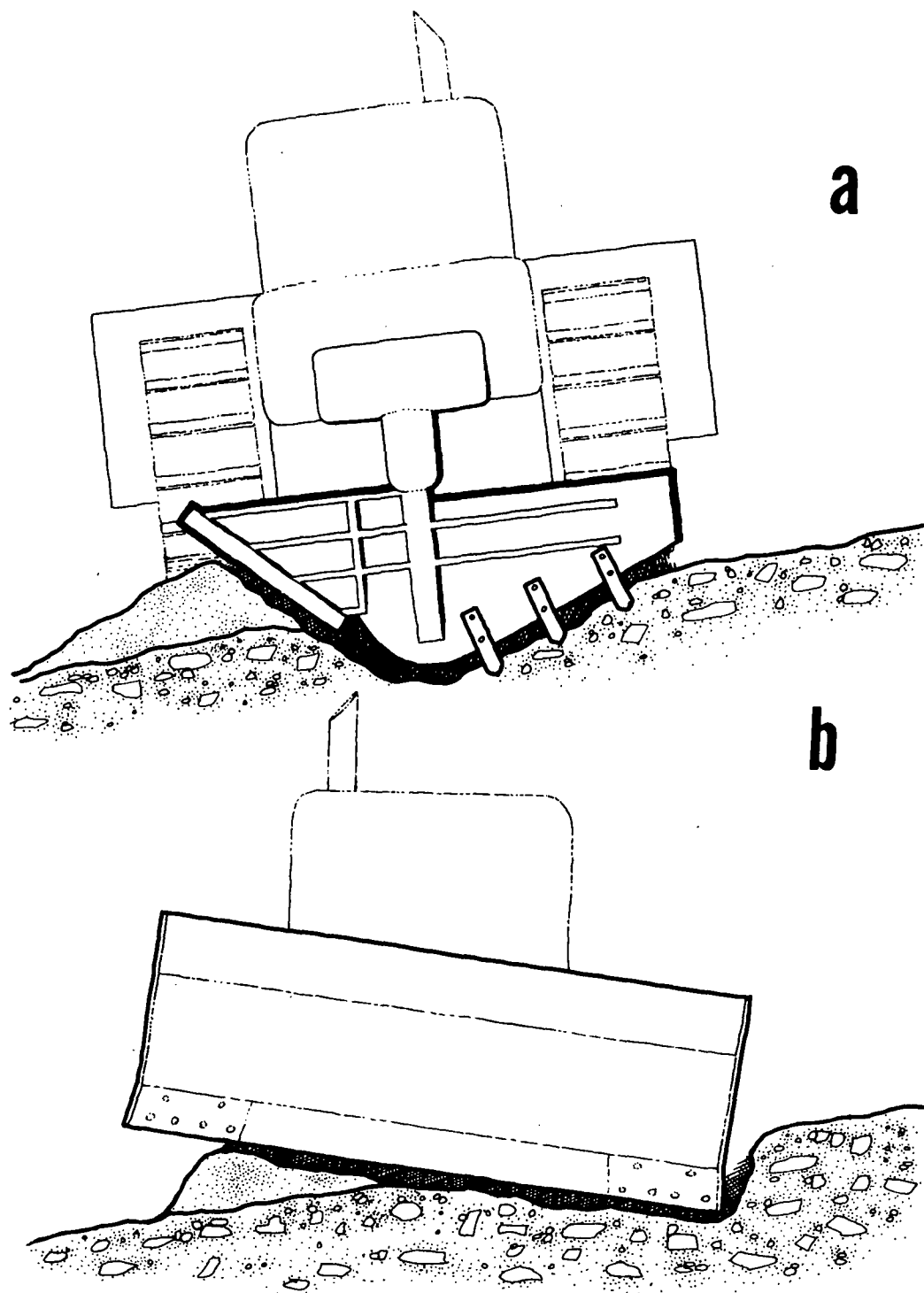


Figure 29. Dozer Basin constructed at the Savage Demonstration with the front blade of a dozer (b-above) resulted in a compacted basin with only one-fourth the detention volume compared to those produced by the dozer basin blade (a-above).

bulldozer because a larger bulldozer required to operate the dozer basin blade was not available (Figure 29). Data indicated that the depressions formed with the front mounted blade were unsatisfactory compared to the basin formed with the rear mounted designed basin blade. Depressions formed with the front mounted dozer blade had a water detention capacity only one-fourth as great as the depressions formed with the basin blade (Table 21, page 58). It was observed that the front mounted blade also formed a highly compacted, smooth depression bottom which was unsuitable as a seedbed and apparently reduced water infiltration rates.

At both the Colstrip and Savage Demonstrations the topsoil-gouged and topsoil-chiseled watersheds consistently underwent more soil profile water recharge during a precipitation event, compared to their nontopsoiled counterparts. Compared to the subsoil, the topsoil is a loose-friable material that provides an ideal medium conducive to construction of gouged and chiseled surface manipulation techniques. This ability to physically manipulate the topsoiled surface in an efficient manner and to influence and enhance infiltration rates resulted in greater soil water recharge.

The amount of water leaching beyond the 250 cm depth at the Colstrip and Savage Demonstrations could be substantial. At the Beulah Demonstration it appeared that very little soil water flow occurred downward through the profile. The next chapter attempts to further quantify the leaching effect.

HYDROLOGIC BALANCE OF THE SOIL BIOSPHERE

Introduction

Soil surface manipulation treatments were designed to increase the conservation of surface soil moisture and to control erosion due to runoff. In order to evaluate treatment effectiveness and determine overall treatment influence on soil water relationships, the hydrologic balance was quantified. The hydrologic balance is simply a budgeting procedure which presents the inputs and outputs of water from the soil system.

Methodology

The principle of conservation of energy states that energy entering and leaving the earth's surface must balance. In a similar manner, water entering and leaving the soil system must also balance. The water relationships may be expressed in the form of the water balance Equation 2.

$$\Delta SWC = PPT - ET - RO (\pm) WF \quad \text{Eq. 2}$$

where ΔSWC = change in soil water content in the zone of measurement

PPT = precipitation

ET = evapotranspiration

RO = runoff

WF = soil water flow by unsaturated or saturated processes
into or out of the zone of measurement

Equation 2 implies no specific time period and could be considered to entail 1 hour, 1 day, or 1 year. At this stage in the project the hydrologic balance is considered on a calendar month basis. Of the five hydrologic components in Equation 2, change in soil water content (ΔSWC),

precipitation (PPT), evapotranspiration (ET), and runoff (RO) are measured, while soil water flow (WF) is found by difference and is subject to the most error. The probable accuracy of the data of the various components can be assembled in descending order as follows: ET, ASWC, RO, PPT, and WF.

Evapotranspiration (ET) was measured with weighing lysimeters (see Appendix A), with one lysimeter in each watershed. The change in soil water content (ASWC) was measured on a monthly basis at five locations within each watershed to a depth of 250 cm with neutron scattering equipment, and these data can be either positive or negative depending whether the soil profile water content increased or decreased during the month. The reader is referred to Schultz (26) for details on theory of the neutron scattering method. The microwatershed design (see Orientation and Design of Demonstration Areas) enabled the measurement of runoff (RO) through a Parshall flume. Precipitation (PPT) for this project refers to the water equivalent of all forms of precipitation which strikes the surface. The precipitation data from all Demonstration Areas are point catches, and it should be noted that there are possible errors involved in assuming that point estimates are equivalent to actual aerial precipitation.

A number of other terms used in this chapter need some definition. Detention storage is that water which is temporarily detained on the soil surface (in rills, basins, or other depressions) or within the zone of aeration as excess water which cannot be held against the flow of gravity (25). It is necessary that there be a distinction made between detention and retention storage. Retention storage is that water which is held or retained by the soil pores against the force of gravity (25). Depression volume is the term used to describe the volume of water held by a depression, excluding all other water within the soil matrix.

Results

Figures 30, 31 and 32 summarize the hydrologic balance variables recorded during the period July 1975 to May 1976, for watersheds located at the Colstrip, Savage and Beulah Demonstrations. Appendix D contains fifteen tables which present numerical data depicted in these figures.

Figure 30 shows the monthly hydrologic balance for the five surface manipulation treatments at the Colstrip Demonstration Area. Evapotranspiration was greatest during the period May through August, with July being the month of most intense evapotranspiration. These data show that evapotranspiration totals for the eleven month period appeared not significantly different between the five treatments and ranged between 45 cm and 50 cm for the period. Therefore, during a twelve month hydrologic year it is estimated that these spoil watersheds with a southerly aspect lost 55 cm to 60 cm of water by the evapotranspirative process.

No major runoff events have been recorded from the watersheds during the period of measurement. Several trace flows occurred but were determined to be of no significance to the hydrological balance. However, these trace flows were monitored for chemical quality, the results of which were presented in an earlier section.

The changes in soil water content in the uppermost two meters of spoils have reflected the inputs from spring rains, as well as outputs from evapotranspiration. From July 1975 to May 1976 all watershed soil profiles to a depth of 2.0 m experienced a net loss of water, except the topsoil dozer basin treatment. Here a net gain of 19.5 cm resulted, although missing data from the July through September period would have decreased

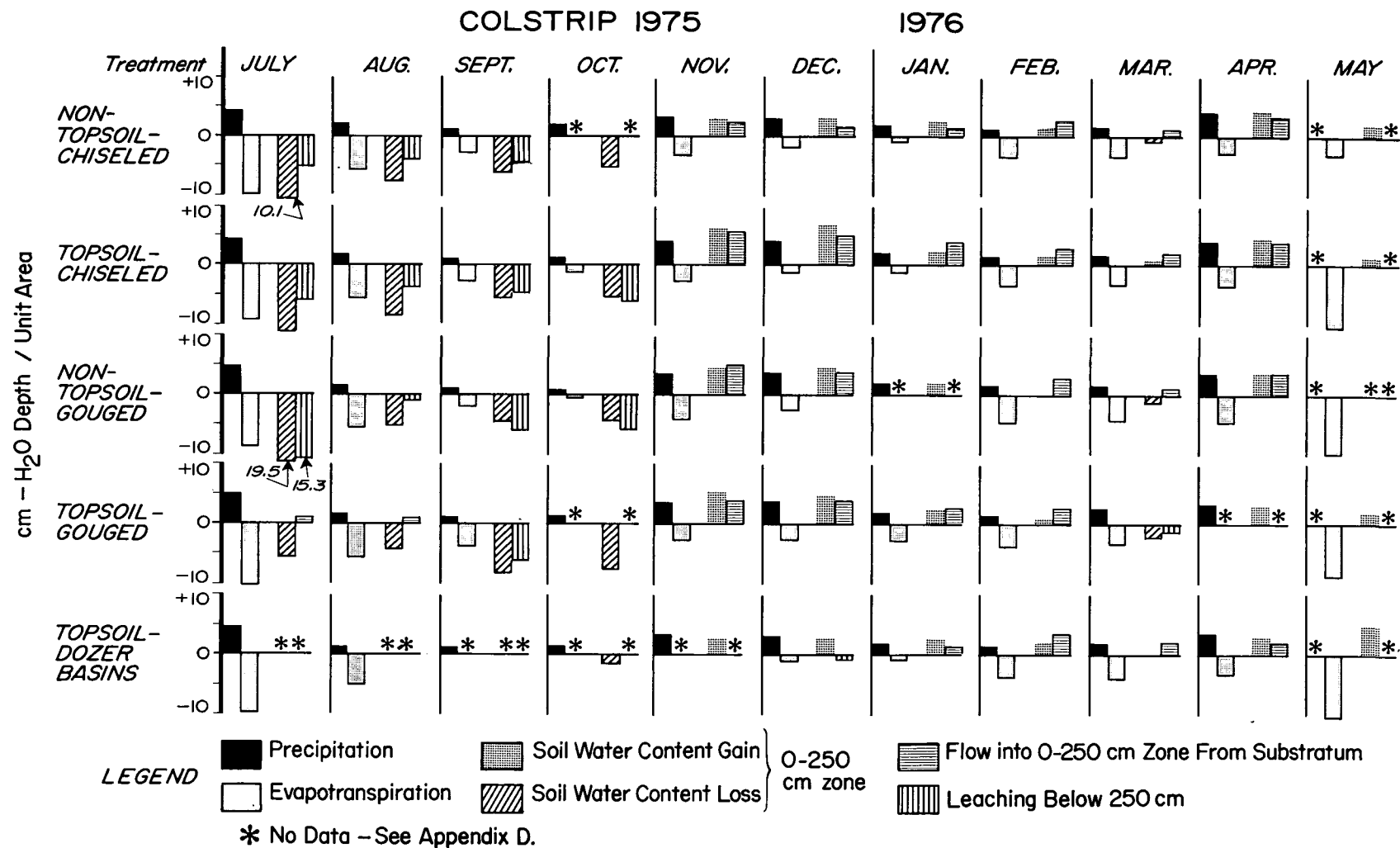


Figure 30. Summary of the monthly hydrologic balance of the spoil biosphere at the Colstrip Demonstration. On each plot the hydrologic parameters are presented left to right as precipitation, evapotranspiration, surface runoff, change in soil water content, and unsaturated flow.

this value somewhat. The topsoiled-gouged treatment lost 7 cm of water and the other three treatments lost 10 to 18 cm of soil water during an eleven month period.

Data in Figure 30 indicate that in the topsoil-chiseled, nontopsoil-gouged, and nontopsoil-chiseled watersheds unsaturated soil water flow (WF) was draining from the surface 2.0 m zone toward the ground-water zone during the late spring to early fall period. Conversely, during late fall through early spring the net flow was from subsurface soil depths toward the surface 2.0 m of spoils. This trend could not be confirmed in the topsoil-dozer basin watershed since data for the year were incomplete. The topsoil-gouged watershed demonstrated very little deep drainage during the year, and generally experienced flow from substratum towards the surface, particularly during the winter.

The net flow (WF) toward the surface during late fall to early spring, when the surface soil material was frozen and often snow covered is a phenomenon observed by other researchers (36, 9). The mechanism of this flow is still not resolved, but it has been attributed in part to soil temperature gradients. It has also been shown that this flow can occur against a water content gradient, that is, flow has been observed from the dryer subsoil towards the wetter frozen zone. Figure 30 indicates these types of processes were occurring in spoils during the winter.

Figure 31 presents the monthly hydrologic balance data for the five surface manipulation treatments at the Beulah Demonstration Area. Evapotranspiration (ET) was greatest during the May through August period, with the peak rate during May. Although data were somewhat incomplete for the hydrologic year, the rate of ET does not appear significantly

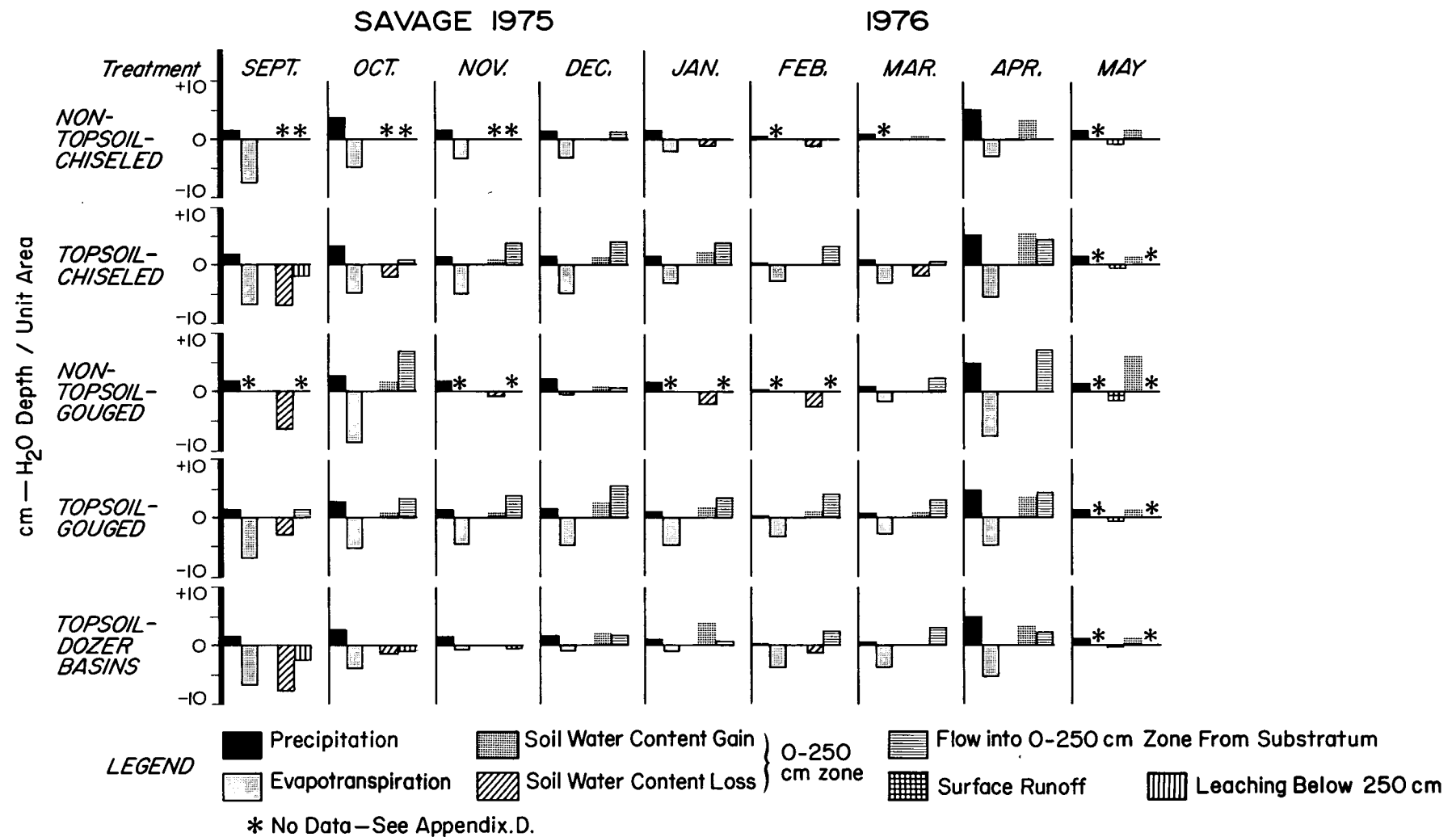


Figure 31. Summary of the monthly hydrologic balance of the spoil biosphere at the Beulah Demonstration. On each plot the hydrologic parameters are presented left to right as precipitation, evapotranspiration, surface runoff, change in soil water content, and unsaturated flow.

different between treatments. Evapotranspiration ranged between about 40 cm and 50 cm for the measurement period, which did not include the month of June. Therefore, during the hydrologic year it was possible that all watersheds lost between about 42 cm and 52 cm of water by the evapotranspiration process.

Two major runoff events were recorded during the period July, 1975, to May, 1976, and both events occurred in March. In the nontopsoil-chiseled watershed, 2.4 cm of water were lost as runoff, and in the nontopsoil-gouged watershed 8.4 cm of water were lost. It should be noted that the magnitude of both runoff events in March exceeded precipitation for the month. The runoff was apparently due to snowmelt or a combination of snowmelt and rainfall. No other watersheds experienced runoff events. Although these data represent a small sample, the fact that runoff occurred only on watersheds without topsoil cannot be overlooked. The topsoil-chiseled and topsoil-gouged watersheds were subjected to the same meteorological effect, yet no runoff occurred. This implies that topsoiled watersheds may have had greater surface water holding capacity and/or a greater infiltration rate.

The monthly changes in soil water content of the surface two meters of each watershed at the Beulah Demonstration Area are shown in Figure 31. During the measurement period July 1975 through April 1976, the topsoil-gouged and topsoil-chiseled treatments experienced a small net loss of soil water, 1.0 - and 2.2 - cm respectively. However, during this same period the nontopsoil-chiseled and nontopsoil-

gouged watersheds experienced a loss of 0.5 cm and no change in soil water content respectively. This implies topsoiling of the clayish soil at the Beulah Study area did not induce recharge of spoil profile water for plant production. This relationship was previously discussed in the section entitled "Soil Hydrological Cycle". The topsoil-dozer basin watershed soil profile increased 3.5 cm in water content during a corresponding period.

The net unsaturated water flow (WF) pattern was consistent in all five watersheds where a positive flow of water was measured into the surface 2 m of soil; that is, unsaturated flow occurred from the subsurface zone towards the surface. The quantity of this flow varied from about 10 cm to 20 cm of water during the July, 1975 to April, 1976 measurement period.

As discussed above, for a ten-month period the net flow was towards the surface. However, data indicate that a substantial deep leaching event occurred during April 1976 in all watersheds, and smaller such events were observed during other months at the Beulah Demonstration. This result is somewhat of a contradiction to the previous chapter (Soil Hydrological Cycle) where it was shown the soil water content of these profiles, although high due to the heavy soil texture, was between soil water potentials of -15.0 and -0.3 bars, generally near -5 bars. At these soil water potentials, it is doubtful that a leaching event could occur of the magnitude determined for April 1976. The sources of error in this type of research are recognizable and are discussed at the end of this chapter.

Figure 32 presents the monthly hydrologic balance for the five surface manipulation treatments located at the Savage Demonstration Area. During the measurement period, September, 1975, to May, 1976, evapotranspiration (ET) was similar between watersheds. The nontopsoil-chiseled and the topsoil-dozer basin treatments lost less water through the ET process than did the other treatments. Each lost about 37 cm of water. During the complete hydrologic year it can be estimated that these watersheds would lose approximately 70 cm to 80 cm of water by ET. This rate of evapotranspiration loss was considerably greater than that observed at either the Colstrip or Beulah Demonstration Areas.

Major runoff events occurred during January and May, 1976 in all five watersheds (Figure 32). During January, the nontopsoil-gouged watershed lost 3.1 cm of water as surface runoff, but there was no measureable runoff from the other four treatments. In May, three to four times more runoff occurred on the nontopsoiled treatments as compared to the topsoiled treatments. For example, during May, 1976 the nontopsoil-gouged and nontopsoil-chiseled watersheds lost 1.2 cm and 0.9 cm of runoff. These data show that at this area, topsoil treated watersheds detained additional surface water and thereby reduced water erosion. The topsoil-dozer basin watershed experienced the least runoff, 0.1 cm, as compared to all other treatments.

