



A premining soil water drainage study on a natural soil
by Roy Duane Noel

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Soils

Montana State University

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Abstract:

A study was initiated in May, 1976, on the site of the future East Decker Mine to determine soil water movement through natural soil profiles toward groundwater and possibly to predict soil water movement subsequent to strip mining.

Equation $d = at^b$ and $Q = et^f$ where d is depth, t is time, Q is quantity of water, and a , b , e , and f are soil parameters used to predict the rate and quantity of water infiltrated into the soil profile. Drainage through the profile was described by equation $W = \alpha x^{\beta+1} t^{-\beta}$ where W is total water above depth x , t is time in hours, and α and β are parameters.

Deep water drainage occurred readily on sites 2, 7, and 8 and these areas provided the potential for groundwater recharge. Sites 1, 3, and 4 exhibited restrictive drainage and deep water drainage was virtually nonexistent. On sites 5, 6, and 9 drainage rates were intermediate.

If the water remained in the profile for substantial periods of time, groundwater recharge could occur, but the possibility is unlikely due to plant uptake.

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Date June 11, 1982

A PREMINING SOIL WATER DRAINAGE STUDY ON A NATURAL SOIL

by

ROY DUANE NOEL

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of

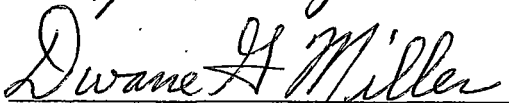
MASTER OF SCIENCE

in

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ABSTRACT

A study was initiated in May, 1976, on the site of the future East Decker Mine to determine soil water movement through natural soil profiles toward groundwater and possibly to predict soil water movement subsequent to strip mining.

Equation $d = at^b$ and $Q = et^f$ where d is depth, t is time, Q is quantity of water, and a , b , e , and f are soil parameters used to predict the rate and quantity of water infiltrated into the soil profile. Drainage through the profile was described by equation $W = \alpha x^{\beta+1} t^{-\beta}$ where W is total water above depth x , t is time in hours, and α and β are parameters.

Deep water drainage occurred readily on sites 2, 7, and 8 and these areas provided the potential for groundwater recharge. Sites 1, 3, and 4 exhibited restrictive drainage and deep water drainage was virtually nonexistent. On sites 5, 6, and 9 drainage rates were intermediate. If the water remained in the profile for substantial periods of time, groundwater recharge could occur, but the possibility is unlikely due to plant uptake.

INTRODUCTION

This study was initiated in order to determine soil water movement and groundwater recharge on natural soils before the advent of strip mining. The soil sites selected were representative of the most common soil series and geomorphic units in the study area. Water movement characteristics obtained from these soil sites should reflect similar characteristics of the other soils comprising the East Decker Mine.

An inventory of each soil profile's visual, physical, and chemical characteristics was necessary to support the infiltration and drainage results obtained with the neutron probe and disturbed and undisturbed hydraulic conductivities.

The objectives of this study were:

- 1) to determine the rate and the quantity of water infiltrating into the soil profile.
- 2) to test and evaluate an unsaturated soil water movement model and apply the model to the natural soils.
- 3) to measure various physical and chemical characteristics of the soils in order to explain differences in water movement which existed.
- 4) to measure and evaluate disturbed and undisturbed hydraulic conductivities and possibly to predict the effects mining would have in the area.

This study was conducted at the East Decker Mine near Decker, Montana.

REVIEW OF LITERATURE

Coal mining has become a prominent industry in the western United States. Montana has 51,300 square miles of coal bearing rock, constituting 13% of the total coal deposits in the United States (National Academy of Sciences, 1974). By the year 2000 an excess of 42,000 acres of land is expected to be disturbed by mining activities (Copeland and Packer, 1972).

Water is of critical importance in this semi-arid, coal mining area. Prior to mining, precipitation is partitioned in a particular way into run-off, soil storage, and deep drainage largely by the properties of the soils of the area. The degree to which this moisture partitioning is modified by mining may be of critical importance. Ground water is a major water supply source of the area and it may be affected by mining activities, especially to the extent that ground water recharge is dependent upon water movement through the soil profile.

Soil properties that are most important in controlling water infiltration and deep drainage are texture, structure, bulk density, clay, chemical characteristics, and profile horizonation. Other factors are soil water content and depth to water table.