Earlier in this report (Soil Hydrological Cycle), it was shown that the soil profile of the dozer basin watershed at the Savage Demonstration generally contained the least soil moisture at any one time, compared to the other treatments. These dozer basins were made with the front blade of a dozer (Figure 29) which left basins with very compact and, possibly,

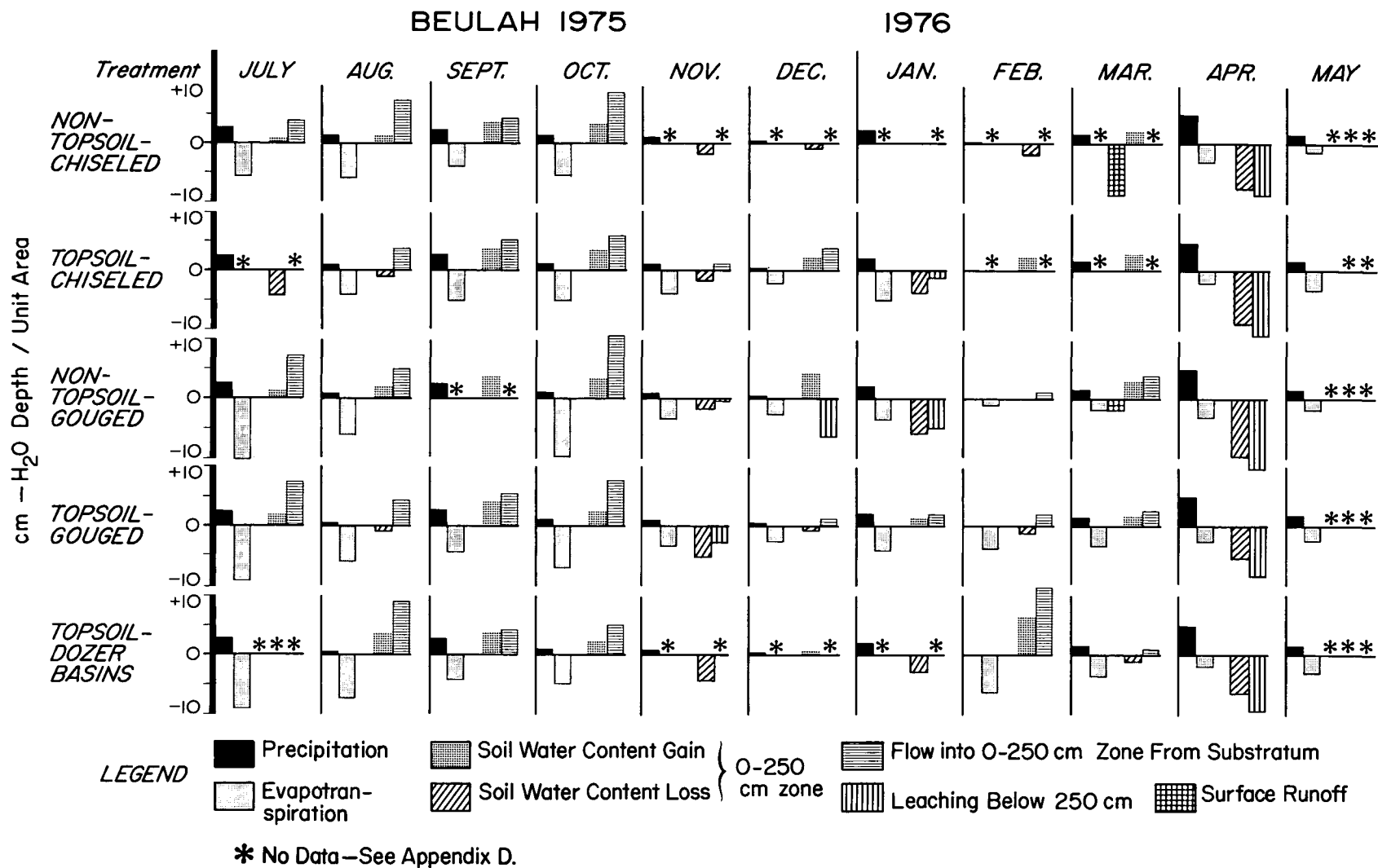


Figure 32. Summary of the monthly hydrologic balance of the spoil biosphere at the Savage Demonstration. On each plot the hydrologic parameters are presented left to right as precipitation, evapotranspiration, surface runoff, change in soil water content, and unsaturated flow.

impermeable bases. This situation apparently may have reduced water infiltration and percolation substantially. Conversely, with a dozer basin implement this compacted situation is alleviated with a set of scarifying teeth that loosens the basin bottom.

The changes in soil water content in the uppermost two meters of soil for a nine-month period at the Savage Demonstration are presented in Figure 32. These data show that all the treatments resulted in a net equilibrium or gain of profile water from September, 1975 to May, 1976. The greatest gain in soil water content was the watershed with a topsoil-gouged treatment.

During the nine-month measurement period the watersheds underwent a net movement of unsaturated soil water flow (WF) from the subsurface depths toward the surface. This means that soil water available in the surface two meters of spoils could not be accounted for by runoff, precipitation, and evapotranspiration. Thus, soil water in the unsaturated phase had to flow upward and into the surface 2 m zone.

Conclusion

This section has quantitatively described the hydrologic balance of the spoil biosphere as a function of surface manipulation treatments at three demonstration areas.

During the hydrologic year, the five surface manipulation treatments were estimated to have lost between 40 cm and 80 cm of water by the evapotranspirative (ET) process. There was little ET variation between watersheds at each area, but some variation between Demonstration Areas. The ET demands at Savage, Colstrip and Beulah Demonstration Areas were approximately 75 cm, 57 cm and 47 cm, respectively. The major reasons

for variation were plant cover, climate, and soil characteristics of the three demonstration areas. The Beulah Demonstration was most recently seeded, and thus vegetation was less developed with transpiration demand correspondingly lower. Also the soils at Beulah crust severely, forming a barrier to the loss of soil water by evaporation.

The unsaturated flow of soil water in the spoil biosphere is a prime concern in reclamation. If a flow gradient develops towards the surface, salinization of the surface soil is a potentially detrimental process. Conversely, if a flow gradient develops toward the ground water, leaching of excess salts into an aquifer is a possible undesirable development.

The unsaturated soil water flow characteristics of these watersheds generally indicated the net flow during the year was near zero or towards the surface. At the Colstrip Demonstration Area, some watersheds had a downward gradient which existed for nearly six months of the year while flow towards the surface occurred during the remainder of the period, the net result being a near balance for the period. However, at the Savage and Beulah Demonstration Areas, the unsaturated flow was consistently toward the surface. At both of the latter areas unsaturated soil water flow from the subsurface zone into the surface 2 m of spoil amounted to 10-20 cm annually. This process can serve the useful purpose of supplying water to the root zone of plants, but also entails the hazard of surface soil salinization.

The flow of unsaturated soil water towards the surface should not be considered a special case common only to newly reshaped, revegetated soils. However, the concern is whether these spoils, which have undergone complete

disarrangement of location and characteristics relevant to original overburden, contain soluble salts which can become mobile in the biosphere. Whether salinization will occur or not in these spoils is not known at the present time.

The effectiveness of these surface manipulation treatments in controlling runoff and erosion is most clearly demonstrated by spoil overland flow data. Unfortunately, this discussion on the spoil biosphere hydrologic balance was prepared during a period of an unusually few number of runoff events. However, during June, 1976, a substantial number of events occurred and clearly demonstrate the effects of these treatments on control of overland flow. Table 31 describes runoff events which have occurred on the Demonstration Areas from inception to June 15, 1976. These data clearly demonstrate that topsoiling management in spoil reclamation improved control of overland flow. In every case when runoff events occurred on both a chiseled and topsoil-chiseled or a gouged and topsoil-gouged watershed, the topsoiled treatment experienced less runoff. Without exception the topsoiled dozer basin treatment demonstrated the maximum control of overland flow compared to all treatments. This relationship was constant at all three Demonstration Areas.

Table 31. Surface runoff events which have occurred on the Demonstration watersheds from inception to June 15, 1976. Runoff in cm means that volume of water x cm deep over an area equivalent to the defined watershed.

defined watershed:			Total Event					
Demon- stration Area	Date of Runoff Event	Watershed Treatment	Event				Runoff (surface cm)	
			1	2	3	4		
Savage	Jan 17, 1976	Nontopsoil-Chiseled		0			0	
		Topsoil-Chiseled		0			0	
		Nontopsoil-Gouged		2.1	.4	.6	3.1	
		Topsoil-Gouged		0			0	
		Topsoil-Dozer Basin		0			0	
	May 25, 1976	Nontopsoil-Chiseled		.86			.86	
		Topsoil-Chiseled		.22			.22	
		Nontopsoil-Gouged		1.35			1.35	
		Topsoil-Gouged		.34			.34	
		Topsoil-Dozer Basin		.13			.13	
	June 2, 1976	Nontopsoil-Chiseled		.76	.84	.34	.33	2.27
		Topsoil-Chiseled		.73	.94	.16		1.83
		Nontopsoil-Gouged		.84	1.00	.36		2.20
		Topsoil-Gouged		malfunction			--	
		Topsoil-Dozer Basin		.05	.15	.30	.05	.55
	June 7, 1976	Nontopsoil-Chiseled		1.26	1.15			2.41
		Topsoil-Chiseled		1.26				1.26
		Nontopsoil-Gouged		1.26	1.19			2.45
		Topsoil-Gouged		malfunction			--	
		Topsoil-Dozer Basin		.17	.06			.23
	June 11, 1976	Nontopsoil-Chiseled		0				0
		Topsoil-Chiseled		.49				.49
		Nontopsoil-Gouged		0				0
		Topsoil-Gouged		malfunction			--	
		Topsoil-Dozer Basin		0				0
Colstrip	June 6, 1976	Nontopsoil-Chiseled		1.26			1.26	
		Topsoil-Chiseled		.64			.64	
		Nontopsoil-Gouged		.84			.84	
		Topsoil-Gouged		.62			.62	
		Topsoil-Dozer Basin		.43			.43	
	June 11, 1976	Nontopsoil-Chiseled		1.40			1.40	
		Topsoil-Chiseled		.32			.32	
		Nontopsoil-Gouged		1.40			1.40	
		Topsoil-Gouged		1.36			1.36	
		Topsoil-Dozer Basin		.29			.29	
Beulah	May 16, 1976	Nontopsoil-Chiseled		8.5			8.5	
		Topsoil-Chiseled		0			0	
		Nontopsoil-Gouged		2.4			2.4	
		Topsoil-Gouged		0			0	
		Topsoil-Dozer Basin		0			0	

Hydrological Measurement Error

The results presented in this chapter are significant in spoil hydrology technology, and it is appropriate to briefly discuss the degree of error inherent in these hydrologic measurements. There appeared to be some error associated with the runoff measurements, but this component, to date, has played a rather small role in the hydrologic budget of the spoil biosphere.

The weighing lysimeter in each watershed appeared to produce reliable data. However, it was realized that there were complications which may have contributed to error in these data. These lysimeters were 1.0 m deep and soil water transport was measured to flow below this depth. Therefore it must be assumed that some water logging at the bottom of the lysimeter occurred. Measurements with neutron access tubes in each lysimeter on a monthly basis indicated a very wet bottom in a few instances, but this situation was temporary. Apparently evapotranspiration utilized this water, since the waterlogged situation often disappeared within a month time period. Therefore, at certain times of the year when this waterlogged condition was being dissipated by the evapotranspirative process, the actual watershed evapotranspiration was possibly overestimated. If evapotranspiration from these spoils was actually less than that reported in this chapter, it would influence the results by enhancement of the deep leaching process.

There was less vegetation on the surface of lysimeters compared to the rest of the watershed. The lysimeter construction period coincided with seeding of these demonstration areas, therefore seeding of the lysimeters was delayed by at least a month. Less vegetation would have the effect of underestimating actual evapotranspiration of the watershed. Blowing snow,

which apparently accumulated excessively on these lysimeters, created a problem. During winter months certain lysimeters occasionally indicated water gains in excess of precipitation, and these data were generally discarded. Even with the above discussed limitations, the lysimeters functioned according to specification in a very reliable manner and data were of the correct magnitude for the type of environment being monitored.

As discussed in the previous chapter, the soil water content data in this report, which are presented as means of five sites within a watershed, contained error described by the standard deviation of the mean which averaged about 5- percent, and ranged from 3- to 13- percent. This error was largely attributed to field soil variations, while less than 1- percent was attributed to operator and instrument error. Also, it should be noted that *in situ* field calibration equations were not derived for the neutron probe method at the Colstrip and Savage Demonstrations. Factory calibrations were used which were supplied with the instrument. Quantitatively, this could present some error, but qualitatively, i.e. changes in water content over time, essentially no error was introduced. At the Beulah Demonstration an *in situ* calibration was determined for the neutron probe equipment.

The precipitation results presented in this chapter can be expected to contain the greatest percentage of error compared to the other hydrological parameters measured. Malfunction of on-site instrumentation often necessitated utilization of precipitation catches from nearby stations. At the Colstrip and Beulah Demonstrations these alternative stations were within 100 m, but at the Savage Demonstration the alternative station was about 8.0 km distant. Hydrologic researchers realize that point catches of precipitation provide

only estimations of actual precipitation, and that the error becomes larger as the wind velocity increases and when the precipitation occurs in the form of snow. This phenomenon has been demonstrated very clearly by Caprio (4) who, at numerous field sites in Montana and through methodology described by Hamon (12), determined that point catches during windy snow storms recorded about 30 percent less precipitation compared to that which actually occurred. The Savage and Beulah Demonstration sites were particularly windy in nature.

Since this type of large scale nonreplicated research often does not lend itself to sound statistical analyses, the magnitude of possible error associated with measurements must be constantly recognized. Generally, it can be stated that the results presented in this chapter are those which have demonstrated consistent patterns and consistent differences over time. The anticipated measurement error would not be expected to substantially change such interpretations.

GROUND-WATER HYDROLOGY

Introduction

The following section presents data on ground-water characteristics at the Colstrip, Savage and Beulah Demonstration Areas. This phase of the project was subcontracted to geohydrologic experts stationed in the area of each Demonstration. The work at the Colstrip Demonstration was supervised by hydrogeologist Wayne Van Voast, Montana Bureau of Mines. Much of the field work and interpretation at the Savage and Beulah Demonstrations was completed by geologist G. Groenewold of the North Dakota Geological Survey.

Methodology

At the Colstrip Demonstration Area spoil reshaping was completed in May, 1975. Wells were installed during October, 1974. Observation well descriptions are shown in Table 32. Locations are shown in Figures 33 and 34.

At the Savage Demonstration, 18 observation wells were installed in November, 1974 (Table 32). Eight of these wells had a one-inch PVC casing and the remainder had four-inch PVC casings. All wells had two-foot inlet screens installed at the bottom. Eight of these wells have the screens located in or near thin undisturbed coal seams underlying the mine spoil. The remainder of the well screens are located at or near the bottom of the mine spoil (Figures 35 and 36). Although these wells extending to the bottom of spoils are shallow in depth it was predicted that an aquifer may develop at this depth since the underlying zone was

Table 32. Observation well information for the Colstrip, Savage, and Beulah Demonstration Areas.

Site	Well No.	Casing Size(ID)		Well Termination	Elevation(1)		Depth of Well		Approximate	
		(in)	(cm)		Top of Casing (feet)	(meters)	Below Top of Casing (feet)	(meters)	Casing Height (feet)	(meters)
Colstrip	1	4	10	Coal	3207.48	977.64	59.34	18.09	4.19	1.28
	2	4	10	Spoil	3207.06	977.51	31.60	9.63	3.88	1.18
	3	4	10	Spoil	3207.76	977.73	28.62	8.72	4.92	1.50
	4	4	10	Spoil	3207.64	977.69	30.75	9.37	4.97	1.51
	5	4	10	Spoil	3206.95	977.48	27.60	8.41	3.18	.97
	6	4	10	Spoil	3208.14	977.84	28.67	8.74	4.20	1.28
	7	4	10	Coal	3208.30	977.89	52.59	16.03	3.84	1.17
	8	4	10	Spoil	3207.57	977.67	28.73	8.76	3.40	1.04
	9	4	10	Coal	3214.86	979.89	37.15	11.32	4.17	1.27
	10	4	10	Spoil	3214.90	979.90	58.28	17.76	5.00	1.52
	11	4	10	Coal	3213.79	979.56	59.35	18.09	3.09	.94
	12	4	10	Spoil	3214.54	979.79	35.40	10.79	2.68	.82
Savage	1	1	2.5	Coal	2289.80	697.93	84.79	25.84	3.00	.91
	2	4	10	Spoil	2289.57	697.86	13.65	4.16	3.11	.95
	3	1	2.5	Coal	2289.76	697.92	83.45	25.44	3.45	1.05
	4	4	10	Spoil	2289.47	697.83	15.60	4.75	2.98	.91
	5(2)	4	10	Coal	2286.99	697.07	63.10	19.23	0.25	.08
	6	4	10	Coal	2289.87	697.95	93.39	28.46	3.80	1.16
	7(2)	4	10	Spoil	2276.31	693.82	14.90	4.54	1.32	.40
	8	1	2.5	Coal	2277.48	694.18	90.39	27.55	3.55	1.08
	9	1	2.5	Coal	2290.94	698.28	100.70	30.69	2.84	.87
	10	1	2.5	Coal	2310.91	704.37	89.38	27.24	3.33	1.01
	11	4	10	Spoil	2312.48	704.84	26.75	8.15	3.18	.97
	12	4	10	Spoil	2309.85	704.04	30.40	9.27	2.81	.86
	13(2)	4	10	Coal	2314.33	705.41	75.85	23.12	0.25	.08
	14	4	10	Spoil	2317.05	706.24	41.49	12.65	4.54	1.38
	15	1	2.5	Coal	2303.06	701.92	101.78	31.02	1.82	.55
	16	4	10	Spoil	2304.20	702.32	31.30	9.54	3.63	1.11
	17	1	2.5	Spoil	2335.00(3)	711.71	59.85	18.24	3.89	1.19
	18	1	2.5	Spoil	2359.08	719.05	73.57	22.42	2.82	.86
Beulah	1	1	2.5	Coal	1967.81	599.79	91.2(4)	27.80	3.8(4)	1.16
	2	1	2.5	Coal	1967.21	599.61	83.1(4)	25.33	3.2(4)	.98
	3	4	10	Spoil	1968.92	600.13	58.84	17.93	2.84	.87
	4	4	10	Coal	1980.60	603.69	90.3(4)	27.52	4.4(4)	1.34
	5	4	10	Spoil	1981.16	603.86	53.1(4)	16.18	3.6(4)	1.10
	6	4	10	Coal	1990.44	606.69	89.90	27.40	2.60	.79
	7(2)	4	10	Spoil	1990.06	606.57	68.93	21.01	.90	.27
	8	1	2.5	Coal	1965.55	599.10	91.6(4)	27.92	4.0(4)	1.22
	9	4	10	Spoil	1965.73	599.15	48.35	14.74	3.10	.94
	10	1	2.5	Spoil	1981.38	603.92	63.3(4)	19.29	2.5(4)	.76
	11	1	2.5	Spoil	1980.93	603.79	52.9(4)	16.12	3.2(4)	.98
	12	4	10	Spoil	1975.80	602.22	58.1(4)	17.71	3.2(4)	.98
	13	1	2.5	Coal	1970.93	600.74	85.3(4)	26.00	3.8(4)	1.16
	14	4	10	Spoil	1971.58	600.94	55.4(4)	16.89	4.0(4)	1.22
	15	1	2.5	Spoil	1967.77	599.78	48.6(4)	14.81	3.7(4)	1.13
	16(2)	4	10	Coal	1954.99	595.88	71.30	21.73	.75	.23
	17(2)	4	10	Spoil	1955.43	596.02	44.16	13.46	.85	.26
	18	4	10	Spoil	1968.29	599.93	53.53	16.32	2.78	.85
	19	4	10	Spoil	1982.59	604.29	62.67	19.10	3.86	1.18
	20	1	2.5	Coal	1981.56	603.98	94.6(4)	28.83	2.3(4)	.70
	21	1	2.5	Coal	1970.24	600.53	86.7(4)	26.43	3.5(4)	1.07
	22	1	2.5	Coal	1983.30	604.51	101.8(4)	31.03	3.7(4)	1.13
	23	1	2.5	Coal	1976.08	602.31	89.5(4)	27.28	3.2(4)	.98

(1) Survey by Christian Spring, Sielbach & Associates--April 1976.

(2) Wells equipped with Leupold and Stevens Water Level Recorder.

(3) Elevation calculated from previous survey, Sielbach & Associates, 1974.

(4) Depth and Casing height scaled from well log charts, not field measurements

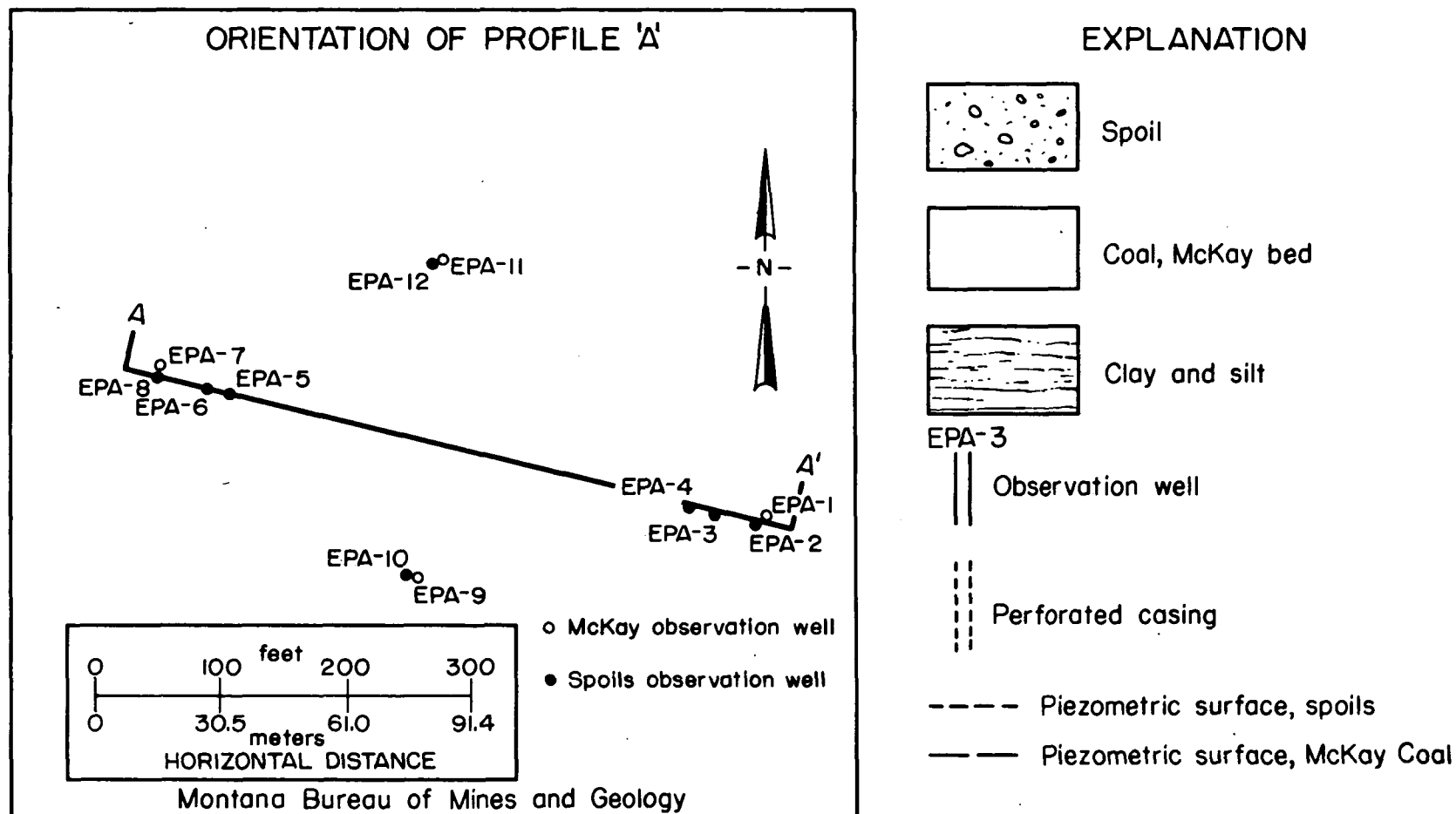


Figure 33. Observation well orientation located at the Colstrip Demonstration Area.
The legend applies to companion Figure 34.

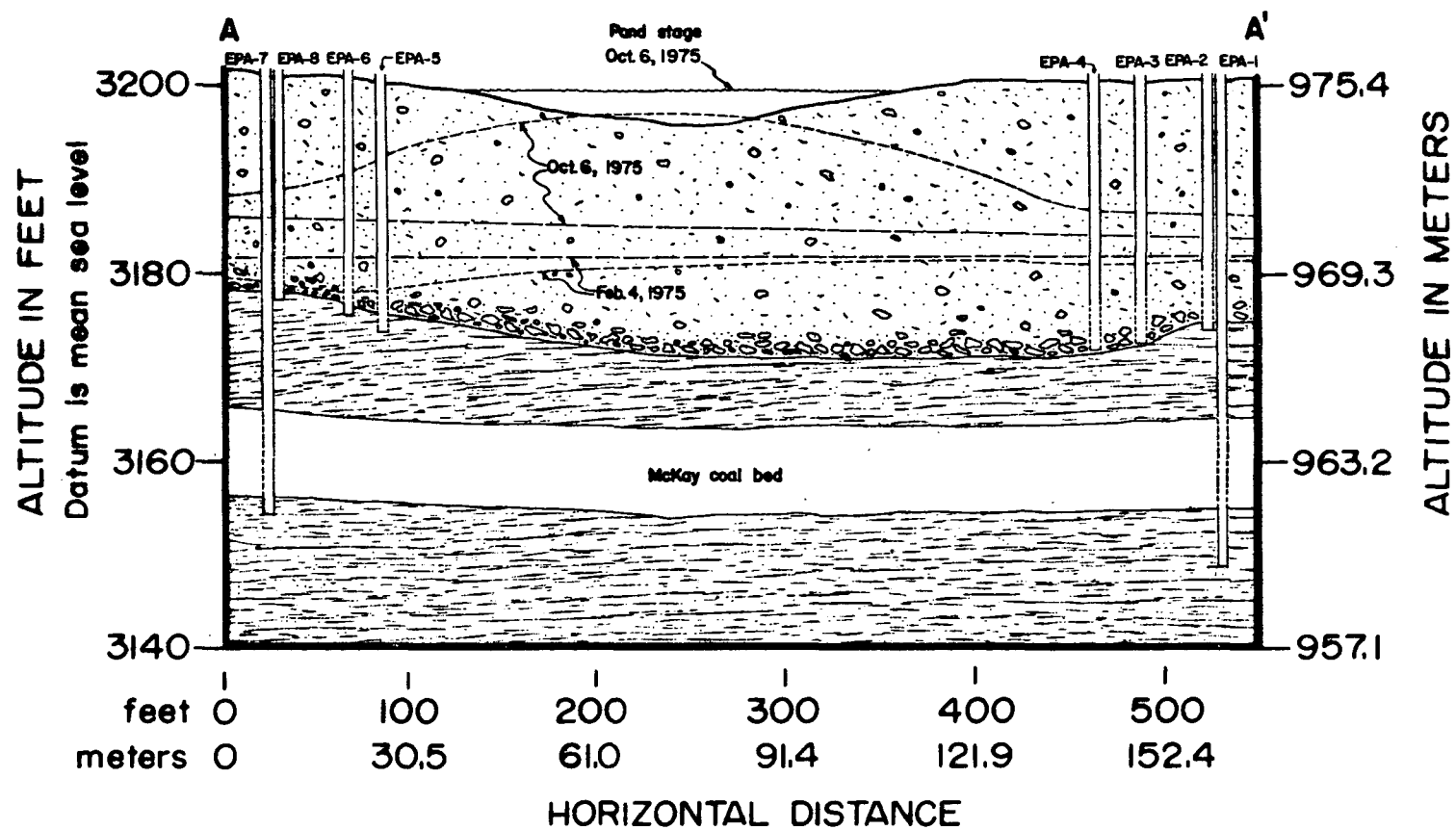


Figure 34. Water level elevation diagram for both the McKay and spoil aquifers on two dates at the Colstrip Demonstration. The legend is shown on companion Figure 33.

relatively impermeable. Pea gravel was placed around the screens to prevent clogging and they were then backfilled with spoil around the casings. Cement caps were poured around the casings at the ground level to prevent ground-water contamination by overland flow. Three wells with four-inch casings were selected for installation of Leopold and Stevens Type F water level recorders. These wells were selected on the basis of their recovery response to pumping tests conducted in October, 1975. The recorders were put into operation in January, 1976.

The spoil material at Savage contains large amounts of sand and gravel which created cave-in problems during drilling at several well locations. In some instances, the well locations had to be abandoned. Some wells were completed by using bentonite mud to stabilize the wells during the drilling operation. At two locations large voids were encountered and mud pump circulation could not be maintained. Due to these problems, it was not possible to obtain a precise record of the geologic strata in which the wells are located.

At the Beulah Demonstration a total of 23 observation wells were installed in October, 1974 (Figure 37). Twelve of these wells monitored aquifer development in spoils above coal while eleven wells were in the coal (Table 32).

Results

To date, measurement of Colstrip wells indicates that a rise in water levels has occurred in both the new spoil aquifer and the deeper undisturbed aquifer associated with the McKay coal bed (Figures 33, 34). Since surface drainage at this site is confined, and

the winter-spring seasons of 1974-1975 and 1975-1976 resulted in above average snowmelt and precipitation, the area produced a pond. These data indicate ground-water recharge is occurring beneath the Demonstration Area. We can speculate that the pond area constitutes the major recharge source for the developing saturated zone at the bottom of the spoils. Also a smaller portion of this ground water could be attributed to the movement of soil water in the unsaturated phase through the spoil profile. The source of this water would be precipitation that has infiltrated the spoils at the surface. This phenomena was shown to exist, particularly during the spring, in a previous section titled "The Hydrologic Balance of the Spoil Biosphere."

At Savage, the observation wells located in the deep and thin coal seam (Figures 35, 36) have shown no distinct trends in water level changes. There have been small seasonal changes in elevations. This suggests that the geologic strata lying between the mine spoils and the thin coal seam has a very low transmissivity. Therefore, at this time, mining activity appears to have very little, if any, influence on the hydrological characteristics of the underlying undisturbed aquifers.

The observation wells extending to the base of the spoils at Savage indicate that little or no recharge of the spoil aquifer has occurred since measurements were initiated. There was a gradual drop in the water levels for the spoil aquifer from August, 1975 to May, 1976. On June 2, 1976, a high intensity short duration convective storm caused a significant surface runoff event. A pond located near

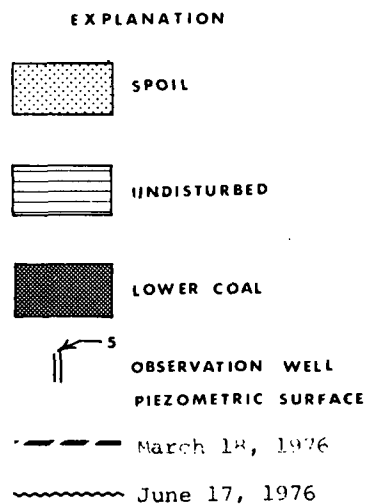
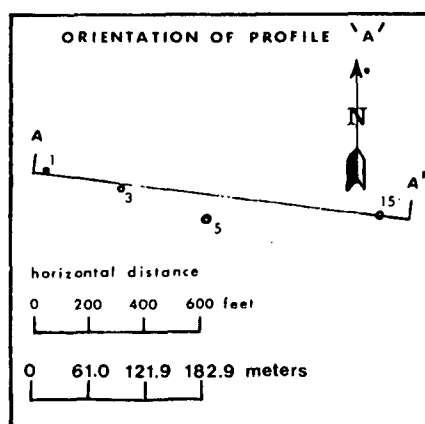
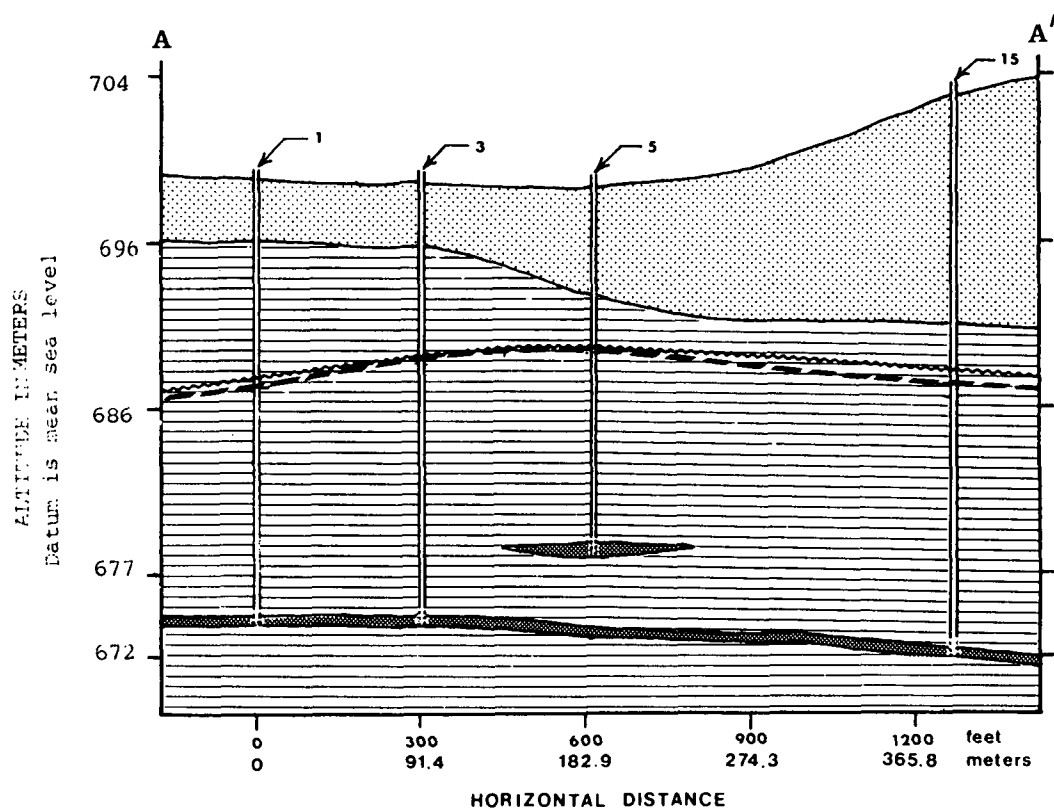


Figure 35. Savage demonstration area piezometric elevation diagram for well numbers 1, 3, 5 and 15. Data collected during 1975 and 1976.

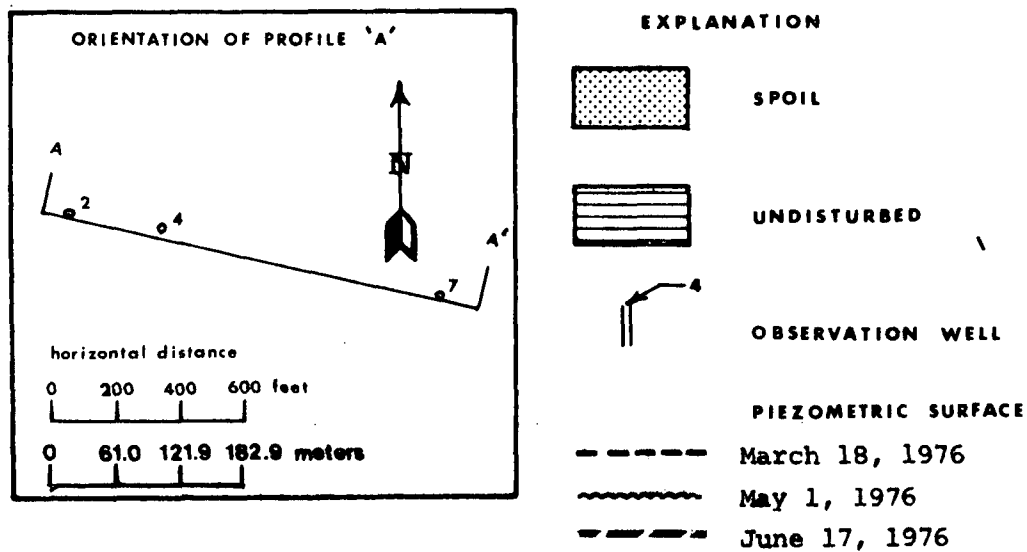
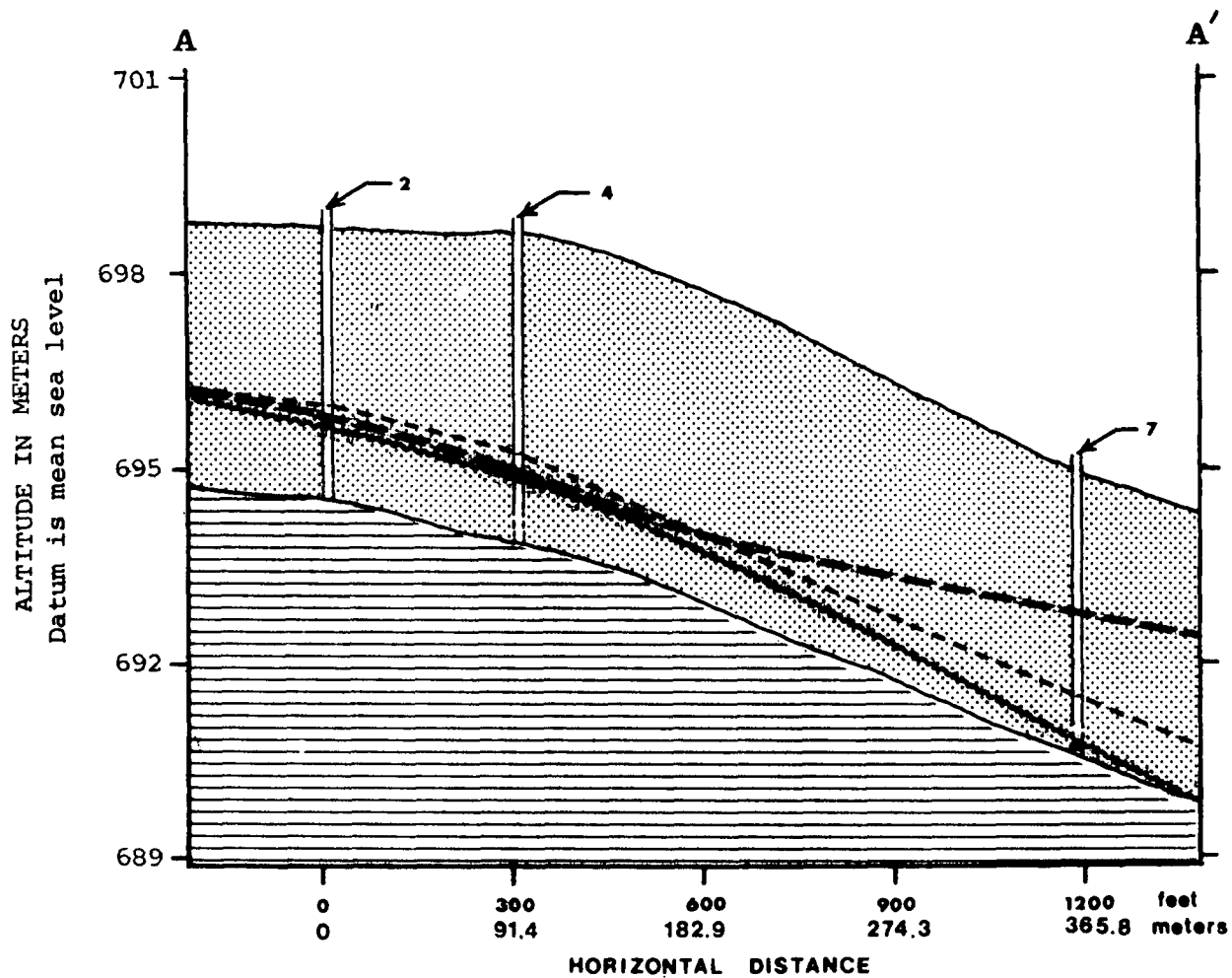


Figure 36. Savage demonstration area piezometric elevation diagram for well numbers 2, 4 and 7. Data collected during 1975 and 1976.

well number 7 rapidly underwent significant recharge. Two hours after this event, well number 7 began to respond to this hydrologic event. During the seven day period from June 2-9, the water level in this well raised approximately 2.1 meters. Unless other large surface runoff events occur, water levels will probably stabilize and then gradually recede. Although this well number 7 was only 4.7 meters deep, it was felt that water did not infiltrate down the walls of the casing. This well was sealed at the surface with concrete, and the casing perforated only in the bottom one meter.

At the Beulah Demonstration Area, the soils are sodic in nature, therefore at least two phenomena must be taken into account when considering the hydrologic characteristics. These are the possible developments of a surface crust on the spoils prior to topsoiling and the possible development of surface cracks which in turn result in piping features and localized surface subsidence and collapse (Groenewold, personal communication, 1976).

The development of impermeable surface crusts commonly seems to eliminate any possibility of effective infiltration. Piping failures on the other hand, greatly increase infiltration and often result in nearly all surface runoff being channeled downward into the spoils. It should be noted that a number of "pipes" did develop on these demonstration watersheds but were plugged up with straw and bentonite. The rates and patterns of water movement in spoils via pipes is unknown at this time. However, data from the demonstration seem to indicate that the channeled water has little effect upon saturation

of the spoils, surface spoils or recharge of aquifers. Apparently then, this channeled water moves rapidly through the spoils and discharges rapidly, probably along the surface traces of slumping failures.

At the Beulah Demonstration Area (Figure 37), initial data suggest that the main source of ground water in the spoils is from lateral seepage from the area of "orphan spoils" immediately to the south of the demonstration. There seems to be a migrating water "front" which presently has saturated the lower six meters of spoils in the southern part of the study area, which rapidly dissipates to the north. Whether this is the case or not will only be known after long term observation of the area. However, it appears to be a logical extension of the surface conditions which exist in the Demonstration Area, and therefore, may once again indicate the need for complete knowledge of the entire landscape if reclamation is to be successful.

Conclusion

The busy work schedules of Mr. Wayne Van Voast and Mr. G. Groenewold have limited the activities of these scientists on this project. The basic aquifer characteristics of these Demonstration Areas have been outlined and monitoring programs established. The chemistry of these aquifers is discussed in the next section.