Soil texture is a major factor controlling infiltration and permeability because of its role in determining pore size and pore size distribution. In general, sandy textured soils display rapid permeabilities, medium textured soils display moderately slow permeabilities,

and fine textured soils have slow permeabilities (O'Neal, 1952). Diebold (1954) linked soil permeability with silt content. He suggested based on work with many soils, that permeability rates were significantly higher in soils with less than 40% silt than in soils with greater than 40% silt, with constant bulk density. Hill, et al. (1976) demonstrated that water drainage from profiles is fast, intermediate, and slow from sandy, loam, and clayey profiles, respectively. Evaporation from the soil tends to be in reverse of the order listed above. Using soil models, Hillel et al. (1976) showed that immediately after precipitation on dry soils, more water is contained in the soils with higher infiltration rates. As precipitation continues, water passes farther into and perhaps through the soils with higher infiltration. At this point, the soils with lower infiltration/permeability store more water in the profile. With enough precipitation, the low permeability soils become saturated at the surface, creating run-off, whereas the highly permeable soils continue to adsorb water. At no point did any of the soils have a storage efficiency of more than 50%. In general, loam soils were intermediate to the sandy or clayey soils but, under select conditions could store more water than either sandy or clayey soils.

The type of clay significantly modifies the effect of texture on infiltration/permeability. Expanding clays such as smectite and vermiculite tend to swell and/or disperse upon wetting and thus decrease the size of pores available for water movement. Also, Waldron et al. (1970)

and Christensen and Ferguson (1966) have shown that expanding clays are especially sensitive to the type of exchangeable cations relative to infiltration/permeability. Calcium dominated clays tend to be much more permeable than sodium dominated clays.

Soil structure has a significant influence on infiltration/permeability. Platy or massive structure with horizontal axes or no axes tend to be slowly permeable. Blocky or prismatic structure with a number of vertical cracks tend to be permeable. O'Neal (1952) found that where the horizontal axes are three to four times longer than the vertical cracks, permeability is likely to be very slow. The more the axes tend toward the vertical in a given soil the faster will be the permeability.

Bulk density affects both soil permeability and soil water holding capacity. High bulk density soils tend to have smaller pores and, thus, slower infiltration/permeability. Hill et al. (1967) reported that increasing the bulk density of soils increased the water holding capacity at low matrix suction in sands, at all matrix suctions in clays, and high matrix suctions but not at low matrix suctions in sand clay loams. Compaction forces tend to increase bulk density; total density is reduced and the relative volume of larger pores is decreased (Hill et al., 1967). In sands, where large pores are abundant, compaction exerts most of its effect on water holding capacity in the low matrix suction range. In silts and clays, however, due to small soil particles and small voids,

compaction exerts an effect on water holding capacity over a wide range of matrix suction but particularly in the high suction range. Thus, compaction, whether at the surface or buried within the profile shows infiltration and/or permeability (O'Neal, 1952).

Entrapped air can retard water infiltration (James et al., 1976). If air is limited in its means of escape, the air pressure build-ups, resulting from initial water adsorption may significantly reduce subsequent infiltration. Large pores are very important in allowing air to escape.

Antecedent soil water content affects both infiltration rates and the advance of the wetted front into soils. Philip (1957) reported that the rate of advance of the wetted front increased, but the rate of infiltration decreased, with increasing soil water content.

Profile stratification can have a major effect on water infiltration and movement. Miller et al. (1962) reported that when a wetting front encounters a material with pore sizes either larger or smaller than that through which the front has moved there is a rapid change in wetted front movement and infiltration. Fine pores underlying large pores will fill immediately when contacted by the wetting front, causing a rapid increase in infiltration until the fine pores are filled. If the pores are extremely fine, the rate of infiltration will soon slow because of the reduced water movement in the small pores. In cases where materials exhibiting fine pores overlies materials exhibiting

large pores, infiltration will slow considerably when the wetted front reaches the large pores. This will continue until the matrix water potential in the materials exhibiting fine pores increases to the point that water can move into the materials exhibiting large pores; the infiltration rate will then immediately increase. In both of the above cases the water retained in the overlying material will be greater than if the profile were not stratified.

Drainage from a soil profile toward a water table is not easily defined. Ligon and Wilson (1972) working with ground water recharge found that deep seepage was the most ambiguous part of their research. They estimated that once the water left the root zone it took between 6 weeks and 6 months to reach a 20 m water table on a Piedmont watershed. Sisson (1972) and Sisson et al. (1980) developed a simple mathematical model for predicting drainage to below some predescribed soil depth. This model is based on the unit gradient approximation and has worked well in several soils. Of course, water movement in deep drainage depends upon most of the soil factors and other phenomena discussed above.

METHODS AND MATERIALS

Site

The East Decker coal mining site encompasses approximately 4 square miles of land east of the Tongue River and the Tongue River Reservoir as shown on the map in Figure 1. Parts of Sections 12, 13, and 14 of R40E, T95, and parts of Sections 7, 8, 17, and 18 of R41E, T95 are included in the mining area. Three streams either touch or run directly through the site. The northern-most and largest drainage is Deer Creek. The mine site lies on the south terrace adjacent to and just above the creek's flood plain. The intermittent southern most drainage is Coal Creek which crosses the site. Intermittent Middle Creek, dubbed so by the researchers, crosses the site and runs between Deer Creek and Coal Creek. All of these creeks run in a northwesterly direction and empty into the Tongue River Reservoir. More detailed information concerning geology and land types is available in EPA Report number R-803727.

Ten research sites were chosen within the proposed mining area. These sites were picked from the local soil series maps superimposed over aerial photos. This information was rated by the apparent acreage abundance within the mining area. The ten soil series selected for study covered approximately 55% of the proposed mining area. The ten sites were topographically distributed so that the total mining area was satisfactorily represented. Estimates of percentage of the total acres represented by the ten sites are given in Table 1.