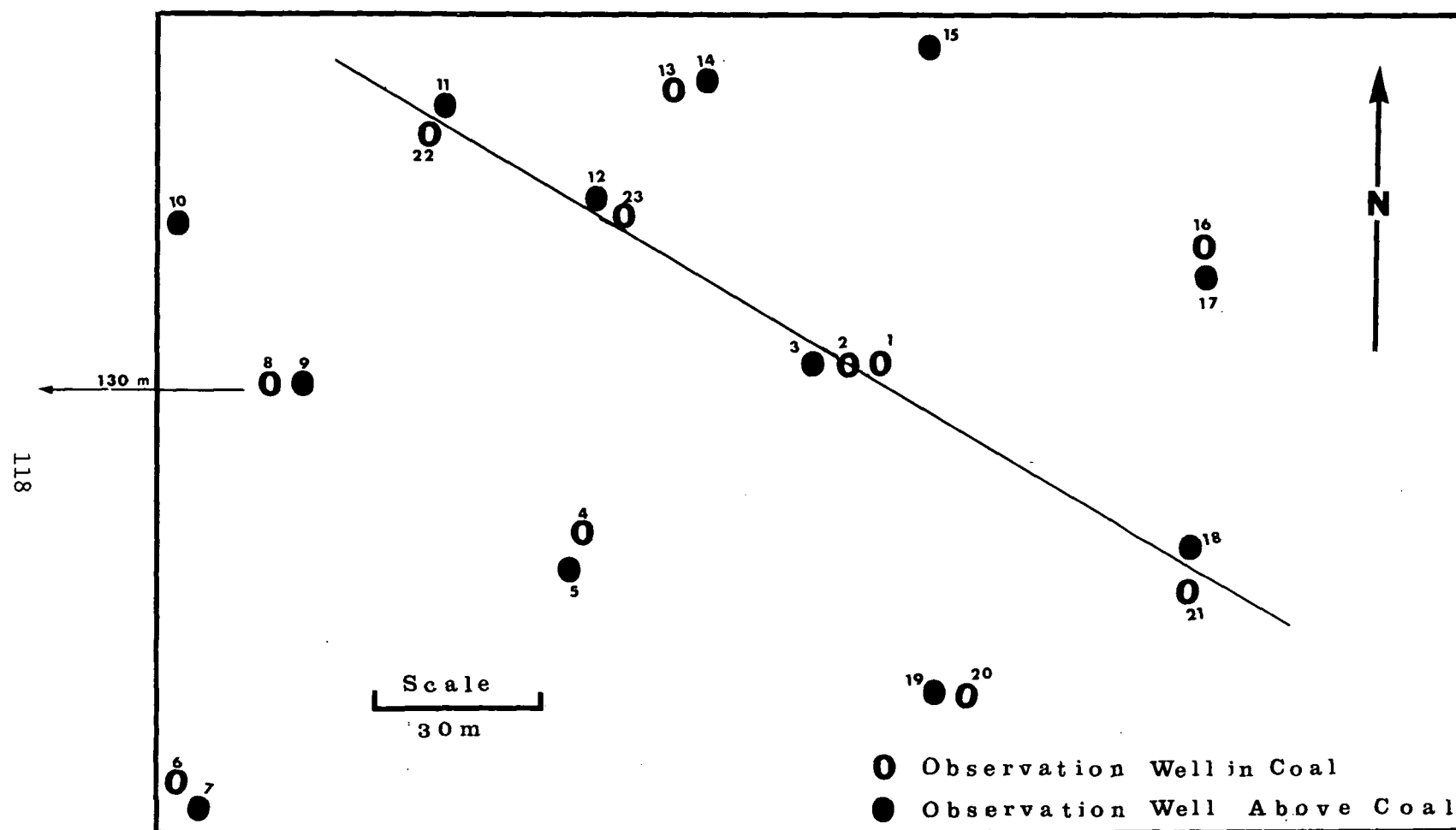


Figure 37. Experimental design of observation wells located at the Beulah Demonstration. The five micro watersheds are centrally located as can be seen in Figure 13.

CHARACTERISTICS OF THE GROUND-WATER CHEMISTRY

Introduction

The leaching of solutes through spoils and into an aquifer system is a potential problem, but the possibility of this phenomenon occurring appears remote under semi-arid climate. Earlier in this report it was shown that at the Colstrip Demonstration deep percolation as unsaturated flow occurred part of the year while the remainder of the year experienced flow towards the surface. At the Savage and Beulah Demonstrations the net unsaturated flow for the hydrologic year was towards the surface, however, during several months deep percolation occurred. Whether these short term flows towards the ground water could eventually transport significant quantities of salt into an aquifer cannot be answered at this time.

Perhaps a more important source that could affect the aquifer chemistry is surface pond formation. In Montana and North Dakota, ponds exist on recontoured spoils where they were nonexistent before the advent of strip mining. Some such ponds attain an area of several hectares in area and three or more meters deep. If sufficient spoil fill is not present between the base of the old pit and the bottom of the pond, a saturated zone of salt translocation could develop across this zone.

At the Colstrip, Savage, and Beulah Demonstrations such ponds have developed in the immediate area. Consider the Colstrip Demonstration

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where during the 1974-75 winter there was no pond in the immediate vicinity. Yet in the spring of 1975 a pond about 150 m long by 50 m wide by 3 m deep developed in the valley base of the Demonstration Area (Figure 38). To date this pond is still present and appears to be a permanent, but fluctuating, feature of the area.



Figure 38. This pond developed during the spring 1975 and, to date, has remained a permanent feature of the Colstrip Demonstration Area.

The interactions of spoil ponds and deep percolation through spoils with a developing aquifer are not known. For this reason the hydrochemistry of the developing aquifer at the base of the spoils and associated deeper aquifers was monitored at each Demonstration Area.

Methodology

Observation wells were installed at each of the three Demonstration Areas to monitor subsurface hydrologic characteristics of the spoil

material and the underlying coal. Locations and monitoring zones for these wells are presented in the previous chapter. Water from selected wells was sampled several times during the course of the investigation to provide baseline hydrochemical data for future review and evaluation.

The observation wells were pumped to obtain water for analysis. Sample bottles were treated with preservatives and then kept refrigerated. Table 48 describes the current preservation methodology as recommended by the Environmental Protection Agency (8).

Table 33. Ground-water sample preservation treatment and corresponding analyses performed. All samples were refrigerated after collection.

Preservation Treatment	Analyses Performed
None	pH, electrical conductance, SO_4 , CO_3 , HCO_3 , $\text{PO}_4\text{-P}$, Cl, B
H_2SO_4 to pH <2	$\text{NO}_3\text{-N}$
HNO_3 to pH <2	Ca, Mg, Na, K, Mn, Cu, Zn, Pb, Cd, Fe (dissolved metals)

The H_2SO_4 treatment and the refrigeration act as bacterial inhibitors. The HNO_3 prevents metal precipitation. When new sample containers were unavailable, previously used bottles underwent a cleansing process before each use which included scrubbing with soap, rinsing several times with tap water, rinsing with dilute HCL solution and finally rinsing several

times with distilled water. Even with this extensive cleaning procedure, there was some indication in the results of several analyses that contamination may have occurred when bottles were reused. Present procedure is to use new containers (as available) for each sample and to rinse the container three times with the water to be sampled before obtaining the final sample.

The filled containers were transported to the lab at Montana State University in ice chests filled with crushed ice to maintain the proper temperature. Unavoidable delays due to long travel times sometimes prohibit analysis of the samples within the recommended time limits of the Environmental Protection Agency (8). The most noticeable effects of this delay would be reflected in the determinations for alkalinity, bicarbonate, carbonate, pH (when not measured in the field), nitrate-N, and total phosphate-P. Procedures for measuring these parameters in the field are presently being evaluated. Specific procedures presently used in the laboratory for analysis of the water samples are summarized in Table 34.

Some concern was expressed by the Montana Bureau of Mines that the Zn procedure may contain error due to the type of filter paper used. To clarify this point, the following test was performed. Three 0.4 micron Nuclepore Membrane Filters (VWR Scientific, Seattle, Washington #28157-960) were wet digested in a 3:2 mixture of redistilled HNO_3 : HClO_4 ,

Table 34. Summary of laboratory procedures used for groundwater analyses.

Element	Procedure*
Pb, Cd, Cu, Fe, Zn, Mn, Ca, Mg, Na, K	Atomic Absorption Spectroscopy
Cl	Hg(NO ₃) ₂ titration
pH	Electrode
Conductivity	Conductance Bridge-Meter
HCO ₃ , CO ₃	Titration
SO ₄	Turbidimetric
PO ₄ -P	Persulfate digestion--colorimetric
B	Curcumin Method
NO ₃ -N	Cadmium Reduction

*All procedures are from "Methods for chemical analyses of water and wastes", EPA (8). All metal analyses are dissolved metals. EPA specifications state water samples for dissolved metal analyses should be filtered (.45 micron) as soon as possible to remove sediment material. This operation was performed in the lab at Montana State University which was generally several days after the sample had been collected at the field sites. Current plans are to filter future samples in the field.

transferred to 25 ml flasks and brought to volume with distilled deionized H₂O. The Zn content was measured using a Varian AA6 with automatic background corrector. The mean Zn content of the filters was 492.9 parts per million. Two samples of distilled deionized H₂O were acidified to a pH < 2 with HNO₃. One was then filtered through a Nuclepore filter. The Zn content of each sample was less than 10 parts per billion. Therefore, no measurable Zn leached from the filter; and no error in the Zn procedure can be attributed to these filters.

Water analyses from observation wells at the three Demonstration Areas were reviewed with regard to charge mass balance. The purpose of this check was to identify, if possible, any contaminated samples or procedural errors in analysis. Theoretically, the sum of anions, expressed in milliequivalents per liter, must equal the sum of cations, in milliequivalents per liter, in any water sample. In practice, the sums are seldom equal because of the unavoidable variations in analysis. This inequality increases as the ionic concentrations increases. A factor which may affect the balance is the presence in the sample of undetermined species. Results of analyses from selected wells at the three Demonstrations Areas are discussed in the following section.

Results

The limited amount of data collected to date are not sufficient to show any significant trends in ground-water quality, however, general characteristics of the waters in the various zones can be described. At the Colstrip Demonstration Area (Table 35), specific conductance is generally highest in the water samples pumped from the spoil materials. Calcium and magnesium are the dominant cations in both the spoils and coal zones. The bicarbonate anion is dominant in samples from the McKay coal zone, whereas, sulfate is the major anion in the developing spoils aquifer. Sulfate concentrations

generally exceed recommended limits for drinking water (Table 25) in the spoils zone and in one well, #7, in the coal. Dissolved solids and manganese concentrations in both aquifers exceed recommended limits.

As previously mentioned, a pond has developed at the Colstrip site. Preliminary chemical data for pond water collected in June, 1976, indicate that concentrations for most of the major cations and anions are significantly lower than found in the underlying aquifers: Ca, 13 mg/l; Mg, 5.0 mg/l; Na, 8.0 mg/l; HCO_3 , 103 mg/l; and SO_4 , 178 mg/l. Trace element concentrations are also lower in the ponded water than in the developing spoils aquifer but approach the levels in the McKay Coal: Mn, 51 $\mu\text{g/l}$; Cu, 29 $\mu\text{g/l}$; Zn, 30 $\mu\text{g/l}$; Pb, 40 $\mu\text{g/l}$; and Cd, < 4 $\mu\text{g/l}$. These data suggest that trace element concentrations in the underlying aquifers will not be significantly increased in the future by vertical recharge from the pond.

Hydrochemical data from selected wells at the Savage Demonstration Area are shown in Table 36. Dissolved solids, sulfate and manganese generally exceed recommended limits (Table 25) in both zones. Calcium and magnesium are the dominant cations in the spoils water whereas sodium is dominant in samples from the coal beds. Bicarbonate and sulfate are the dominant anions in both zones. The sodium absorption ratio (SAR) is highest in waters from the coal.

At the Beulah Demonstration Area (Table 37), sodium is the dominant cation in both the spoils and the coal. The major anion in the developing spoils aquifer is sulfate, while bicarbonate is dominant in the coal waters. Concentrations of manganese, sulfate, and dissolved solids exceed recommended limits for drinking water in both zones (Table 25). Relatively high sodium values result in high sodium absorption ratios (SAR) in waters from both the coal beds and the spoil materials.

Table 35. Chemical analyses of groundwater from observation wells in the immediate vicinity of the watershed study located at the Colstrip Demonstration Area.

		pH (Laboratory) (*field)	Specific Conductance	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Lead (Pb)	Cadmium (Cd)	Boron (B)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	TDS (Calculated)	SAR	S = Spoils M = McKay Coal	Comments		
Well Number	Date of Collection		µmhos/ cm	mg/l			µg/l						mg/l												
1	03/25/76	7.3	830	62	57	-	565	130	32	435	< 5	11	-	479	0	151	-	.01	0	-	-	-	M		
1	05/29/76	6.9*	770	54	65	-	96	60	30	22	<10	< 2	.28	338	0	149	-	.02	.01	-	-	-	M		
1	09/13/76	7.6	930	97	78	64	8920	372	84	123	18	12	.62	552	0	180	14.2	.00	.03	715	1.17	M	(1)		
2	03/25/76	7.2	1850	187	190	-	72	288	31	653	< 5	10	-	719	0	851	-	.01	0	-	-	-	S	(2)	
2	05/29/76	6.5*	1450	86	110	-	148	139	27	14	<10	< 2	.25	381	0	674	-	.04	.01	-	-	-	S		
2	09/13/76	7.8	900	98	71	72	2720	152	60	68	12	< 5	.59	506	0	174	14.2	.44	.02	682	1.35	S	(1)		
3	03/25/76	7.3	1100	110	98	-	52	108	22	350	< 5	8	-	481	0	460	-	<.01	0	-	-	-	S	(2)	
3	05/29/76	6.4*	1360	75	80	-	155	112	12	14	<10	< 2	.21	314	0	519	-	.11	.02	-	-	-	S		
3	09/13/76	7.5	1580	96	180	54	2820	520	45	58	<10	<10	.60	705	0	524	9.4	.18	.09	1213	.74	S	(1)		
4	05/29/76	6.4*	1300	83	105	-	172	72	12	24	<10	< 2	.21	360	0	452	-	.03	.10	-	-	-	S		
5	03/25/76	7.1	2620	246	275	-	70	600	28	388	< 5	10	-	964	0	1483	-	1.24	0	-	-	-	S		
6	03/25/76	7.0	2800	245	290	-	68	1360	27	725	< 5	5	-	933	0	1612	-	1.23	.01	-	-	-	S	(2)	
6	05/29/76	6.5*	2250	127	152	-	182	450	6	16	<10	< 2	-	526	0	1121	-	1.35	.16	-	-	-	S		
7	03/25/76	7.2	1950	177	162	-	88	245	23	904	< 5	4	-	816	0	976	-	<.01	0	-	-	-	M	(2)	
7	05/29/76	6.7*	850	71	80	-	200	30	6	11	< 10	< 2	.24	305	0	441	-	.03	.02	-	-	-	M		
7	09/13/76	7.4	1780	184	192	55	800	252	58	33	< 10	< 5	-	758	0	628	9.4	.00	.03	1437	.68	M	(1)		
8	03/25/76	7.2	1900	215	158	-	78	348	22	535	< 5	8	-	841	0	856	-	.10	0	-	-	-	S	(2)	
8	05/29/76	6.5*	1800	100	91	-	210	120	4	10	<10	< 2	.10	442	0	742	-	.23	0	-	-	-	S		
9	03/25/76	7.2	620	54	43	-	73	70	13	332	< 5	12	-	381	0	86	-	<.01	0	-	-	-	M	(2)	
9	05/29/76	8.8	550	20	25	-	208	< 10	< 4	4	<10	< 2	.24	244	18	88	-	.03	.11	-	-	-	M		
9	09/13/76	7.7	700	72	64	66	6640	518	96	73	<10	< 5	-	448	0	128	5	.49	.01	563	1.36	M	(1)		
10	03/25/76	7.1	1620	173	168	-	94	305	20	770	< 5	10	-	556	0	792	-	.01	.05	-	-	-	S	(2)	
10	09/13/76	7.7	1100	118	80	48	6400	476	124	70	<10	< 5	.54	470	0	344	9.4	.18	.02	839	.84	S	(1)		
11	03/25/76	7.3	650	46	36	-	70	47	19	325	< 5	12	-	423	0	70	-	<.01	0	-	-	-	M	(2)	
12	03/25/76	7.1	1590	138	103	-	74	127	13	218	< 5	15	-	537	0	630	-	.30	0	-	-	-	S	(2)	
12	09/13/76	7.5	1610	156	116	70	2200	180	60	50	< 10	< 5	.34	631	0	528	11.8	.00	.03	1195	1.03	S	(1)		

Comments: suspected sample contamination or analytical problem; (1) iron; (2) zinc.

Table 36. Chemical analyses of groundwater from observation wells in the immediate vicinity of the watershed study at the Savage Demonstration Area.

		pH(Laboratory) (%field)					Specific Conductance	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Lead (Pb)	Cadmium (Cd)	Boron (B)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	TDS (Calculated)	SAR	S=Spills U=Uncultivated C=Coal	Comments		
Well No.	Date of Collection	umhos/ cm					mg/l	ug/l					mg/l																
2	10/01/75	-	2270	244	205	59	<10	330	21	<5	<5	5	-	-	-	1164	-	-	.13	-	.67	S							
2	02/27/76	6.1*	1950	204	223	-	51	642	46	410	0	8	-	393	0	1408	-	0	0	-	-	S							
5	02/27/76	6.2*	920	80	73	-	52	152	7	43	0	8	-	403	0	412	-	0	0	-	-	C							
5	07/04/76	6.2*	1500	135	116	-	94	251	0	<10	<10	<4	.84	694	0	418	-	0	.03	-	-	C							
5	09/11/76	7.6*	850	49	19	170	11100	340	120	190	<10	5	-	358	0	170	19	0	.24	615	5.23	C					(1)		
6	02/27/76	6.4*	1820	40	34	624	29	30	5	10	0	10	-	702	0	831	-	0	0	1875	17.49	C					(2)		
6	09/11/76	7.0*	2070	67	37	499	10200	360	68	192	<10	10	-	955	0	498	26.4	.01	.26	1607	12.16	C					(1)(2)		
7	02/27/76	5.9*	1650	125	136	46	13	30	9	24	0	0	-	515	0	805	-	0	.01	1365	.68	S							
7	07/04/76	7.04	1450	150	128	-	107	118	38	<10	<10	<4	1.12	510	0	543	-	0	.12	-	-	S							
13	02/27/76	-	600	60	45	-	81	148	8	30	0	5	-	391	0	103	-	0	0	-	-	C							
13	07/04/76	6.3*	860	76	50	-	72	220	37	<10	<10	<4	.53	592	0	97	-	0	.11	-	-	C							

Comments: Suspected sample contamination or analytical problems; (1) iron; (2) sodium.

Table 37. Chemical analyses of groundwater from observation wells in the immediate vicinity of the watershed study at the Beulah Demonstration Area.

		pH(Laboratory) (#Field)		Specific Conductance																						
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Lead (Pb)	Cadmium (Cd)	Boron (B)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Nitrate-N (NO ₃ -N)	Phosphate-P (PO ₄ -P)	TDS (Calculated)	SAR	S=Spills U=Undisturbed C=Coal				
Well No.	Date of Collection	µmhos/ cm		mg/l			µg/l						mg/l													
6	03/25 76	7.2*	1850	20	10	590	530	88	31	560	< 5	5	-	1099	0	514	-	-	0	1676	26.90	C				
16	03 25/76	7.2*	3500	40	25	1150	160	120	12	280	< 5	15	-	1281	0	1505	-	< .01	.01	3350	35.08	C				
17	03/25/76	6.9*	4900	160	105	1450	133	872	22	480	< 5	12	-	1428	0	2096	-	< .01	.01	4515	21.87	S				
19	07 05 76	7.1*	7000	141	109	1360	150	1700	55	29	< 10	< 4	.24	2119	0	3119	-	.20	.05	5773	20.94	S				

DISCUSSION

At five active coal strip mine areas within the tri-state region of Montana, North Dakota and Wyoming a system of intensively monitored micro-watersheds were constructed to demonstrate the effects of several specific soil surface manipulation treatments on control of runoff, chemistry of runoff, soil water flow, aquifer characteristics and vegetation establishment. Treatments were chiseling and gouging with and without topsoiling practices, and dozer basins with topsoiling. This early report and discussion is limited to the three original of five locations: Colstrip, Montana; Savage, Montana; Beulah, North Dakota. Construction of these sites was initiated during summer 1974 and intensive monitoring initiated summer 1975.

These study sites were located in mined areas of individually unique edaphic, topographic, and climatic characteristics. The Colstrip spoil's watersheds are characterized as having a sandy loam profile dominated by illite and kaolinite clay mineralogy resulting in relatively rapid infiltration characteristics. The average degree of watershed slope is 15° but ranges from 9° to 16° . Watersheds at Savage are characterized by having gravelly sandy loam soil profile dominated by smectite clay resulting in initial rapid infiltration rates which decrease rapidly, conditions extremely conducive to excessive erosion. The average degree of watershed slope is 15° , but ranges from 13° to 17° . The Beulah watersheds are characterized as having silty clay soil profiles that are saline-sodic in nature and dominated by smectite type clay mineral, that typically results in a crusted and very deeply cracked

soil surface. At the initiation of a precipitation event, infiltration rates for all treatments varied from rapid to slow depending upon the influence of surface cracks, but eventually the rate became slow as the volume of conducting pores decreased from soil swelling. The average degree of watershed slope is 3.75° , and ranges from 3.5° to 4.5° .

Topsoiling management is unequivocally a major reclamation tool in the control of surface runoff by increasing infiltration. Without exception, during a runoff event topsoiled watersheds underwent less runoff than similar nontopsoiled watersheds. Not all precipitation events produced measureable runoff at these Demonstration Areas, but eight events resulted in runoff from one or more watershed treatments. The total quantity of runoff from these eight events was 1.63 cm for topsoil-dozer basins, 2.32 cm for topsoil-gouged, 4.76 cm for topsoil-chiseled, 13.74 cm for nontopsoil-gouged, and 16.70 cm for nontopsoil-chiseled.

The control of runoff and erosion is the initial basic prerequisite to mine spoil reclamation. The degree of erosion at a site is largely a function of slope, precipitation intensity and duration, and soil characteristics, therefore each Demonstration was subjected to a different combination of erosive forces. Erosion characteristics at each Demonstration correlated in a positive manner with runoff results. For example, the amount of soil material displaced resulting in gullies at the Colstrip and Savage Demonstration watersheds was 2.7 m^3 for topsoil-dozer basins, 8.1 m^3 for topsoil-gouged, 23.7 m^3 for nontopsoil-gouged, 26.4 m^3 for topsoil-chiseled, and 43.1 m^3 for nontopsoil-chiseled. Thus, the fundamental principle of less

runoff - less erosion was substantiated on these spoil watersheds. At this stage of the study it seems apparent that surface manipulation, particularly gouging and to a greater extent dozer basins, will be an effective means of controlling runoff on many types of site conditions in the semiarid West. The inclusion of topsoiling processes enhances this result.