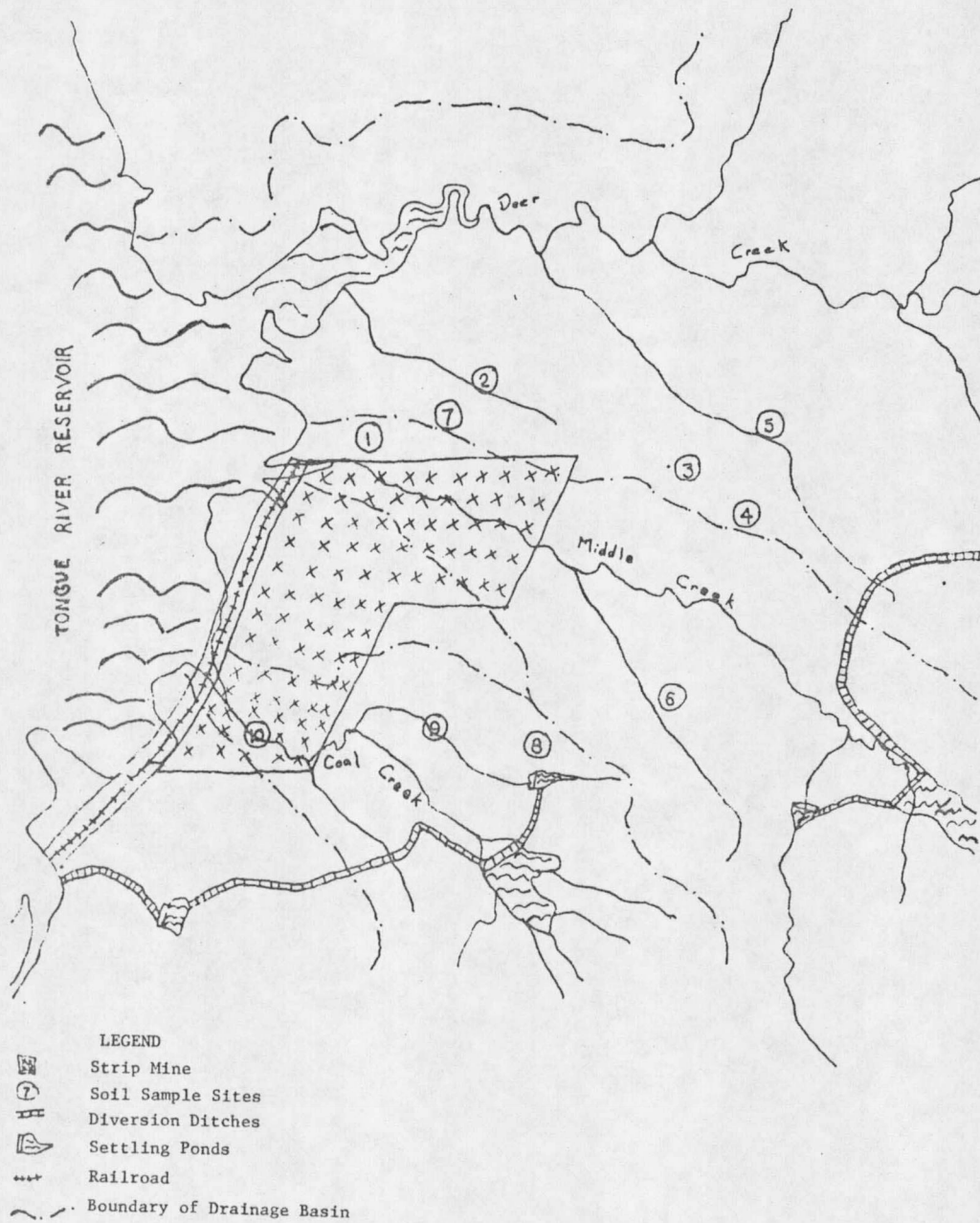


Figure 1. Location of soil sample sites and other mining activities, East Decker Area.

Table 1. The percent of the total study area represented by each of the 10 soil series (sites) studied.

Site	Percent of Soil Series in Study Area
1	4
2	9
3	6
4	7
5	2
6	12
7	5
8	4
9	3
10	3
	<hr/> 55

Approximately 30 percent of the remaining 45 percent of the area consisted of slopes so steep that field infiltration runs could not be conducted. It was estimated that the majority of precipitation falling on these slopes ran off. The remaining portion of the area (about 15 percent) consisted of various combinations of the major series.

Field Sampling

Disturbed soil samples were collected at each site to approximately 250 cm unless profile characteristics such as bedrock (i.e., site 3) interfered. Samples were collected at site 1 with a hydraulic sampler (Giffings) at 25 cm depth increments. At the other sites (2-10) a pit was dug to 250 cm or bedrock. Samples were collected from the pit walls based on profile properties (texture, structure, color) or, if no discernable boundaries were evident, at about 25 cm intervals.

Undisturbed soil cores were obtained by using a modified soil sampling tube that held a "heat-shrink" sleeve. Molding of the heat shrink tubing to fit inside the special king tube was required before samples could be taken. First the tubing was cut into 56 cm lengths, a length which was approximately the length of the tube-holding chamber in the sampling tube. The tubing was then pre-shrunk by placing wooden molds inside the heat shrink tubing. The mold did not allow the outside diameter of the shrink tubing to shrink smaller than the inside diameter of the sampling tube. The oven used for shrinking was set between 600 and 700 C. After shrinking to mold size, the tubing was cooled quickly

with cold running water. The shrink tubing was then separated from the mold. Due to the diagonal split through the length of the wooden mold, as one pushed on one side of the split, the mold was forced to slide along the diagonal surface, and the circumference of the mold decreased, therefore the heat shrink tubing and mold were separated. Paraffin applied to the diagonal surfaces of the mold served as lubrication and decreased friction between the two diagonal pieces.

To collect undisturbed soil samples the sample tube knife was unscrewed and a length of shrink tubing was inserted into the tube chamber. The knife was screwed back onto the sampling tube, the operator carefully observed that the heat shrink tubing abutted the flange just behind the knife's edge. The tube was then connected to the Giddings hydraulic soil sampler and the Giddings hydraulically pushed the tube 56 cm into the soil. By using the same soil sampling hole, it was possible to take samples to a depth of approximately 200 cm, the end of the extender bar, or until the sampling tube hit bedrock. After the soil sample was lifted from the ground, the tube was removed from the Giddings and the knife was unscrewed from the tube. The heat shrink tubing containing the soil sample was then removed from the sampling tube chamber. The soil core at this point was held loosely inside the heat shrink tubing. An electric heater and blower plugged into a gas generator served to shrink the heat shrink tubing snugly against the soil core. Paraffin melted and poured over the ends of the soil core

functioned as a sealant and prevented algae from growing in the pore spaces. The soil sample was thus collected in a sealed, durable mold.