Perhaps the most unknown and difficult to measure component in spoil hydrology is deep percolation. Since surface manipulation techniques are designed to decrease runoff and increase soil water, the theoretician may expect deep leaching to be enhanced. Without *in-situ* studies, such as the one at hand, we can only theorize that deep percolation is or is not occurring in mine spoils which may or may not cause eventual leaching into ground-water resources.

Deep percolation events do occur on mine spoils, but generally this is an infrequent event rather than a constant process. In watersheds of this study, deep percolation events were measured, and this phenomenon was generally enhanced by techniques that reduced runoff such as topsoiling, gouging, and dozer basin treatments. But it is important to consider the final destination of these deep percolation events on a hydrologic year basis. Although a quantity of precipitation may move in the unsaturated state to perhaps the 7- to 10- m depth or deeper in a short period of time, and leach anions and cations to some extent, we must realize this is a reversible process. Such an event is typically followed by a period of evapotranspirational loss and this water, which attained a depth of 7- to 10- m and is continuing downward, may undergo a reversal of direction to satisfy the evapotranspiration demand. Not only may the soil water reverse flow direction but any

movement of anions and cations may also reverse movement direction; a salinization process. Therefore, this is a very dynamic process, difficult and time-consuming to measure since this requires a constant monitoring scheme over a long period of time.

The importance of the deep percolation phenomenon is demonstrated by the "Saline Seep" problem in Montana and North Dakota. This is a situation where change in surface management over several decades caused enhancement of deep percolation which created a salt seepage problem. It is a remote possibility that a similar situation might develop on some mine spoils locations, therefore unsaturated soil water flow in mine spoils should not be dismissed as an insignificant effect in spoil hydrology. Rather, this process may dictate the long term success or failure of reclamation. Certainly proper surface management will enter into and influence this process. This reasoning formed a major objective in this study which was to measure the deep percolation phenomenon concerning treatments associated with these surface manipulation watersheds.

At the Savage and Beulah Demonstrations a net 10- to 20- cm of water moved from the subsurface zone into the surface 2 m zone in four of the five watersheds during the hydrologic year. In these watersheds deep percolation events occurred during this time but ultimately this water was evapotranspired, and an additional 10- to 20- cm of deep stored water that existed before the initiation of our measurements flowed into the surface 2 m zone. If this process were to continue over decades there would be some potential of salinization of the surface soil, particularly at the North Dakota Demonstration where the

spoil contains high levels of salt that could translocate toward the surface. This hydrologic situation exists in all watersheds except the nontopsoil-chiseled treatment.

The nontopsoil-chiseled watersheds at the Savage and Beulah Demonstrations experience a near equilibrium condition and net downward flow, respectively. In these watersheds, deep percolation occurred but at the Savage Demonstration this water was ultimately consumed by evapotranspiration. At the Beulah Demonstration, however, this deep water was not all evapotranspired and percolation in excess of a 2.0 m depth was the result. At the Colstrip Demonstration the gamut of situations occurred between watersheds for the hydrologic year, meaning net equilibrium flow, net upward flow, and net downward flow.

Deep percolation phenomenon derived from these demonstration watersheds cannot be conclusively described with just the one year of data presented in this report. However, the trends to date have been presented and as this study matures, these data should reveal the patterns of deep percolation in spoils at their representative locations in the semiarid West.

These evapotranspiration data measured in each watershed with weighing lysimeters were necessary for evaluation of the deep percolation process in this study. In addition, these data shall serve a corollary function to other scientists engaged in the study of water interactions with strip mining in the semiarid West who do not have the opportunity to employ lysimeter technology. Lysimetry is expensive and very involved so these published evapotranspiration data in mine spoils, to the best of our knowledge, are otherwise nonexistent and such data from these watersheds should be a useful reference.

In retrospect, it appears that dozer basins should not be constructed with the tipped front blade of a crawler tractor as a substitute for the rear mounted dozer basin implement. When the front blade is used a basin of relatively low water detention capacity and a very compacted-impermeable base is produced. Although these basins are still very effective in the control of runoff, our data show very little of this detained runoff is absorbed as soil water. Rather, the water is ponded and evaporated, thus lowering somewhat the revegetation potential.

The quality of surface runoff water from spoil watersheds is of major concern. Levels of $\text{NO}_3\text{-N}$, Mg, Ca, soluble salts and most trace elements were found in low concentrations in watershed runoff water. Exceptions were Mn and Fe, where concentrations in watershed runoff waters at all Demonstrations often exceeded federal standards for drinking water, but were probably acceptable for irrigation purposes. Occasional samples contained Cd, Pb and $\text{PO}_4\text{-P}$ at levels which exceeded desirable levels. The quality of runoff as a function of watershed surface manipulations shows, to date, no trends.

The relationship of surface spoil hydrology to aquifer characteristics is discussed, and the aquifer chemical quality presented in this report. Preliminary data indicate that some ground-water recharge is taking place at the Colstrip demonstration area. However, water level observations at Savage and Beulah show no significant trends to date. At all Demonstration

Sites, manganese was the only trace element in the ground water which consistently exceeded federal standards for human consumption.

Surface manipulation treatments will have varying degrees of success at different sites in the semiarid West depending upon several site factors and the true intent of such techniques. If the intent is to control runoff and erosion, then surface manipulation techniques should be useful under most conditions. However, if the conservation of soil water is of equal or higher priority, then surface manipulation techniques will have varied influence. For example, at the Colstrip and Savage sites the recharge of soil water during a precipitation event was related in a positive manner with topsoiling and surface detention capacity. But at the Beulah Demonstration this was not the case. This site is characterized as having a silty clay soil profile with saline-sodic conditions, and these data show that neither topsoiling, gouging nor dozer basins will increase soil moisture more than chiseling alone.

Because of mine site specificity, there will be no universally best surface manipulation treatment. At this stage of research, it is apparent that surface manipulation techniques will be widely applicable, but there will be instances when such techniques will have explicit limitations.

This report covers about a one year time span of field measurements, and another year or more is yet to follow. Therefore, this is an interim report and not a final report, and the discussions and results to date should be considered preliminary.

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APPENDIX A. LYSIMETRY - DEVELOPMENT AND TESTING

LYSIMETRY - DEVELOPMENT AND TESTING

Introduction

An economical lysimeter has been developed, field tested and found very useful for measurements of evapotranspiration. The principle is not original with the author as Ekern in Hawaii, Tanner in Wisconsin and Hanks in Colorado (13) have used the pressure pillow type of lysimeter for several years.

The Colstrip, Savage and Beulah Demonstration Areas have one lysimeter in each of 5 watersheds, for a total of fifteen units. Each Demonstration Area has four lysimeters equipped with pressure pillow transducers. The fifth lysimeter in each area was equipped with a load cell transducer.

Methodology

Figure 39 shows the two types of lysimeters. The tanks were constructed of corrugated galvanized steel culvert. The inner tank had a 0.476 cm thick metal plate welded to one end. The inner tank was equipped with a soil water vacuum extraction system and aluminum neutron access tube. The soil moisture status of the lysimeter was determined with a neutron probe on a monthly schedule as were the other neutron tubes located throughout each watershed. Thus, it could be confirmed that the soil moisture status of a lysimeter was representative of the entire watershed. If a lysimeter became waterlogged, the vacuum extraction unit enabled removal of soil water. The extraction unit consisted of two 0.635 cm O.D. copper tubes leading from the soil surface to three porous extraction

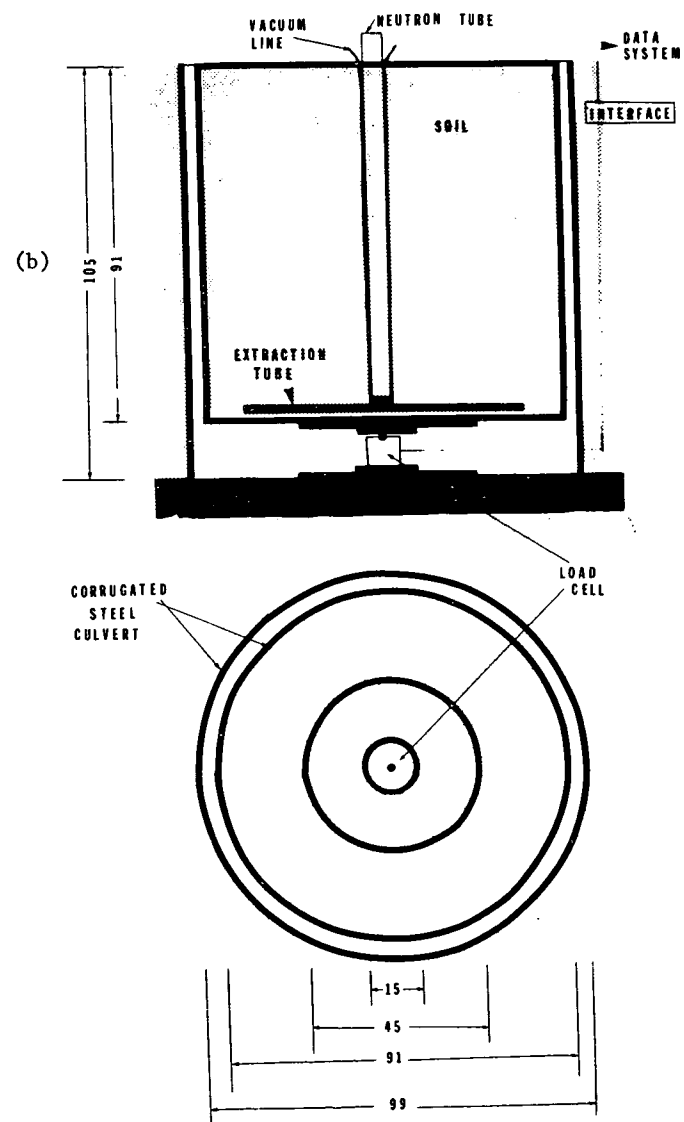
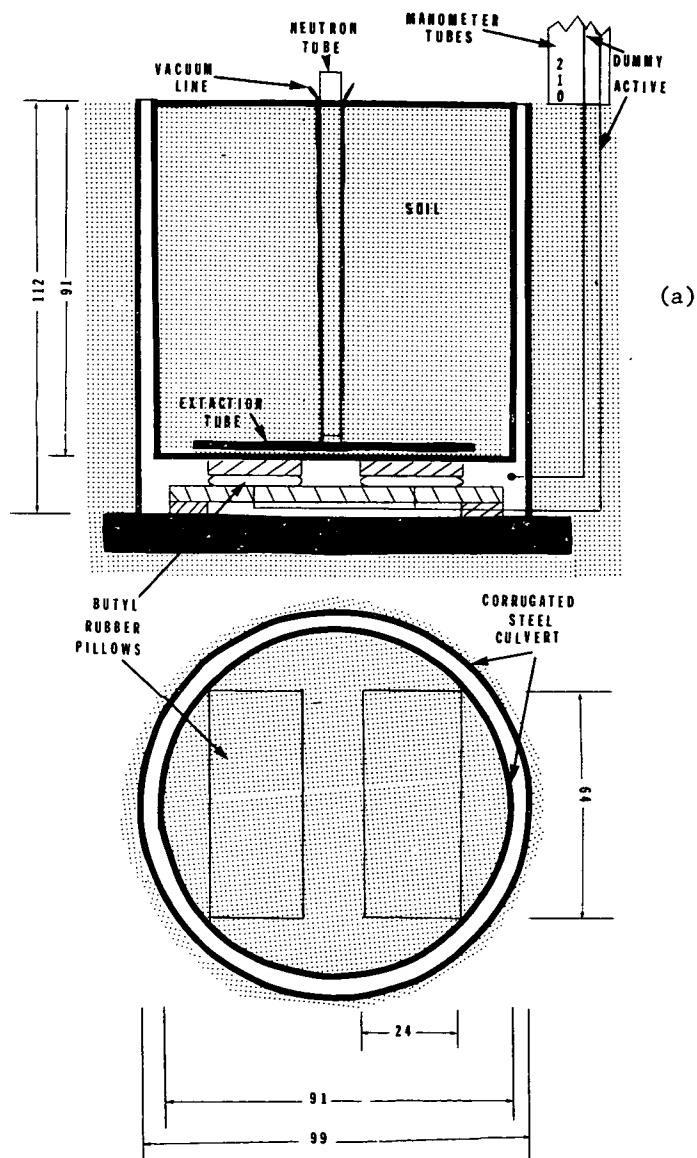


Figure 39. Lysimeter construction details for both pressure pillow (a) and loadcell (b) type transducers.

tubes^{1/} located near the bottom of the lysimeter. One copper tube served for vacuum extraction operations while the second copper tube allowed air entry during extraction.

Pressure Pillow Transducer

Figure 39 shows that the total weight of the lysimeter was distributed over two wooden blocks which sat upon two rubber pillows. These pillows were constructed^{2/} of nylon-reinforced butyl rubber irrigation tubing, 20.32 cm in diameter. The fluid in the pillows was a mixture of 50% anti-freeze solution and 50% distilled water. The pressure of the fluid in the bags was equal to the total weight of the inner tank and contents, divided by the area of the two wooden support blocks. The wooden blocks were used to maintain a constant area over which the weight was distributed. The two pillows were connected to a pipe tee by 0.476 cm O.D. copper tubing and to an above-ground manometer by a single 0.635 cm O.D. "active" copper tube. A "dummy" 0.635 cm O.D. copper tube used for temperature correction, paralleled the active tube and terminated on the floor of the lysimeter chamber. At the soil surface both the active and dummy copper tubes were connected by a tygon tubing sleeve to 0.635 cm O.D. glass tubing. This glass tubing was mounted next to a meter

^{1/} 30.48 cm long by 1.27 cm diameter porous tubes were supplied by Soil Moisture Equipment Co., Box 30025, Santa Barbara, CA 93105.

^{2/} Supplied by Watersaver, Co. Inc., 3560 Wynkop St., Denver, CO 80216.

stick. The lysimeter soil weight was measured as a function of the height of the fluid in the active manometer tube. A cabinet with doors housed the manometer tubes up to a maximum height of 4.0 m (Figure 40). This cabinet was located about 7 m from the lysimeter and was oriented so as not to cast a shadow over the lysimeter during the day. All hydraulic lines were buried 60 cm below the soil surface.

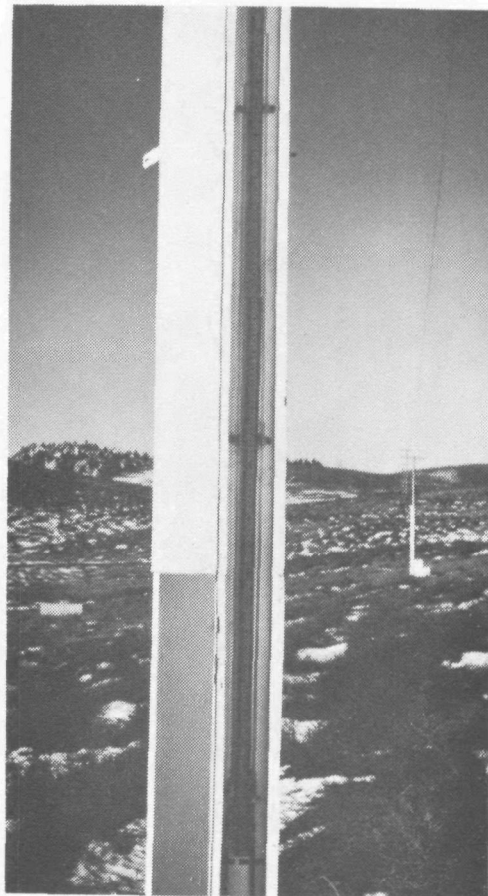


Figure 40 Housed in a wooden cabinet, two glass manometer tubes registered changes in mass of a lysimeter located about 7 m away. In the background another manometer cabinet can be seen.

Load Cell Transducer

Researchers have devised force transducers that produce voltage output which is directly proportional to the applied force. Thus, transducers provide an opportunity to connect weighing lysimeters to automatic data acquisition systems.

Figure 39 shows the position of a 908 kg capacity load cell^{3/} under a lysimeter. Figure 41 shows the mounting bracket which enabled the lysimeter to be placed on the load cell. The load cell, center of photo, was screwed onto a steel plate. The load cell button, top,

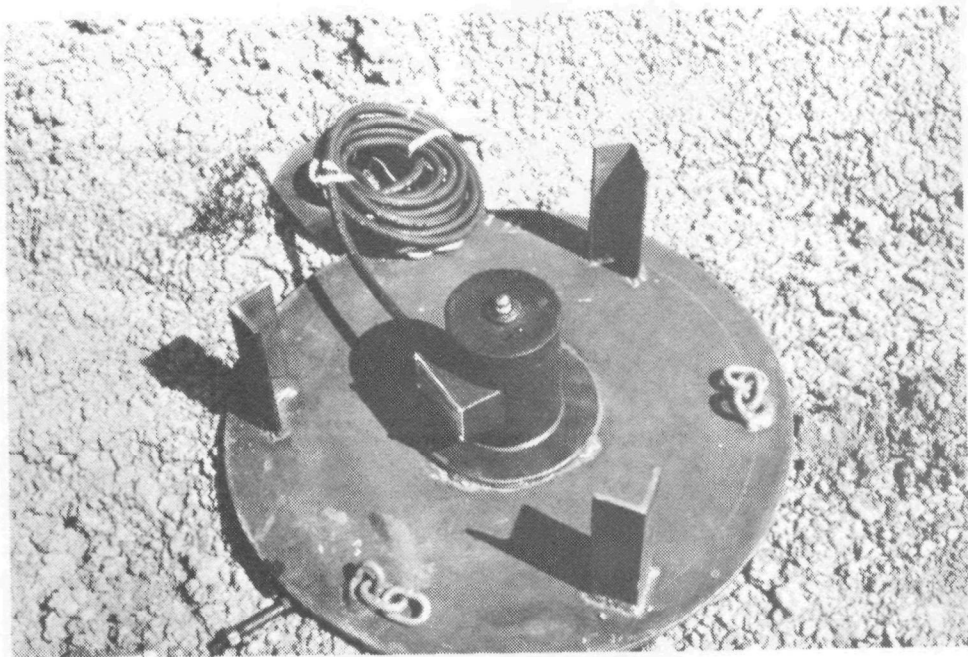


Figure 41. Load cell mounting bracket. Entire lysimeter mass sat upon a single .95 cm diameter ball bearing, center of photo.

^{3/} Load cell type C3P1 was supplied by BLH Electronics, Inc., 42-4th Ave., Waltham, MA 02154.

contains a 0.95 cm diameter ball bearing. A second steel plate, Figure 42, which had a 0.95 cm socket machined into it, rests

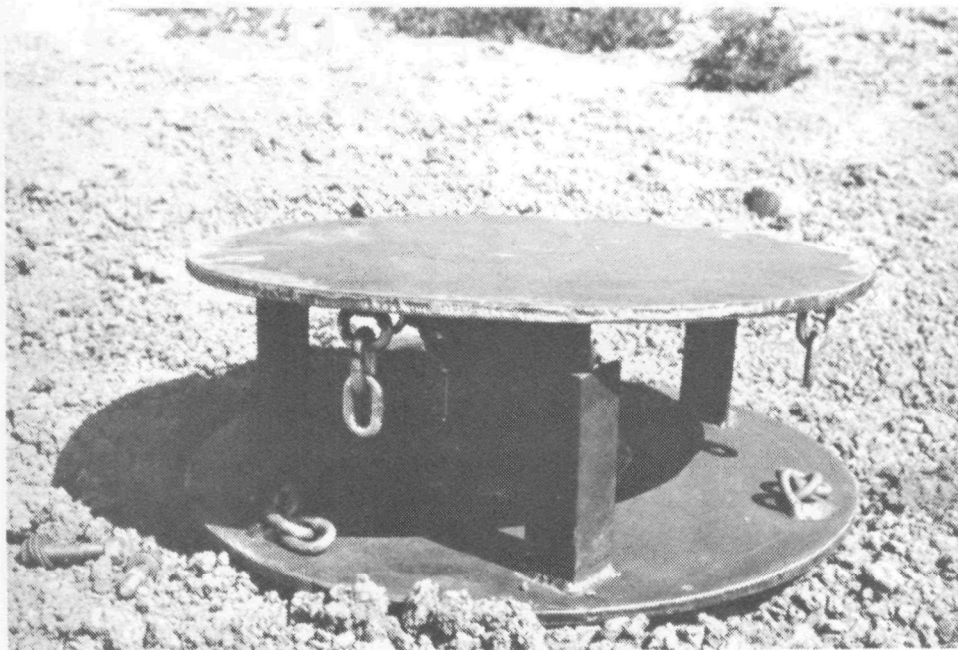


Figure 42. Complete load cell transducer unit.

upon the top steel plate. Thus the entire lysimeter mass was concentrated onto one ball bearing, which ideally converted all lysimeter motion into a vertical force on the load cell. The chains and angle iron braces shown in Figure 44 protected the load cell in case excessive tipping of the lysimeter occurred during installation.

The load cell transducer used for this system was rated at 150% capacity, or 1362 kg. This was an important factor since these lysimeters ranged in weight from about 900 to 1200 kg. Therefore, load cell output when loaded with the lysimeter was between about 45 and 60 mV, depending on actual lysimeter mass. Our goal was to detect evapotranspiration changes of 1 mm which was equivalent

to a change in lysimeter mass of .656 kg. A change in mass of .656 kg would have resulted in a load cell output differential of about 30 mV. This was the magnitude of signal that could be successfully amplified by the circuit drawn in Figure 43. Basically, this circuit was designed to amplify the load cell voltage signal to a level that the data acquisition system could accept.

The load cell lysimeter interface (Figure 43) was powered by a Dynamic Measurements Corporation, type 402-C Modular Power supply. This power supply provided regulated ± 15 volts from the 115 VAC line voltage input. Two operational amplifiers were used in conjunction with a battery summing circuit. An analog Device, type 232-J, chopper stabilized operation amplifier converted the dual outputs from the load cell to a single amplified output of approximately -1 V maximum. This negative voltage was summed with a variable positive voltage from a 1.3 V battery to provide an input of approximately -.1 V to the second operational amplifier. An Analog Device type 118-A, discrete operational amplifier converted the summed output of the 232-J to a positive voltage suitable for use with the data collection system, 1.0 V maximum.