Deep overburden samples and interburden samples were collected at site 7 with a large drill rig. Site 7 was chosen for deep drilling because it was the site of the highest elevation and contained clinker material. With the large drill rig we were able to gather disturbed samples down to shale, core samples from the shale, and core samples from the interburden. However, we were unsuccessful in gathering undisturbed samples deeper than had been previously taken with the Giddings.

Field Water Movement Studies

Since we used a neutron probe to measure changes in soil water content and, thus, soil water movement, a first step was calibration of the neutron probe. Three soil cores were taken to a depth of 75 cm. These cores were split into 15 cm increments, and placed in plastic bags. A neutron access tube was placed in each hole and readings were made at the center of each 15 cm core measurement. A 3.6 x 2.6 m area around the hole was flooded until water had moved at least 75 cm into the profile. The soil sampling and neutron reading process was then repeated. Using water content by weight and bulk densities determined from the soil cores a calibration curve of percent H₂O by volume and the count ratio of neutron reading in the soil/reading in the shield was constructed. The field calibration curve was very similar to the factory calibration curve.

A neutron access tube, plugged at the bottom with a rubber stopper, was inserted at each site to the maximum possible depth. The access tube was cut off approximately 15 cm above the ground level and capped. A dike was constructed around the access tube by digging a 5 cm deep, 3.6 m square trench and placing planks in the trench. A bentonitic soil material shoveled into the trench served as a sealer when the inside of the dike was filled with water. A heavy clay material was also placed around the neutron probe pipe to prevent water from seeping around the edge of the pipe.

Before the site was flooded, an initial neutron probe reading was taken to establish the initial water content throughout the soil profile. This was the dry reading. The following procedure was followed to make neutron probe readings:

1. Five background readings were taken inside the probe canister. These were later averaged to establish the probe standard.
2. The neutron probe was lowered in 15 cm increments to the bottom of the neutron probe pipe.
3. At each 15 cm a reading was taken and the ratio of this reading over the averaged background reading was combined with the calibration curve to determine the soil water content.

After the dry reading was taken, the site was flooded using an 800-gallon tank filled with lake water. Standing water was maintained on the site until either the soil was wet to 122 cm or the water remained on the surface without infiltrating for several days.

The first neutron probe reading after wetting was made within two hours. Neutron probe readings were then made twice a day for ten days following flooding. One reading a day was made for several days following that, then a reading every other day for the rest of the summer.

Montana State University's XDS 7 computer was used to process the data and obtain percent water by volume for each 15 cm of soil, total soil water for each 15 cm depth, cumulative soil water to a particular depth of soil, cm of "plant available" soil water for each 15 cm and cumulative cms of water depleted from each depth. The above information was obtained for each site.

The position or depth of the wetted front was fit to the equation:

$$d = e t^f \quad [1]$$

where: d = depth of wetted front in cm;

t = time in hours after water is applied;

e and f are parameters discussed in The Results and

Discussion section.

This describes the rate of initial infiltration when there is a constant head of water (Nogmousch, 1956). This equation can be linearized with a logarithmic transformation:

$$\log d = \log a + b \log t$$

and the parameters determined.

An equation of the same form describes quantity of infiltration:

$$Q = a t^b \quad [2]$$

where: Q = quantity of water;

t = time;

a and b are parameters discussed in Results and Discussion section.

The data for equations 1 and 2 are extensive and is on file at the Department of Plant and Soils, Montana State University.

A mathematical model developed by Sisson (1972) and Sisson et al. (1980) was used to describe unsaturated water flow and drainage. Two criteria required for successful use of the mathematical model are that no soil restricting layers exist and that a uniform matrix potential exists in the wetted portion of the profile.

The model equation is:

$$W = \alpha x^{\beta+1} t^{-\beta} \quad [3]$$

where: W = total water above depth x ;

x = depth (cm) to which the ψ_m is constant and below the plant root zone (92 cm);

t = time in hours from occurrence of soil water recharge;

and $\alpha+\beta$ = soil parameters.

Work performed by Arnold (1976) modified Sisson's equation setting:

$$R = \alpha x^{\beta+1}$$

obtaining the equation

$$W = R t^{-\beta}$$

which, when written in logarithmic form, becomes linear,

$$\log W = \log R - \beta \log t.$$

Using the water contents, W , as a function of time, t , linear regressions were calculated on each site. The parameters α and β were obtained from these data; knowing these, the rate of leaching (ΔW) could be calculated for any depth at any time.

Laboratory Water Movement Studies

Saturated flow properties of the disturbed soil samples were determined as follows. Plastic pipe (PVC), with 8 cm internal diameter, was cut in about 13 cm sections and a plastic sheet was glued on one end of each section. A small hole was then drilled in the center of the base. A funnel was glued to the base so that liquid flowing through the hole entered the funnel. To prevent soil loss, a screen and filter paper were placed inside the container to cover the hole in the base.

Soil was poured into the containers to a depth of about 5.5 cm. A vibrator held against the side of the PVC soil container served to pack the soil.

The containers were set on a holding rack and a .005 normal solution of CaCl_2 , similar to the Tongue River Reservoir water, was poured

on the soil surface. The funnel was plugged and the soil water solution equilibrated for about 24 hours. After approximately 24 hours, water was allowed to flow through the soil. A constant head of water from a manifold hookup from a 20 liter jar was maintained on the soil. Every few hours the percolate caught in the container below the nozzle of the funnel was measured with a graduated cylinder. The samples were to run until the percolate volume and therefore the rate, reached stability with time. Stability was usually attained between 30 and 60 hours.

The height of the soil and the depth of the head of water was measured. With this information and with the volume of water collected in a known amount of time the hydraulic conductivity in centimeters per hour of water was calculated.

Darcy's equation, which determines water flow velocity, is

$$\frac{Q}{A t} = K \frac{h}{L} = V \quad [4]$$

where: V = Velocity

Q = quantity of water in cm³;

t = time in hours;

K = hydraulic conductivity in cm per hour;

h = sum of water head in cm and soil depth in cm;

L = depth of soil in cm;

A = surface area of soil

and algebraically rearranged becomes (Bauer et al. (1972)

$$K = \frac{Q L}{A t h} \quad [5]$$

The arrangement used to determine the hydraulic conductivity (K) of the undisturbed core was as follows: A hole was bored in the bottom of a 500 ml plastic container with a diameter just larger than the undisturbed soil core. The soil core was inserted into the plastic container about 1 cm. Silicon seal was applied as a sealant and a bonding agent between the plastic container and the heat shrink tubing. The silicon seal proved strong enough to hold the weight of a suspended soil core.

A piece of gauze was wrapped under the bottom of the soil core and held with rubber bands to the heat shrink tubing to hold the soil in place. A small funnel was placed directly under the gauze. Plastic wrap fastened to the heat shrink tubing above the gauze and to the nozzle of the funnel with rubber bands held the funnel in place and prevented water evaporation from the gauze and also from the percolate container. A constant head of water was maintained in the plastic container with a bubbler device on a 500 ml erlenmeyer flask.

After a head of water was applied to the samples and leachate was observed, the samples were left to run from 30 to over 200 hours depending on the rate and stability of water flow. Hydraulic conductivities were determined for each sampling period using the Darcy equation.

Potential Measurements

Soil water contents were measured at saturation, 1/3 bar, and 15 bar on each disturbed sample. This data are used as an indication

of the presence of expanding clays among other things. Water content of the soil samples at 1/3 bar and 15 bars was determined with the pressure membrane equipment (Black et al., 1965). Saturated water content of the soil samples was determined immediately after hydraulic conductivities had been run on the undisturbed soil samples.

Other Laboratory Data

The bulk densities shown in the Results and Discussion were determined by oven drying two cm sections of the undisturbed soil samples which had a known circumference. A mass over volume calculation was then solved (Black et al., 1965).

The textural and chemical data in the Results and Discussion were measured by Dr. M. Klages and are also available in EPA Report number R-803727. Clay mineral analysis and other data pertinent to this thesis were a valuable aide in making drainage determinations and predictions and are available in EPA Report number R-893727.

RESULTS AND DISCUSSION

Soil Surface and Vegetative Characteristics

All sites were located on slopes of less than two percent. Sites 1, 6, and 8 were located on terraces just above the intermittent streams. Sites 2 and 4 were located next to sink areas that held water during the spring. Sites 3, 5, and 9 were near the bottom of small valleys between ridges, the valleys were shallow and water seldom if ever collected in the bottom. Site 7 was located on a ridge top in a clinker area and site 10 was on the flood plain of an intermittent stream that contained water most of the summer. Vegetation encountered on most of the sites was big sagebrush, silver sagebrush, fringed wage wort, green needle grass, needle and thread grass, western wheat grass, glue grama, cheat grass, Indian rice glass, salsify, bluebunch wheatgrass, prickly pear cactus, Japanese brome, and other less dominant species. Sites 3 and 4 were predominantly western wheat grass. Site 10 was nearly a pure stand of western wheat grass.