Even though the operational amplifiers used were temperature compensating, the discrete components used were affected by temperature extremes. Therefore, a constant temperature circuit was designed and fabricated. This was attached piggy-back on the interface board. A 2K-0.1 W power resistor, enclosed in a finned heat sink, was the heater element. Alternating current to the power resistor was switched

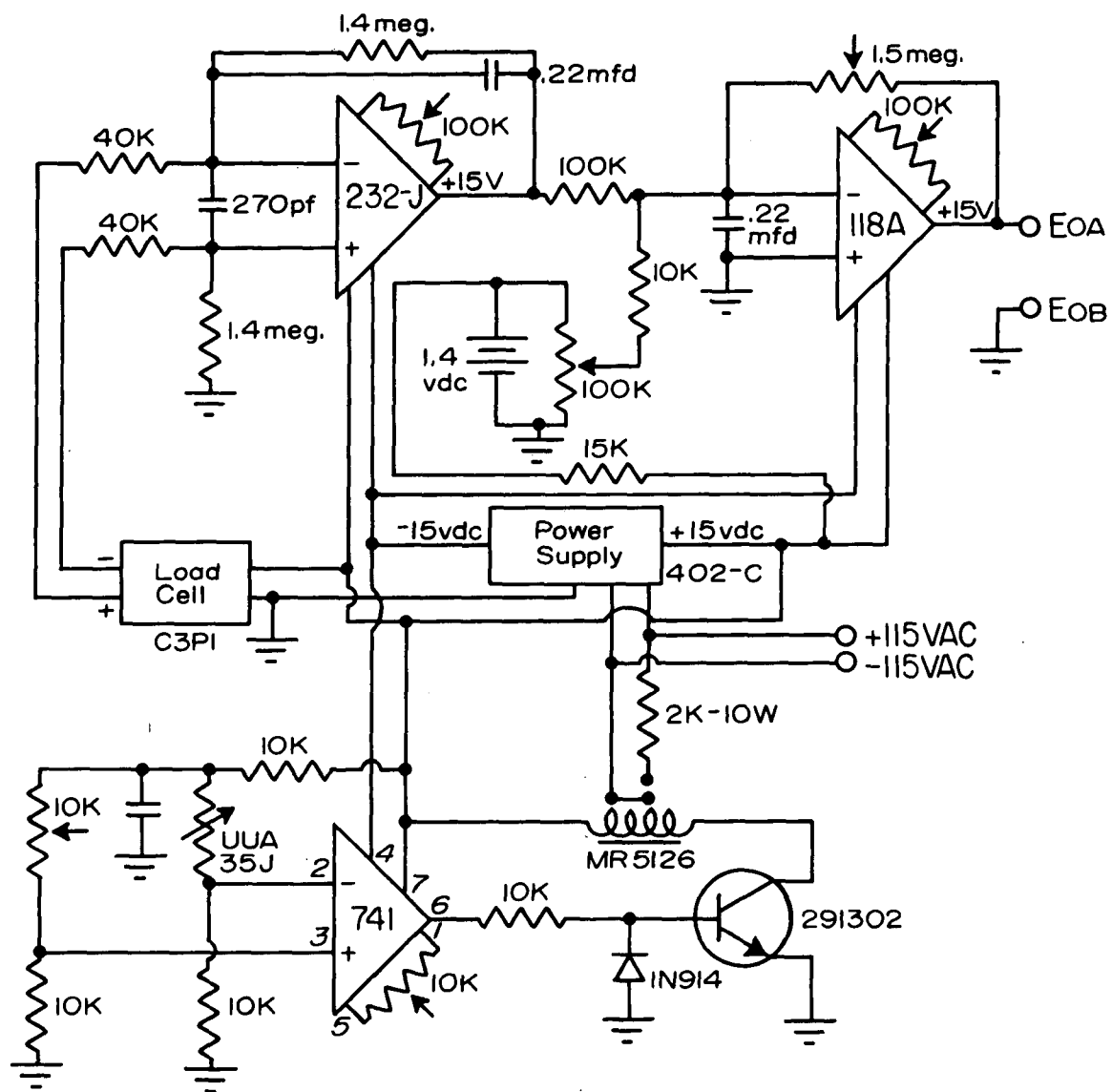


Figure 43. Circuitry used to interface lysimeter load cell to data acquisition system.

by an MR-512C relay, 12V-800 meg. The relay control circuit was a LM 741 driving an N.P.N. transistor, type 2N1302. A series-parallel voltage divider network provided the dual inputs to the LM741. One series leg was a 10K resistor and a UUA35J thermistor. The other series leg was a 10K resistor and a 10K potentiometer. One potentiometer could be adjusted to balance the two series legs and thereby

Table 38. Load cell lysimeter interface parts list.

<u>Quantity</u>	<u>Description</u>
1	118A - Analog Devices, operation amplifier
1	232J - Analog Devices, chopper stabilized operational amplifier
1	402C - Dynamic Measurements Corp., power supply (+ 15 vdc)
1	C3P1 - BLH load cell, 2000 lb. capacity, 3 ma/A
1	LM741 - operational amplifier
1	MR-512C 12 V relay, International Rectifier
1	E-9 Everready, 1.4 mercury battery
1	44A-35J1 UniCurve, thermistor
1	2N-1302 transistor
1	1N-914 diode
<u>Capacitors</u>	
1	270 pf, 500 V, MICA
1	1 mfd, 25 V, tant.
2	.22 mfd, 12 V, ceramic discs
<u>Resistors</u>	
3	100K, 15 turn trim potentiometer
2	10K, 20 turn trim potentiometer
1	1.5 meg, 20 turn trim potentiometer
4	10K, 1/8w, 20% carbon
1	15K, 1/8w, 20% carbon
1	10K, precision, film, 1/8w
2	40K, precision, film, 1/8w
1	100K, precision, film, 1/8w
2	1.4 meg, precision, wirewound, 1/2w
1	2K, wirewound, 10%, 10w

set the switch on temperature of the heater. Table 38 presents the load cell lysimeter interface parts list. This circuit was being successfully used in the field but additional development will further improve the system.

Installation

A backhoe was used at each demonstration area to excavate necessary pits. The soil was removed in 1-foot depth increments and piled separately. To avoid soil moisture loss these piles were covered with plastic. The lysimeter tanks were incrementally packed as soon as possible. During the packing process a pocket penetrometer^{4/} was used intensively to make sure the original spoil density was obtained. Table 39 shows the profile density configuration for 15

Table 39. Compaction factor in the 15 lysimeter soil profiles is given in kg/cm².

Lysimeter	Soil Depth			
	Topsoil	1 foot	2 feet	3 feet
<u>Colstrip Demonstration</u>				
#1	.25	1.5	2.5	4.0
#2	.25	1.3	3.0	2.25
#3	.5	.6	1.75	3.0
#4	--	1.75	1.25	2.5
#5	--	1.0	2.0	4.0
<u>Savage Demonstration</u>				
#1	.5	1.25	1.25	1.75
#2	--	.5	1.5	1.0
#3	.5	1.5	1.75	1.25
#4	--	1.0	1.25	1.25
#5	.5	.75	1.25	1.5
<u>Beulah Demonstration</u>				
#1	.25	1.0	2.5	1.75
#2	--	4+	4+	4+
#3	--	4+	4+	4+
#4	.5	2.5	2.25	2.75
#5	.5	2.0	2.5	3.0

^{4/}Model CL-700 by Soil Test, Inc., 2205 Lee St., Evanston, IL 60202.

lysimeters. The lysimeter soil surfaces were seeded with the identical perennial grass seed mixture planted on the watersheds.

As shown in Figure 39, the lysimeter foundation consists of a re-bar reinforced 10 cm thick concrete pad placed on gravel fill. When the concrete had cured sufficiently, the outer tank was centered on the pad and backfilled around the outside.

The force transducer was then prepared and positioned on the concrete pad. The transducer pillows were filled with fluid and then the connectors were soldered to the 0.635 cm outside diameter copper tube leading to the manometer cabinet. A portable overhead hoist system (Figure 44) was designed for this lysimeter work. It

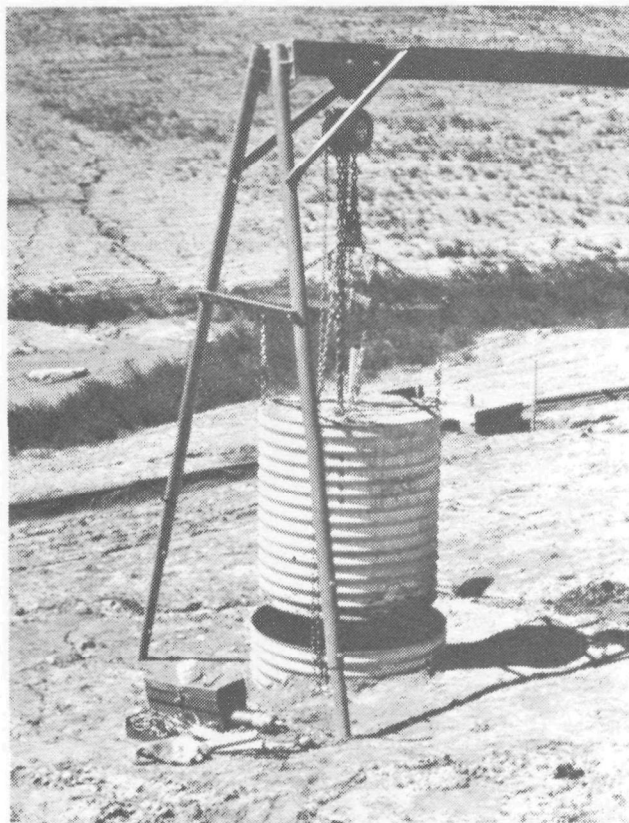


Figure 44. Portable overhead hoist system was used to install the lysimeter.

consisted of four adjustable legs (7.62 cm diameter pipe) and an overhead 3.6 m long by 15 cm I-beam. The major stress points were braced with angle iron. A trolley with a 1362 kg capacity chain hoist on the I-beam enabled one person to lift and position the inner tank into the outer tank. Once the lysimeter was in place atop the transducer, a suspension system was installed to prevent the inner tank from tipping. This consisted of three equidistant points of connection around the circumference of the lysimeter. Each connection was made with airplane cable which extended in triangular pattern from the outer tank--to the inner tank--and back to the outer tank. Test showed that this arrangement allowed the tank to move free vertically, yet prevented any tipping motion.

Since these lysimeters were installed on a slope, a cutting torch was used to match the tank soil surface edge to the slope. No balancing complications were introduced by this procedure, apparently because the mass of the section removed was insignificant compared to the entire mass of the lysimeter. Installation was completed with the installation of a black polyethylene collar between the inner and outer tanks.

Calibration

Lysimeters were calibrated by applying a known force and recording the response. Table 40 presents these data for the pillow transducer lysimeters. Lysimeter number 2 located at the Savage Demonstration was apparently tipped during the calibration since the sensitivity was reduced. On the average 1 mm evapotranspiration loss registers

a lysimeter manometer change of 2.4 mm. Therefore, these lysimeters registered evapotranspiration accurately to a fraction of a millimeter. The sensitivity of these lysimeters was very satisfactory.

Table 40. Lysimeter calibration during August, 1975. A mass change of 656.7 g was equivalent to a loss-gain factor of 1 mm of H₂O.

Lysimeter	No Force (cm)		Applied Force kg	Force (cm)		Calibration*
	Active	Dummy		Active	Dummy	
<u>Savage Demonstration</u>						
1	65.62	122.77	12.9	67.79	122.77	1.10
2	40.10	141.80	12.9	40.27	141.80	.09
3						
4	186.22	136.79	12.9	191.10	136.22	2.48
5	112.92	166.17	12.9	117.41	166.17	2.28
<u>Colstrip Demonstration</u>						
1	170.32	55.70	4.8	172.00	55.70	2.20
2	160.28	54.15	4.8	162.31	54.15	2.73
3						
4	175.78	99.60	4.8	177.64	99.60	2.50
5	178.86	88.72	4.8	180.55	88.72	2.27
<u>Beulah Demonstration</u>						
1	155.90	86.92	8.6	159.33	86.92	2.60
2	140.72	81.08	8.6	144.26	81.08	2.69
3	148.49	73.08	8.6	152.12	73.08	2.76
4						
5	152.20	65.30	8.6	156.04	65.30	2.92

* mm manometer deflection per 1 mm of evapotranspiration.

APPENDIX B. VOLUMETRIC SOIL WATER CONTENTS

Table 11. Volumetric soil water contents with depth and time are presented for each watershed treatment at the Colstrip Demonstration. Samples collected on sixteen dates during 1975 and 1976.

Each datum is an average from five sites and the standard error of these means are shown.

Watershed Treatment	Sampling Interval Depth (cm)	0-22.5 H ₂ O %	S _E	22.5-37.5 H ₂ O %	S _E	37.5-52.5 H ₂ O %	S _E	52.5-67.5 H ₂ O %	S _E	67.5-82.5 H ₂ O %	S _E	82.5-105 H ₂ O %	S _E	105-135 H ₂ O %	S _E	135-165 H ₂ O %	S _E	165-195 H ₂ O %	S _E	195-225 H ₂ O %	S _E							
W.S. #1	0-22.5	39*	.0431	23	.0291	02	.0030	01	.0036	27*	.0070	26	.0137	16	.0457	10*	.0157	17	.0064	11	.0133	20*	.0102	26	.0034	33*	.0094	
	22.5-37.5	34	.0111	52	.0100	32	.0101	33	.0198	34	.0205	32	.0281	24	.0175	24	.0232	17	.0119	29	.0224	31	.0102	29	.0201	31	.0171	
	37.5-52.5	37	.0179	56	.0222	43	.0224	43	.0314	35	.0270	42	.0277	26	.0209	27	.0270	18	.0158	29	.0124	30	.0116	28	.0184	31	.0110	
	52.5-67.5	30	.0204	32	.0255	42	.0275	41	.0273	36	.0131	33	.0105	30	.0118	70	.0365	19	.0234	27	.0258	29	.0254	28	.0079	30	.0195	
	67.5-82.5	29	.0092	32	.0075	43	.0164	43	.0133	36	.0216	35	.0208	31	.0314	32	.0649	23	.0331	20	.0345	28	.0163	18	.0235	30	.0276	
	82.5-105	31	.0195	42	.0176	41	.0237	43	.0145	39	.0161	38	.0132	36	.0248	24	.0317	31	.0220	30	.0375	30	.0375	30	.0249	31	.0261	
	105-135	34	.0230	36	.0201	42	.0236	46	.0134	38	.0104	37	.0150	37	.0148	37	.0580	26	.0293	29	.0155	29	.0235	28	.0212	30	.0210	
	135-165	33	.0195	35	.0140	37	.0186	43	.0150	40	.0108	39	.0140	39	.0154	40	.0437	26	.0170	28	.0171	29	.0178	28	.0197	30	.0173	
	165-195	32	.0167	34	.0116	36	.0176	39	.0242	38	.0136	37	.0156	38	.0186	40	.0426	27	.0122	27	.0145	28	.0086	27	.0123	29	.0107	
	195-225	33	.0137	32	.0135	34	.0142	35	.0150	38	.0159	34	.0120	40	.0177	41	.0390	30	.0085	28	.0141	30	.0065	28	.0097	29	.0091	
S _E		.0400** n=4		.0227 ns n=4		.0407** n=4		.0312** n=4		.0303** n=4		.0410** n=4		.0353 ns n=4		.1222** n=4		.0492** n=4		.0436** n=3		.0496** n=4		.0345** n=4		.0378** n=4		
W.S. #2	0-22.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	22.5-37.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	37.5-52.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	52.5-67.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	67.5-82.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	82.5-105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	105-135	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	135-165	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	165-195	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	195-225	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
S _E		.0395** n=5		.0319 ns n=4		.0439** n=4		.0574** n=3		.0457** n=4		.0406** n=3		.0306** n=5		.0252** n=5		.0307** n=4		.0414** n=5		.0406** n=5		.0376** n=5		.0401** n=5		
W.S. #3	0-22.5	33*	.0135	18	.0184	02	.0027	02	.0033	22*	.0040	15	.0135	09	.0043	09*	.0050	11	.0148	25	.0138	23*	.0079	19	.0077	30*	.0059	
	22.5-37.5	36	.0104	43	.0078	26	.0098	30	.0169	34	.0062	25	.0230	13	.0183	13	.0072	10	.0029	26	.0082	29	.0092	27	.0064	32	.0067	
	37.5-52.5	39	.0137	41	.0194	38	.0082	43	.0052	39	.0051	34	.0179	22	.0094	19	.0083	12	.0149	25	.0091	30	.0074	30	.0079	31	.0078	
	52.5-67.5	33	.0157	36	.0190	43	.0150	47	.0028	37	.0109	35	.0133	24	.0133	21	.0132	14	.0133	20	.0178	26	.0145	27	.0127	28	.0139	
	67.5-82.5	31	.0173	34	.0195	41	.0075	45	.0045	38	.0182	35	.0169	26	.0158	22	.0153	13	.0077	19	.0198	24	.0188	26	.0144	27	.0159	
	82.5-105	31	.0184	31	.0176	39	.0156	44	.0151	38	.0225	36	.0231	33	.0161	25	.0149	15	.0152	21	.0208	22	.0224	25	.0189	27	.0210	
	105-135	32	.0225	31	.0237	36	.0285	47	.0273	38	.0220	36	.0231	33	.0185	30	.0178	21	.0233	24	.0225	23	.0212	24	.0217	26	.0214	
	135-165	32	.0209	31	.0275	34	.0290	36	.0466	34	.0229	38	.0178	36	.0161	33	.0135	24	.0225	26	.0178	25	.0168	25	.0180	26	.0210	
	165-195	32	.0260	32	.0277	34	.0290	35	.0477	35	.0211	37	.0278	35	.0196	33	.0141	23	.0258	26	.0198	24	.0211	25	.0218	26	.0206	
	195-225	33	.0238	32	.0310	33	.0325	33	.0430	35	.0262	39	.0234	38	.0193	37	.0186	27	.0219	29	.0157	27	.0171	27	.0177	28	.0156	
S _E		.0395** n=5		.0319 ns n=4		.0439** n=4		.0574** n=3		.0457** n=4		.0406** n=3		.0306** n=5		.0252** n=5		.0307** n=4		.0414** n=5		.0406** n=5		.0376** n=5		.0401** n=5		
W.S. #4	0-22.5	32*	.0176	18	.0540	04	.0410	03	.0179	25*	.0000	19	.0951	07	.0252	07*	.0285	12	.0776	28	.0500	22*	.0556	18	.0054	27*	.0779	
	22.5-37.5	40	.0148	43	.0085	29	.0281	32	.0726	38	.0000	33	.1635	16	.0422	15	.0349	14	.0556	21	.0186	28	.0233	25	.0131	27	.0704	
	37.5-52.5	37	.0107	40	.0117	39	.0094	42	.0934	37	.0000	30	.1512	15	.0396	15	.0321	11	.0526	16	.0320	23	.0146	23	.0130	23	.0533	
	52.5-67.5	28	.0186	34	.0225	37	.0087	41	.1116	33	.0000	29	.1470	13	.0439	16	.0338	12	.0472	16	.0396	20	.0182	20	.0137	23	.0531	
	67.5-82.5	24	.0143	26	.0219	36	.0167	38	.0551	37	.0000	35	.1740	24	.0566	21	.0479	15	.0450	17	.0286	20	.0231	22	.0171	24	.0550	
	82.5-105	26	.0159	20	.0145	37	.0146	40	.0401	37	.0000	38	.1911	28	.0637	23	.0536	16	.0453	20	.0178	19	.0122	22	.0119	25	.0617	
	105-135	30	.0101	30	.0147	35	.0188	39	.0381	37	.0000	38	.1898	30	.0786	29	.0680	21	.0615	23	.0232	24	.0284	24	.0394	25	.0664	
	135-165	31	.0182	32	.0203	32	.0203	42	.0350	38	.0000	40	.1999	35	.0862	33	.0722	24	.0641	27	.0135	27	.0170	26	.0272	27	.0675	
	165-195	31	.0053	33	.0076	33	.0057	39	.0127	36	.0000	40	.1983	38	.0872	34	.0730	25	.0629	25	.0091	25	.0121	25	.0091	25	.0614	
	195-225	29	-	30	-	30	-	36	-	34	-	40	-	36	-	33	-	25	-	26	-	25	-	26	-	26	-	
S _E		.0233** n=5		.0204 ns n=5		.0476** n=5		.1473** n=3		.0595** n=3		.0595** n=3		.0764** n=3		.0538 ns n=3		.0371 ns n=4		.0327 ns n=5		.0287** n=4		.0287** n=4		.0565** n=5		
W.S. #5	0-22.5	39*	.0190	23	.0339	04	.0144	03	.0113	26*	.0187	18	.0230	08	.0264	07*	.0243	10	.0269	20	.0123	23*	.0182	19	.0171	27*	.0172	
	22.5-37.5	38	.0114	44	.0064	30	.0404	31	.0762	33	.0345	25	.0439	14	.0298	12	.0202	10	.0195	20	.0238	23	.0196	21	.0203	26	.0215	
	37.5-52.5	33	.0352	41	.0250	37	.0312	34	.0287	34	.0530	27	.0606	19	.0332	17	.0282	11	.0176	21	.0360	23	.0333	23	.0267	26	.0333	
	52.5-67.5	27	.0340	35	.0436	37	.0351	37	.0115	35	.0574	30	.0598	22	.0363	21	.0336	13	.0239	21	.0436	23	.0467	24	.0381	25	.0402	
	67.5-82.5	27	.0363	31	.0368	39	.0450	40	.0342	36	.0340	32	.0370	26	.0349	24	.0349	16	.0277	21	.0340	23	.0445	23	.0422	25	.0332	
	82.5-105	28	.0286	33	.0363	40	.0413	41	.0329	39	.0368	35	.0376	30	.0443	28	.0447	20	.0354	23	.0299	24	.0367	24	.0343	26	.0322	
	105-135	29	.0206	35	.0211	39	.0254	39	.0265	40	.0345	37	.0365	34	.0301	32	.0332	23	.0199	24	.0173	24	.0182	25	.0195	27	.0168	
	135-165	32	.0228	35	.0226	38	.0294	38	.0276	39	.0122	38	.0241	36	.0226	35	.0199	25	.0186	26	.0173	27	.0124	27	.0143	28	.0137	
	165-195	31	.0214	34	.0237	37	.0265	35	.0262	38	.0305	37	.0147	36	.0112	36	.0108	26	.0127	25	.0114	26	.0091	25	.0102	27	.0120	
S _E		.0531** n=5		.0422 ns n=5		.0436 n=5		.0436** n=5		.0905** n=3		.1007** n=3		.0658** n=5		.0606** n=5		.0431** n=5		.0586** n=5		.0583** n=5		.0551** n=5		.056		

Table 42.