Soil Series and Soil Profile Characteristics

The soil series and soil classification characteristics gathered by the Decker coal Company for all sites are given in the Appendix (Decker Coal Co., 1976).

The first 13 cm of all the sites were field classified as sandy loam material containing abundant plant litter. Below 13 cm the

similarities ceased to exist. Each site's soil series and soil profile characteristics will be discussed individually.

The series at site 1 is a Keiser silty clay loam and the soil is classified as Ustollic Haplargid fine-silty, mixed, Mesic. Site 1's B horizon was approximately 30 cm thick, contained a significant amount of clay and had a blocky structure. The C horizon between 74 and 123 cm was massive in structure and more clay enriched than the two upper horizons.

Site 2 was located on a Sperlin-Wibaux soil association with a soil classification name of Ustic Torriorthent, coarse-loamy mixed (calcareous), Mesic for Sperlin; and Lithic Ustic Torriorthent, loamy, mixed (calcareous), Mesic for the Wibaux series. Although classified an Entisol, that is, no argillic horizon, there was some evidence of a B horizon with an accumulation of clay and a blocky structure. This horizon was approximately 30 cm thick. The C horizon had a massive structure with approximately the same clay content as above. The entire profile was a bit sandier than the profile on site 1.

Site 3 was located on a Valent-Tullock loamy sand and the classification name is a Ustic Torripsamment, mixed Mesic for both the Valent and Tullock series. This site was located in a depression between two ridges. Decades of slight soil erosion deposited the very fine silts and clays in the bottom of the depression. These silts and clays were

accumulated at depths between 10 and 30 cm and have developed a weak blocky clay to clay loam structure. The structure was massive from 30 to 157 cm. The texture became sandy at 81 cm and bedrock was encountered at 172 cm. This soil profile is not consistent with the mapped soil classification and probably should be designated as a deep soil inclusion.

Site 4 was situated on a Nelson-Tossel sandy loam and the classification name is an Ustic Torriorthent, coarse-loamy-mixed (calcareous), Mesic for the Nelson series and a Ustic Torriorthent, loamy, mixed (calcareous), Mesic, shallow for the Tossle series. This site, similar to site 3, was situated in a depression between two ridges adjacent to a shallow pot hole that collected water in the spring and early summer. The soil profile was dominated with clay from 18 to 125 cm. A weak blocky structure was noticed between 12 and 50 cm. Below 50 cm the soil structure was massive and below 125 cm the soil profile became sandy.

This soil site proved to be in sharp contrast to the mapped soil unit, therefore the profile selected for study should be designated as an inclusion.

Site 5 was located on Nelar loam, the classification for this series is Ustic Torriorthent, coarse-loamy, mixed (calcareous), Mesic. The entire profile on site 5 had a reddish tint. There was a weakly developed B horizon from 13 to 51 cm with a slight accumulation of clay and a very weak prismatic structure. Beyond 51 cm the soil structure

was massive with slight changes in the reddish color. The texture varied little with an increase in the clay content near the bottom of the profile.

Site 6 was located on a Terry-Tossel sandy loam; the classification for the Terry is Ustollic Haplargid, coarse-loamy, mixed, Mesic. The classification name for Tossel is given on Site 4. The B horizon extended from 13 to 48 cm and there was a definite blocky structure with more clay than in the A horizon. From 48 to 107 cm the soil structure became massive. From 107 to 213 cm the soil structure remained massive but there was an increase in sand content. Below 213 cm there was a change in texture with an increase in clay. Considering the amount of clay indicated in the 13 to 107 cm depth this soil profile may be located in a sandy clay loam phase of the Terry-Tossel soil complex.

Site 7 was located on a Sperlin-Wibaux loam; the soil classification name for Sperlin and Wibaux was given on site 2. The entire profile was dominated by sand with slight changes in clay content. From 79 cm to the bottom of the pit the soil profile contained large fractured sandstone rock mixed with very sandy soil.