Volumetric soil water contents with depth and time are presented for each watershed treatment at the Savage Demonstration. Each datum is an average from five sites and the standard error of these means are shown. Samples collected on thirteen dates during 1975 and 1976.

Watershed Surface Treatment	Sampling Increment Depth (cm)	8-06-75 H ₂ O _x	S _x	9-08-75 H ₂ O _x	S _x	10-12-75 H ₂ O _x	S _x	11-04-75 H ₂ O _x	S _x	12-09-75 H ₂ O _x	S _x	1-13-76 H ₂ O _x	S _x	2-28-76 H ₂ O _x	S _x	4-01-76 H ₂ O _x	S _x	5-01-76 H ₂ O _x	S _x
W.S. #1 Topsoil- Chiseled	0-22.5	14+	.0432	11	.0363	08+	.0307	14	.0540	27+	.0148	28	.0131	23+	.0177	20	.0319	32+	.0099
	22.5-37.5	24	.0206	25	.0175	19	.0158	22	.0114	24	.0128	26	.0215	27	.0168	29	.0139	34	.0158
	37.5-52.5	32	.0268	32	.0261	25	.0241	25	.0331	36	.0190	22	.0177	27	.0202	30	.0242	35	.0244
	52.5-67.5	34	.0143	34	.0130	27	.0105	25	.0136	25	.0071	26	.0157	25	.0100	28	.0171	29	.0140
	67.5-82.5	33	.0250	33	.0237	28	.0213	25	.0210	25	.0208	27	.0218	26	.0245	28	.0221	28	.0266
	82.5-105	33	.0270	33	.0258	27	.0177	25	.0254	27	.0139	27	.0154	26	.0179	27	.0193	27	.0195
	105-135	37	.0180	38	.0118	33	.0176	31	.0174	30	.0108	30	.0150	30	.0130	31	.0111	33	.0154
	135-165	40	.0410	41	.0420	38	.0353	38	.0521	34	.0385	36	.0357	34	.0391	35	.0378	35	.0390
	165-195	38	.0492	39	.0498	35	.0382	38	.0693	32	.0412	35	.0661	31	.0417	33	.0466	34	.0603
	195-225	39	.0641	40	.0664	38	.0612	37	.0971	34	.0642	39	.0669	33	.0622	34	.0623	35	.0690
	225-245	38	-	39	-	37	-	27	-	32	-	31	-	31	-	33	-	35	-
	S _x		.0679** n=5		.0679** n=5		.0372 ns n=5		.0477 ns n=3		.0415 ns n=5		.0480 ns n=4		.0472* n=5		.0495* n=5		.0700** n=5
W.S. #2 Nontopsoil- Gauged	0-22.5	14+	.0745	14	.0794	08+	.0544	17	.0420	29+	.0236	30	.0165	20+	.0583	13	.0675	31+	.0202
	22.5-37.5	23	.0856	24	.0847	18	.0733	26	.0302	24	.0173	26	.0195	26	.0188	22	.0496	32	.0165
	37.5-52.5	27	.0495	29	.0482	24	.0469	27	.0326	25	.0419	26	.0456	27	.0357	28	.0223	32	.0280
	52.5-67.5	33	.0585	34	.0608	29	.0641	30	.0582	25	.0405	24	.0205	25	.0272	29	.0310	28	.0277
	67.5-82.5	30	.0424	31	.0442	25	.0379	26	.0322	23	.0318	24	.0212	22	.0224	25	.0232	25	.0334
	82.5-105	29	.0466	29	.0475	25	.0418	26	.0290	24	.0268	27	.0250	23	.0196	23	.0203	26	.0284
	105-135	34	.0568	35	.0600	30	.0772	32	.0661	28	.0521	28	.0402	27	.0417	27	.0457	29	.0472
	135-165	34	.0440	35	.0473	32	.0677	30	.0651	28	.0470	30	.0472	27	.0393	28	.0403	29	.0437
	165-195	33	.0296	33	.0291	28	.0182	29	.0413	25	.0244	26	.0114	25	.0177	27	.0227	28	.0200
	195-225	29	.0200	30	.0206	28	.0293	26	.0106	25	.0061	27	.0090	24	.0085	25	.0093	26	.0092
	225-245	34	-	35	-	31	-	28	-	26	-	27	-	26	-	27	-	28	-
	S _x		.135** n=4		.139** n=4		.136** n=4		.0885 ns n=3		.0752** n=4		.0523** n=5		.0581** n=5		.0772** n=5		.0626** n=5
W.S. #3 Topsoil- Gauged	0-22.5	09+	.0563	13	.0000	05	.0407	11	.0494	18+	.0247	25	.0531	19+	.0571	17	.0660	23+	.0545
	22.5-37.5	18	.0313	13	.0000	11	.0238	15	.0174	18	.0414	19	.0486	23	.0468	24	.0328	28	.0323
	37.5-52.5	23	.0548	13	.0000	17	.0461	16	.0418	16	.0420	18	.0383	22	.0465	23	.0447	27	.0401
	52.5-67.5	24	.0484	13	.0000	17	.0463	18	.0404	17	.0401	20	.0410	22	.0414	23	.0414	26	.0468
	67.5-82.5	27	.0517	16	.0000	20	.0478	19	.0427	19	.0408	20	.0444	22	.0454	23	.0449	25	.0442
	82.5-105	28	.0537	17	.0000	22	.0525	21	.0471	28	.0444	22	.0492	24	.0498	28	.0517	25	.0520
	105-135	28	.0340	20	.0000	20	.0302	20	.0289	19	.0277	20	.0269	20	.0268	22	.0427	22	.0408
	135-165	29	.0328	23	.0000	24	.0322	23	.0314	22	.0290	22	.0292	23	.0315	24	.0387	24	.0388
	165-195	29	.0220	25	.0000	24	.0339	24	.0227	22	.0244	22	.0334	23	.0283	24	.0304	24	.0331
	195-225	27	.0419	27	.0900	25	.0364	22	.0363	21	.0342	23	.0338	22	.0368	22	.0390	24	.0413
	225-245	26	-	27	.0000	24	-	23	-	22	-	23	-	22	-	22	-	23	-
	S _x		.0890** n=4		.0885** n=1		.0832** n=4		.0730** n=4		.0814** n=4		.0907** n=4		.1072** n=4		.1067** n=4		.0971** n=4
W.S. #4 Topsoil- Chiseled	0-22.5	-	-	-	-	-	-	-	-	-	-	26	.0238	27+	.0115	24	.0143	28+	.0163
	22.5-37.5	-	-	-	-	-	-	-	-	-	-	23	.0229	23	.0245	24	.0203	27	.0205
	37.5-52.5	-	-	-	-	-	-	-	-	-	-	21	.0162	21	.0194	22	.0202	25	.0203
	52.5-67.5	-	-	-	-	-	-	-	-	-	-	20	.0201	21	.0157	24	.0191	25	.0141
	67.5-82.5	-	-	-	-	-	-	-	-	-	-	19	.0219	18	.0210	20	.0203	23	.0202
	82.5-105	-	-	-	-	-	-	-	-	-	-	19	.0185	18	.0201	19	.0211	21	.0197
	105-135	-	-	-	-	-	-	-	-	-	-	23	.0205	22	.0235	21	.0215	22	.0239
	135-165	-	-	-	-	-	-	-	-	-	-	25	.0241	23	.0251	25	.0238	23	.0273
	165-195	-	-	-	-	-	-	-	-	-	-	23	.0059	21	.0092	21	.0120	21	.0111
	195-225	-	-	-	-	-	-	-	-	-	-	24	.0132	23	.0135	23	.0196	23	.0118
	225-245	-	-	-	-	-	-	-	-	-	-	34	-	29	-	28	-	30	-
	S _x											.0430** n=5		.0408** n=5		.0417** n=5		.0427** n=5	
W.S. #5 Topsoil- Dozer Basins	0-22.5	18+	.0213	-	-	07+	.0106	16	.0095	25+	.0130	24	.0280	26+	.0122	24	.0131	28+	.0124
	22.5-37.5	23	.0118	-	-	16	.0185	18	.0215	18	.0186	18	.0239	20	.0219	22	.0168	25	.0166
	37.5-52.5	22	.0235	-	-	16	.0219	16	.0201	18	.0167	19	.0158	18	.0111	19	.0145	22	.0083
	52.5-67.5	26	.0163	-	-	18	.0289	29	.0239	20	.0363	21	.0434	20	.0432	21	.0332	22	.0399
	67.5-82.5	30	.0436	-	-	21	.0456	21	.0431	20	.0427	20	.0366	20	.0396	21	.0446	22	.0422
	82.5-105	30	.0347	-	-	22	.0405	21	.0367	20	.0400	23	.0418	21	.0364	21	.0362	22	.0376
	105-135	37	.0243	-	-	26	.0343	25	.0295	25	.0278	25	.0179	24	.0200	25	.0245	25	.0158
	135-165	35	.0335	-	-	26	.0348	25	.0226	25	.0222	29	.0337	25	.0261	26	.0231	25	.0246
	165-195	38	.0556	-	-	29	.0483	29	.0410	28	.0407	25	.0391	26	.0408	26	.0379	26	.0418
	195-225	31	.0542	-	-	26	.0460	24	.0426	22	.0389	22	.0411	22	.0391	22	.0397	22	.0368
	225-245	42	-	-	-	36	-	32	-	32	-	32	-	31	-	33	-	31	-
	S _x		.0417 ns n=4				.055* n=4		.0420 ns n=4		.0464 ns n=4		.0475 ns n=4		.0328 ns n=4		.0350 ns n=4		.0276 ns n=4

* Significant at the 0.05 level

** Significant at the 0.01 level

* These data plotted in figure 27

ns Not significant

Table 43. Volumetric soil water contents with depth and time are presented for each watershed treatment at the Beulah Demonstration. Each datum is an average of five sites and the standard error of these means are shown. Samples collected on eleven dates during 1975 and 1976.

Watershed Surface Treatment	Sampling Increment Depths (cm)	6-23-75 H ₂ O%	S _x	8-5-75 H ₂ O%	S _x	8-25-75 H ₂ O%	S _x	10-25-75 H ₂ O%	S _x	11-28-75 H ₂ O%	S _x	12-29-75 H ₂ O%	S _x	1-31-76 H ₂ O%	S _x	2-29-76 H ₂ O%	S _x	4-3-76 H ₂ O%	S _x	5-5-76 H ₂ O%	S _x
W.S. #1	0-22.5	39+	.0072	21	.0323	19+	.0311	34	.0173	34+	.0181	35	.0181	34	.0076	38	.0128	39+	.0065	36+	.0082
	22.5-37.5	36	.0112	35	.0129	35	.0125	36	.0141	35	.0149	36	.0141	35	.0103	36	.0159	37	.0174	33	.0125
	37.5-52.5	34	.0168	36	.0166	34	.0163	35	.0173	34	.0162	35	.0210	33	.0143	34	.0217	34	.0197	31	.0132
	52.5-67.5	33	.0187	34	.0225	34	.0236	35	.0179	34	.0205	35	.0206	33	.0288	34	.0201	35	.0187	32	.0099
	67.5-82.5	32	.0201	33	.0179	33	.0156	33	.0202	32	.0203	33	.0240	32	.0317	33	.0218	36	.0212	32	.0118
	82.5-105	32	.0128	32	.0132	32	.0130	35	.0103	34	.0101	35	.0130	34	.0204	35	.0156	36	.0150	33	.0153
Topsoil-Chiseled	105-135	36	.0192	35	.0096	34	.0114	37	.0214	37	.0194	37	.0196	36	.0180	37	.0206	39	.0177	34	.0200
	135-165	33	.0163	35	.0208	35	.0192	35	.0205	34	.0192	35	.0189	34	.0197	37	.0172	36	.0175	31	.0238
	165-195	35	.0127	34	.0138	34	.0143	36	.0152	35	.0152	36	.0136	35	.0174	36	.0161	37	.0143	32	.0163
	S _x	0.0321** n=5		0.0288 n=5	ns	0.0297* n=5		0.0329** n=5		0.0320** n=5		0.0365** n=5		0.0344** n=5		0.0445** n=5		0.0361** n=5		0.0314** n=5	
W.S. #2	0-22.5	35+	.0117	33	.0146	36+	.0137	36	.0152	35+	.0180	37	.0174	36	.0134	39	.0208	38+	.0138	32+	.0100
	22.5-37.5	35	.0211	35	.0207	40	.0183	40	.0233	38	.0210	39	.0247	38	.0197	38	.0178	41	.0330	35	.0199
	37.5-52.5	37	.0359	38	.0267	40	.0317	40	.0329	38	.0390	39	.0337	38	.0333	38	.0350	40	.0353	35	.0306
	52.5-67.5	39	.0377	39	.0322	44	.0333	44	.0269	42	.0269	42	.0297	42	.0309	42	.0316	42	.0257	38	.0253
	67.5-82.5	40	.0300	40	.0277	44	.0288	44	.0134	43	.0157	44	.0168	43	.0161	42	.0164	44	.0145	39	.0106
	82.5-105	41	.0152	42	.0062	44	.0084	44	.0121	43	.0136	44	.0105	42	.0116	42	.0096	44	.0143	38	.0126
Nontopsoil-Gouged	105-135	41	.0173	42	.0168	43	.0182	44	.0144	42	.0156	43	.0148	42	.0140	45	.0158	43	.0154	38	.0136
	135-165	39	.0222	40	.0174	44	.0170	43	.0358	43	.0335	43	.0315	42	.0309	43	.0293	43	.0275	39	.0342
	165-195	39	.0192	40	.0116	43	.0114	44	.0121	41	.0158	42	.0121	41	.0109	41	.0137	42	.0130	37	.0140
	S _x	0.0519** n=5		0.0343* n=5		0.0372** n=5		0.0409** n=5		0.0462** n=5		0.0440** n=5		0.0434** n=5		0.0434** n=5		0.0514** n=5		0.0403** n=5	
W.S. #3	0-22.5	35+	.0215	30	.0332	28+	.0305	37	.0227	36+	.0234	36	.0198	36	.0229	36	.0205	36+	.0209	33+	.0177
	22.5-37.5	35	.0155	37	.0216	36	.0194	38	.0210	36	.0219	36	.0201	37	.0194	35	.0160	37	.0152	32	.0154
	37.5-52.5	34	.0159	36	.0207	35	.0176	37	.0131	36	.0136	36	.0129	34	.0107	34	.0102	35	.0130	32	.0126
	52.5-67.5	32	.0281	35	.0200	45	.0210	36	.0292	36	.0316	36	.0292	34	.0283	34	.0267	35	.0268	32	.0247
	67.5-82.5	32	.0278	35	.0275	34	.0259	38	.0304	37	.0327	36	.0334	37	.0315	35	.0341	37	.0298	33	.0242
	82.5-105	35	.0308	36	.0314	34	.0295	38	.0265	37	.0278	37	.0271	37	.0283	36	.0274	37	.0254	33	.0205
Topsoil-Chiseled	105-135	34	.0290	37	.0264	37	.0257	38	.0291	37	.0283	36	.0271	36	.0289	36	.0285	37	.0265	32	.0238
	135-165	36	.0220	37	.0298	36	.0267	40	.0253	40	.0258	39	.0244	39	.0230	38	.0260	39	.0230	35	.0213
	165-195	38		38		39		43		41		41		41		41		41		36	
	S _x	0.0648** n=5		0.0638** n=5		0.0648** n=5		0.0695** n=5		0.0762** n=5		0.0693** n=5		0.0676** n=5		0.0687** n=5		0.0658** n=5		0.0583** n=5	
W.S. #4	0-22.5	38+	.1171	34	.0085	31+	.0209	40	.0297	38+	.0270	32	.0788	38	.0288	38	.0252	39+	.0272	5-6-76 36+	.0168
	22.5-37.5	39	.1199	39	.0077	39	.0079	41	.0073	39	.0094	39	.0071	39	.0112	39	.0091	40	.0068	37	.0100
	37.5-52.5	33	.1055	38	.0133	38	.0110	39	.0185	37	.0177	38	.0164	38	.0174	37	.0140	37	.0185	34	.0145
	52.5-67.5	34	.1067	36	.0109	35	.0081	39	.0177	36	.0105	37	.0084	37	.0108	37	.0116	38	.0109	33	.0090
	67.5-82.5	34	.1065	36	.0106	35	.0115	39	.0219	37	.0102	37	.0099	37	.0069	37	.0105	37	.0122	34	.0046
	82.5-105	34	.1066	34	.0155	34	.0148	38	.0262	35	.0214	36	.0209	35	.0173	35	.0159	36	.0204	35	.0135
Topsoil-Gouged	105-135	33	.1035	32	.0140	33	.0144	36	.0220	34	.0147	34	.0164	34	.0126	32	.0124	34	.0144	32	.0174
	135-165	32	.1022	32	.0104	32	.0119	33	.0261	32	.0167	33	.0162	33	.0169	32	.0167	33	.0191	32	.0140
	165-195	33	.1035	34	.0262	33	.0249	35	.0342	33	.0275	33	.0281	34	.0242	33	.0250	34	.0301	33	.0187
	S _x	0.0042 n=2	ns	0.0227* n=5		0.0233* n=5		0.0550** n=5		0.0292* n=5		0.0406 n=5	ns	0.0237 n=5	ns	0.0225 n=5	ns	0.0338** n=5		0.0276** n=5	
W.S. #5	0-22.5	-		26	.0336	28+	.0325	37	.0400	35+	.0351	39	.0992	38	.0968	40	.1020	36+	.0358	35+	.0170
	22.5-37.5	-		35	.0189	36	.0156	40	.0200	38	.0169	37	.0959	36	.0918	38	.0978	40	.0154	35	.0151
	37.5-52.5	-		35	.0267	36	.0268	37	.0136	35	.0146	34	.0890	33	.0849	36	.0928	36	.0116	33	.0125
	52.5-67.5	-		31	.0175	31	.0192	33	.0221	31	.0222	31	.0816	31	.0828	33	.0887	34	.0204	33	.0199
	67.5-82.5	-		31	.0199	32	.0229	35	.0172	33	.0167	33	.0860	32	.0850	34	.0894	34	.0195	32	.0170
	82.5-105	-		32	.0082	32	.0061	36	.0149	34	.0138	33	.0868	33	.0857	36	.0933	36	.0141	32	.0210
Topsoil-Dozer Basins	105-135	-		34	.0173	35	.0178	37	.0143	35	.0158	34	.0880	32	.0842	36	.0925	37	.0159	32	.0174
	135-165	-		32	.0097	33	.0098	32	.0133	30	.0140	31	.0836	32	.0846	33	.0857	32	.0224	28	.0198
	165-195	-		31	.0131	32	.0137	32	.0153	33	.0154	33	.0858	33	.0867	34	.0886	33	.0162	29	.0136
	S _x			0.0151 n=5	ns	0.0101 n=5	ns	0.0095 n=5	ns	0.0148 n=5	ns	0.0049 n=5	ns	0.0294* n=4		0.0382** n=4		0.0236 n=5	ns	0.0272* n=5	

* Significant at the 0.05 level

** Significant at the 0.01 level

+ These data plotted in figure 28

ns Not significant

APPENDIX C. SOIL BULK DENSITY

Table 44. Soil profile bulk density (g/cm^3) in each watershed at the Colstrip Demonstration. Measurements were made with a Troxler depth density probe and Troxler depth moisture neutron probe.

SOIL DEPTH (cm)	TOPSOIL			NO TOPSOIL	
	GOUGED	DOZER BASINS	CHISELED	GOUGED	CHISELED
0-15	2.14	1.92	1.90	2.16	1.49
15-30	2.17	1.81	1.65	1.85	1.35
30-45	2.14	1.91	1.73	-	1.43
45-60	2.14	1.88	1.74	-	1.59
60-75	2.10	1.88	1.74	1.91	1.45
75-90	2.10	1.85	1.93	1.97	1.48
90-120	2.15	1.74	1.86	1.65	1.48
120-150	2.11	1.77	1.74	1.77	1.52
150-180	2.13	1.70	1.84	2.06	1.39
180-210	2.02	1.66	1.76	2.06	-

Table 45. Soil profile bulk density (g/cm^3) in each watershed at the Savage Demonstration. Measurements were made with a Troxler depth density probe and Troxler depth moisture probe.

SOIL DEPTH (cm)	TOPSOIL			NO TOPSOIL	
	GOUGED	DOZER BASINS	CHISELED	GOUGED	CHISELED
0-15	1.44	1.68	1.58	1.87	1.63
15-30	1.65	1.55	1.55	1.83	1.39
30-45	1.69	1.29	1.51	1.72	1.29
45-60	1.65	1.33	1.56	1.40	1.25
60-75	1.59	1.20	1.61	1.11	1.25
75-90	1.45	1.15	1.59	1.24	1.18
90-120	1.39	1.43	1.37	1.08	1.26
120-150	1.42	1.41	-	1.46	1.13
150-180	1.29	1.58	-	1.51	1.08
180-210	1.38	1.63	-	1.38	1.11

Table 46. Soil profile bulk density (g/cm^3) at five sites in each watershed at the Beulah Demonstration. Determinations were made with mass and volume measurements of profile cores.

Soil Depth (cm)	Site 1	Site 2	Site 3	Site 4	Site 5	Mean
<u>Topsoil Chiseled</u>						
0-30	1.06	0.65	1.42	0.51	1.23	0.97
30-60	1.42	1.39	1.46	1.34	1.40	1.40
60-90	1.29	1.30	1.44	1.50	1.43	1.39
90-12	1.38	1.48	1.37	1.46	1.29	1.40
120-15	1.16	1.22	1.07	0.89	1.25	1.12
150-18	1.24	1.24	1.15	0.72	1.30	1.13
180-21	1.29	1.37	1.07	1.22	1.20	1.23
210-24	1.22	1.27	1.22	1.28	1.16	1.23
240-27	1.27	1.35	1.51	1.16	1.23	1.30
<u>Nontopsoil Gouged</u>						
0-30	0.56	1.35	1.38	0.80	1.48	1.11
30-60	1.36	1.36	1.24	1.42	1.26	1.33
60-90	1.04	1.36	0.71	1.37	1.29	1.15
90-12	1.74	1.30	0.94	1.45	1.48	1.38
120-15	0.99	0.55	1.04	0.95	1.32	0.97
150-18	1.45	0.94	1.32	1.25	1.34	1.26
180-21	1.37	1.38	-	1.14	0.92	1.20
210-24	1.28	0.95	-	1.48	1.42	1.28
240-27	1.26	0.99	-	1.63	1.39	1.32
<u>Nontopsoil Chiseled</u>						
0-30	1.12	1.07	1.11	0.58	0.96	0.97
30-60	1.42	1.33	1.49	1.38	1.46	1.42
60-90	1.40	1.20	1.55	1.29	1.25	1.34
90-12	1.19	1.20	1.00	1.62	1.00	1.20
120-15	1.05	1.28	1.04	1.05	0.95	1.07
150-18	1.34	1.12	1.22	0.79	1.87	1.27
180-21	1.20	1.20	1.25	1.42	1.09	1.23
210-24	1.25	1.41	1.18	1.35	0.40	1.12
240-27	1.56	1.30	1.34	1.37	1.11	1.34
<u>Topsoil Gouged</u>						
0-30	0.73	0.88	-	1.58	1.19	1.10
30-60	1.48	1.39	-	1.42	1.41	1.43
60-90	1.47	0.81	-	1.54	1.55	1.34
90-12	1.47	1.31	-	1.45	1.27	1.37
120-15	1.90	1.11	-	1.34	1.14	1.37
150-18	1.33	1.12	-	1.22	1.16	1.21
180-21	1.51	1.39	-	1.26	1.20	1.34
210-24	1.47	1.39	-	1.13	1.09	1.27
240-27	1.30	1.21	-	1.21	1.32	1.26
<u>Topsoil Dozer Basins</u>						
0-30	1.14	1.38	1.27	1.40	0.86	1.21
30-60	1.46	1.34	1.26	1.58	1.39	1.41
60-90	1.27	1.39	1.38	1.35	1.22	1.32
90-12	1.33	1.33	1.35	1.24	1.33	1.31
120-15	1.25	1.30	1.24	1.18	1.32	1.26
150-18	1.25	1.39	1.51	1.26	1.42	1.37
180-21	1.29	1.52	1.16	1.58	1.30	1.37
210-24	1.24	1.36	1.58	1.37	1.11	1.33
240-27	1.17	1.28	1.59	1.61	1.47	1.42

APPENDIX D. HYDROLOGIC BALANCE

Table 47. Monthly hydrologic balance (cm) of the surface two meters of spoil for the nontopsoil-chiseled treatment, EPA Demonstration Area, Colstrip, Montana.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
⁺ Precipitation(PPT)	4.4	1.8	1.5	2.0	3.6	3.6	2.2	1.6	1.8	4.8	--	27.3
[#] Evapotranspiration(ET)	-10.1	-5.6	-2.3	*	-3.2	-1.5	-0.8	-3.0	-3.1	-2.8	-3.8	-36.2
Runoff(RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waterflow(WF)	-4.8	-3.2	-4.2	--	2.6	1.4	1.1	2.4	0.8	3.0	--	-0.9
Change Soil Water Content (Δ SWC)	-10.5	-7.0	-5.0	-4.5	3.0	3.5	2.5	1.0	-0.5	5.0	2.0	-10.5

⁺ Monthly precipitation computed by averaging collections of two storage gauges, one located approximately 800 m north and one 700 m northeast of the EPA Demonstration Area.

[#] Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

--Insufficient data for calculation.

Table 48. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-chiseled treatment, EPA Demonstration Area, Colstrip, Montana.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation PPT	4.4	1.8	1.5	2.0	3.6	3.6	2.2	1.6	1.8	4.8	--	27.3
*Evapotranspiration ET	-9.9	-6.0	-2.6	-0.7	-3.2	-1.8	-1.6	-3.9	-3.2	-3.6	-9.5	-46.0
Runoff RO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0
Waterflow WF	-7.0	-4.8	-5.4	-6.8	5.6	4.7	1.9	3.3	1.9	4.3	--	-2.3
Change Soil Water Content Δ SWC	-12.5	-9.0	-6.5	-5.5	6.0	6.5	2.5	1.0	0.5	5.5	1.0	-10.5

+Monthly precipitation computed by averaging collections of two storage gauges, one located approximately 800 m north and one 700 m northeast of the EPA Demonstration Area.

--Insufficient data for calculation.

*Evapotranspiration values were computed by averaging the available data from the other four watersheds.

Table 49. Monthly hydrologic balance (cm) of the surface two meters of spoil for the nontopsoil-gouged treatment, EPA Demonstration Area, Colstrip, Montana.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+ Precipitation (PPT)	4.4	1.8	1.5	2.0	3.6	3.6	2.2	1.6	1.8	4.8	--	27.3
# Evapotranspiration (ET)	-8.6	-6.0	-1.9	-0.7	-4.0	-2.4	*	-4.6	-3.5	-4.8	-12.0	-48.5
Runoff (RO)	0.0	0.0	0.0	trace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	trace
Waterflow (WF)	-15.3	-0.8	-4.6	-5.8	4.9	3.3	--	3.0	1.2	5.0	--	-9.1
Change Soil Water Content (ΔSWC)	-19.5	-5.0	-5.0	-4.5	4.5	4.5	2.0	0.0	-0.5	5.0	--	-18.5

+ Monthly precipitation computed by averaging collections of two storage gauges, one located approximately 800 m north and one 700 m northeast of the EPA Demonstration Area.

Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

--Insufficient data for calculation.

Table 50. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-gouged treatment, EPA Demonstration Area, Colstrip, Montana.

Hydrologic Component	1975						1976					Total
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	
+ Precipitation (PPT)	4.4	1.8	1.5	2.0	3.6	3.6	2.2	1.6	1.8	4.8	--	27.3
# Evapotranspiration (ET)	-11.0	-6.4	-3.6	*	-2.4	-2.4	-2.9	-3.9	-2.9	--	-10.1	-45.6
Runoff (RO)	0.0	0.0	0.0	trace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	trace
Waterflow (WF)	1.1	0.6	-6.4	--	4.3	3.8	3.7	2.8	-0.9	--	--	11.3
Change Soil Water Content (Δ SWC)	-5.5	-4.0	-8.5	-7.5	5.5	5.0	3.0	0.5	-2.0	4.5	2.0	-7.0

+ Monthly precipitation computed by averaging collections of two storage gauges, one located approximately 800 m north and one 700 m northeast of the EPA Demonstration Area.

Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

-- Insufficient data for calculation.

Table 51. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-dozer basin treatment, EPA Demonstration Area, Colstrip, Montana.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+ Precipitation (PPT)	4.4	1.8	1.5	2.0	3.6	3.6	2.2	1.6	1.8	4.8	--	27.3
# Evapotranspiration (ET)	-10.0	-5.4	--	--	*	-0.9	-1.1	-4.2	-3.5	-3.1	-12.0	-40.2
Runoff (RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waterflow (WF)	--	--	--	--	--	-0.2	1.9	5.1	1.7	2.8	--	11.3
Change Soil Water Content (Δ SWC)	--	--	--	-1.5	2.5	2.5	3.0	2.5	0.0	4.5	6.0	19.5

+ Monthly precipitation computed by averaging collections of two storage gauges, one located approximately 800 m north and one 700 m northeast of the EPA Demonstration Area.

Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

--Insufficient data for calculation.

*Gain in lysimeter weight exceeded precipitation (may have been caused by inflow of surface water, blowing soil, blowing snow, or errors in precipitation catch).

Table 52. Monthly hydrologic balance (cm) of the surface two meters of spoil for the nontopsoil-chiseled treatment, EPA Demonstration Area, Beulah, North Dakota.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	3.2	0.9	3.1	1.5	1.1 ^x	0.4 ^x	2.6 ^x	0 ^x	1.5 ^x	5.1	1.6	21.0
# Evapotranspiration(ET)	-6.6	-8.0	-3.9	-7.1	*	*	*	*	*	-3.9	-1.3	-30.8
Runoff (RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-8.4	0.0	--	-8.4
Waterflow (WF)	3.9	9.1	4.8	8.6	--	--	--	--	--	-9.2	--	17.2
Change Soil Water Content (Δ SWC)	0.5	2.0	4.0	3.0	-2.0	0.0	0.0	-2.0	2.0	-8.0	--	-0.5

+Precipitation data collected from North Dakota State University, Rangeland Study Site located approximately .75 miles north of EPA Demonstration Area.

Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

^xPrecipitation data collected from Climatological Summary for North Dakota, Beulah, North Dakota.

--Insufficient data for calculation.

Table 53. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-chiseled treatment, EPA Demonstration Area, Beulah, North Dakota.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation (PPT)	3.2	0.9	3.1	1.5	1.1 ^x	0.4 ^x	2.6 ^x	0 ^x	1.5 ^x	5.1	1.6	21.0
# Evapotranspiration (ET)	*	-4.7	-5.2	-4.9	-4.1	-1.8	-4.6	*	*	-1.7	-3.4	-30.4
Runoff (RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waterflow (WF)	--	3.3	5.6	6.4	1.5	3.9	-1.0	--	--	-11.4	--	8.3
Change Soil Water Content (Δ SWC)	-4.0	-0.5	3.5	3.0	-1.5	2.5	-3.0	3.0	2.8	-8.0	--	-2.2

+Precipitation data collected from North Dakota State University Rangeland Study Site located approximately .75 miles north of EPA Demonstration Area.

Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow of errors in precipitation catch).

^xPrecipitation data collected from Climatological Summary for North Dakota, Beulah, North Dakota.

--Insufficient data for calculation.

Table 54. Monthly hydrologic balance (cm) of the surface two meters of spoil for the nontopsoil-gouged treatment, EPA Demonstration Area, Beulah, North Dakota.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	3.2	0.9	3.1	1.5	1.1 ^x	0.4 ^x	2.6 ^x	0 ^x	1.5 ^x	5.1	1.6	21.0
#Evapotranspiration(ET)	-10.1	-4.0	*	-9.9	-3.1	-2.7	-3.2	-1.2	-2.6	-3.1	-1.2	-41.1
Runoff (RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.4	0.0	--	-2.4
Waterflow(WF)	7.9	5.1	--	11.4	-0.5	-6.8	-4.9	1.2	4.1	-11.5	--	6.0
Change Soil Water Content (Δ SWC)	1.0	2.0	4.0	3.0	-2.5	4.5	-5.5	0.0	3.0	-9.5	--	0.0

+Precipitation data collected from North Dakota State University, Rangeland Study Site located approximately .75 miles north of EPA Demonstration Area.

#Evapotranspiration was measured by the weighing lysimeter method. (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

^xPrecipitation data collected from Climatological Summary for North Dakota, Beulah, North Dakota.

--Insufficient data for calculation.

Table 55. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-gouged treatment, EPA Demonstration Area, Beulah, North Dakota.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	3.2	0.9	3.1	1.5	1.1 ^x	0.4 ^x	2.6 ^x	0 ^x	1.5 ^x	5.1	1.6	21.0
*Evapotranspiration(ET)	-8.3	-5.8	-4.2	-6.6	-3.6	-2.2	-3.9	-4.0	-2.9	-2.5	-2.2	-46.2
Runoff(RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0
Waterflow (WF)	7.1	4.4	5.6	7.6	-2.5	1.3	2.8	2.5	3.4	-8.6	--	23.6
Change Soil Water Content(Δ SWC)	2.0	-0.5	4.5	2.5	-5.0	-0.5	1.5	-1.5	2.0	-6.0	--	-1.0

+Precipitation data collected from North Dakota State University, Rangeland Study Site located approximately .75 miles north of EPA Demonstration Area.

^xPrecipitation data collected from Climatological Summary for North Dakota, Beulah, North Dakota.

--Insufficient data for calculation.

*Evapotranspiration values were computed by averaging the available data from the other four watersheds.

Table 56. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-dozer basin treatment, EPA Demonstration Area, Beulah, North Dakota.

Hydrologic Component	1975						1976					Total
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	3.2	0.9	3.1	1.5	1.1 ^x	0.4 ^x	2.6 ^x	0 ^x	1.5 ^x	5.1	1.6	21.0
#Evapotranspiration(ET)	-8.2	-6.5	-3.6	-4.5	*	*	*	-6.8	-3.2	-1.4	-3.0	-37.2
Runoff(RO)	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0
Waterflow(WF)	--	9.1	4.0	5.5	--	--	--	13.8	0.7	-9.7	--	23.4
Change Soil Water Content (ΔSWC)	--	3.5	3.5	2.5	-4.5	1.0	-2.5	7.0	-1.0	-6.0	--	3.5

+Precipitation data collected from North Dakota State University, Rangeland Site located approximately .75 miles north of EPA Demonstration Area.

#Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

^xPrecipitation data collected from Climatological Summary for North Dakota, Beulah, North Dakota.

--Insufficient data for calculation.

Table 57. Monthly hydrologic balance (cm) of the surface two meters of spoil for the nontopsoil-chiseled treatment, EPA Demonstration Area, Savage, Montana.

Hydrologic Component	1975				1976					Total
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	1.7	2.9	1.7	1.8	1.2	trace	0.6	5.7	1.2	16.8
#Evapotranspiration(ET)	-6.9	-4.5	-3.4	-3.0	-2.4	*	*	-3.4	--	-23.6
Runoff(RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-0.9
Waterflow(WF)	--	--	--	1.2	0.7	--	--	0.7	--	2.6
Change Soil Water Content (Δ SWC)	--	--	--	0.0	-0.5	-0.5	0.5	3.0	1.5	4.0

+Precipitation data collected from Climatological Summary for Montana, Savage, Montana.

--Insufficient data for calculation

#Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

Table 58. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-chiseled treatment, EPA Demonstration Area, Savage, Montana.

Hydrologic Component	1975				1976					Total
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	1.7	2.9	1.7	1.8	1.2	trace	0.6	5.7	1.2	16.8
*Evapotranspiration(ET)	-6.8	-5.3	-4.8	-5.1	-3.6	-3.4	-2.9	-5.1	--	-37.0
Runoff(RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-0.3
Waterflow (WF)	-1.9	0.4	4.1	5.3	4.4	3.4	0.3	4.9	--	20.9
Change Soil Water Content (Δ SWC)	-7.0	-2.0	1.0	2.0	2.0	0.0	-2.0	5.5	1.5	1.0

+Precipitation data collected from Climatological Summary for Montana, Savage, Montana.

--Insufficient data for calculation.

*Evapotranspiration values were computed by averaging the available data from the other watersheds.

Table 59. Monthly hydrologic balance of the surface two meters of spoil for the nontopsoil-gouged treatment, EPA Demonstration Area, Savage, Montana.

Hydrologic Component	1975				1976					Total
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation (PPT)	1.7	2.9	1.7	1.8	1.2	trace	0.6	5.7	1.2	16.8
# Evapotranspiration (ET)	--	-8.5	*	-0.5	*	*	-1.8	-7.2	--	-18.0
Runoff (RO)	0.0	0.0	0.0	0.0	-3.1	0.0	0.0	0.0	-1.2	-4.3
Waterflow (WF)	--	7.1	--	-0.3	--	--	1.2	8.0	--	16.0
Change Soil Water Content @SWC)	-7.0	1.5	-0.5	1.0	-1.5	-2.5	0.0	6.5	2.5	0.0

+Precipitation data collected from Climatological Summary for Montana, Savage, Montana.

--Insufficient data for calculation.

#Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

*Gain in lysimeter exceeded precipitation (may have been caused by inflow of surface water, blowing snow or errors in precipitation catch).

Table 60. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-gouged treatment, EPA Demonstration Area, Savage, Montana.

Hydrologic Component	1975				1976					Total
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation(PPT)	1.7	2.9	1.7	1.8	1.2	trace	0.6	5.7	1.2	16.8
*Evapotranspiration(ET)	-6.8	-5.3	-4.8	-5.1	-3.6	-3.4	-2.9	-5.1	--	-37.0
Runoff(RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	-0.3
Waterflow(WF)	2.1	3.4	4.1	5.8	3.9	4.4	3.3	3.4	--	30.4
Change Soil Water Content(ΔSWC)	-3.0	1.0	1.0	2.5	1.5	1.0	1.0	4.0	2.0	11.0

+Precipitation data collected from Climatological Summary for Montana, Savage, Montana.

--Insufficient data for calculation.

*Evapotranspiration values were computed by averaging the available data from the other watersheds.

Table 61. Monthly hydrologic balance (cm) of the surface two meters of spoil for the topsoil-dozer basin treatment, EPA Demonstration Area, Savage, Montana.

Hydrologic Component	1975				1976					Total
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
+Precipitation (PPT)	1.7	2.9	1.7	1.8	1.2	trace	0.6	5.7	1.2	16.8
*Evapotranspiration (ET)	-6.8	-3.0	-1.4	-1.6	-1.2	-3.4	-4.0	-4.8	--	-26.2
Runoff (RO)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
Waterflow (WF)	-2.4	-0.9	-0.3	1.8	0.5	2.4	3.4	2.1	--	6.6
Change Soil Water Content (Δ SWC)	-7.5	-1.0	0.0	2.0	0.5	-1.0	0.0	3.0	1.5	2.5

+Precipitation data collected from Climatological Summary for Montana, Savage, Montana.

--Insufficient data for calculation.

*Evapotranspiration was measured by the weighing lysimeter method (See Appendix A).

APPENDIX E. SOIL DESORPTION CHARACTERISTICS

Table 62. Desorption characteristics (% H₂O by Volume) of soil profiles from the Colstrip Demonstration.

SOIL DEPTH (cm)	PRES- SURE (bars)	TOPSOIL			NO TOPSOIL	
		GOUGED	CHISELED	DOZER BASINS	GOUGED	CHISELED
0-30	0	52.5	44.6	48.4	49.7	36.9
	0.3	31.6	22.4	24.5	27.9	20.4
	15	8.1	8.9	8.0	6.5	3.6
30-60	0	57.3	45.8	53.0	52.5	43.4
	0.3	32.3	25.4	28.1	29.6	24.3
	15	9.5	7.0	10.5	4.2	4.2
60-90	0	52.9	46.9	47.7	49.5	47.9
	0.3	26.0	23.5	26.0	27.7	25.6
	15	10.3	6.1	9.4	4.8	3.9
90-120	0	58.4	53.5	50.1	55.1	50.8
	0.3	28.7	29.2	27.5	30.4	28.4
	15	8.7	6.9	8.5	7.9	7.4
120-150	0	-	49.4	51.6	52.9	41.2
	0.3	-	26.4	29.4	29.4	21.2
	15	-	8.1	8.9	8.5	8.1
150-180	0	-	51.5	45.5	47.3	42.5
	0.3	-	28.8	28.3	26.1	19.4
	15	-	9.4	7.1	5.2	6.5

Table 63. Desorption characteristics (% H₂O by Volume) of soil profiles from the Savage Demonstration.

SOIL DEPTH (cm)	PRES- SURE (bars)	TOPSOIL			NO TOPSOIL	
		GOUGED	CHISELED	DOZER BASINS	GOUGED	CHISELED
0-30	0	44.5	56.3	48.4	39.9	39.1
	0.3	27.2	29.1	26.5	23.4	23.0
	15	6.2	12.8	8.2	8.2	15.4
30-60	0	50.1	59.0	36.1	34.3	43.6
	0.3	37.0	33.5	22.5	19.0	24.4
	15	5.6	11.5	8.6	4.3	6.5
60-90	0	46.2	56.3	39.5	26.9	36.9
	0.3	28.9	31.1	21.0	15.2	20.4
	15	7.1	9.4	5.7	5.7	7.4
90-120	0	42.2	36.5	39.4	36.4	40.8
	0.3	24.2	22.7	22.2	20.1	18.7
	15	4.5	7.1	7.4	5.1	8.1
120-150	0	36.3	-	42.8	-	31.6
	0.3	23.1	-	24.9	-	18.9
	15	3.7	-	9.1	-	3.8
150-180	0	41.8	-	54.9	-	-
	0.3	26.18	-	29.7	-	16.3
	15	4.4	-	10.1	-	-

Table 64. Desorption characteristics (% H₂O by Volume) of soil profiles from the Beulah Demonstration.

SOIL DEPTH (cm)	PRES- SURE (bars)	TOPSOIL			NO TOPSOIL	
		GOUGED	CHISELED	DOZER BASINS	GOUGED	CHISELED
0-30	0	38.28	32.9	32.5	89.4	66.9
	0.3	28.5	26.9	26.0	54.2	36.8
	15	13.1	12.7	12.0	25.6	19.0
30-60	0	88.6	122.1	76.1	116.1	111.4
	0.3	45.9	47.7	41.7	54.0	48.9
	15	19.0	21.0	19.0	31.0	18.1
60-90	0	100.1	125.7	100.7	110.7	125.6
	0.3	45.8	49.1	47.2	58.5	62.3
	15	20.0	24.0	17.0	26.0	17.0
90-120	0	104.2	118.1	95.4	110.6	118.3
	0.3	55.1	62.1	50.9	55.3	50.8
	15	17.0	22.0	22.5	28.0	16.5
120-150	0	101.7	103.5	109.7	91.4	122.5
	0.3	56.1	57.7	60.2	53.4	58.4
	15	22.0	22.0	26.0	24.0	20.2
150-180	0	92.9	112.8	109.6	115.2	74.3
	0.3	49.8	47.9	54.4	50.6	40.7
	15	20.9	19.8	18.0	23.7	16.0