Site 7 was one of the sites from which deep samples were taken with the split spoon and core drill. From 4.6 meters to 21 meters the soil was rocky and sandy. From 21 meters to 26.7 meters, solid shale was encountered. The coal seam existed from 27 meters to 48 meters. Beyond 48 meters solid shale was again encountered.

Site 8 was located on a Stoneham loam; the soil classification is Ustic Haplargid, fine-loamy, mixed, Mesic. From 13 cm to 53 cm there was evidence of a weak prismatic structure with a very slight increase in clay content compared to the A horizon. The rest of the profile had a massive structure with slight changes in texture; for the most part the soils were sandy. The soil site selected for sampling occurred on a loamy sand to 115 cm where the texture changed to a silty clay loam. The soil profile located on a terrace may have been on a loamy sand phase of the Stoneham series.

Site 9 was situated on an Olney fine sandy loam; the soil classification is Ustollic Haplargid, fine-loamy, mixed, Mesic. The B horizon from 18 to 48 cm had good prismatic structure with clay accumulation. The C horizon had a massive structure and exhibited less clay below 127 cm. There were occasional red streaks on lamellae at 203 cm and 244 cm. At lower depths plant and animal fossils were discovered. Site 9 from 18 to 127 cm exhibited above 50 percent clay. This conflicts with the soil classification given in the survey. The profile excavated for sampling was located on the toe of a small knoll. Here again fine to very fine sediments comprised of silts and clays were probably deposited in the area. Illuviation has occurred and the clays are located below 18 cm.

Site 10 on Aquic Flurent, located on the Coal Creek alluvial floodplain consisted of a coarse, sandy loam on the surface and changed

abruptly to a cobbly sand near 15 cm. The water table was discovered at 203 cm. It was impossible to install the neutron probe in this soil and thus samples were not collected for laboratory analysis.

Sites 3, 4 and 9, which were located on soil inclusions within the designated soils survey; may have lowered the percent of area each soil represented and in turn the total percent of the area represented.

Physical and Chemical Characteristics

The particle size distribution and texture of disturbed samples from the pits are shown in Table 2. In general, the soils are of coarse to medium textures. Exceptions are site 1 which contains approximately 30 percent clay throughout the profile and sites 3, 4 and 9 which contain over 40 percent clay in at least the second sampling depth. This is inconsistent for the classification for 3, 4, and 9; but, it appears that these three sites were located in low spots that had accumulated clay and were not totally representative of their specific soil series.

Chemical characteristics of these same samples are presented in Table 3. None of the values are abnormal for the soils of this area. Sites 1, 2, 4, and 9 have zones that are saline but not highly so and with scattered exceptions the SAR is not higher than 15. The surface layers which are critical for water infiltration do not have a sodium problem at any of the sites.

The bulk densities and water contents at saturation, 1/3 bar, and 15 bars are shown in Table 4. The sample depth increments are different

Table 2. Particle size distribution of the site profiles.

Sample (cm)	Mechanical Analysis					Texture
	Clay	Silt	Total	% Sand		
Coarse				Very Fine		
1						
0- 20	39.4	34.1	36.5	10.6	15.9	CL
20- 46	33.5	29.3	37.2	21.6	15.6	CL
46- 74	34.6	34.8	30.6	16.8	13.8	CL
74- 98	41.9	49.0	9.1	1.6	7.5	SiC
98-123	32.6	41.0	26.4	5.8	20.6	CL
123-148	28.5	37.7	33.8	14.2	19.6	CL
148-173	24.4	36.2	39.4	17.2	22.2	L
173	35.3	38.2	26.5	11.6	14.9	CL
208+	37.4	41.2	21.4	7.0	14.4	CL
2						
0- 15	16.3	23.0	60.7	44.8	15.9	SL
15- 38	18.3	22.6	59.1	43.6	15.5	SL
38- 63	24.4	33.2	42.4	32.8	9.6	L
63- 88	22.8	34.8	42.4	28.4	14.0	L
88-114	22.4	35.2	42.4	28.0	14.4	L
114-139	16.2	62.4	21.4	7.4	14.0	SiL
139-165	22.2	48.9	28.9	11.9	17.0	L
165-190	20.3	56.1	23.6	7.3	16.3	SiL
190-216	18.3	61.7	20.0	4.2	15.8	SiL
216+	16.2	60.7	23.1	1.8	21.3	SiL
3						
0- 10	24.4	37.4	38.2	23.9	14.3	L
10- 30	44.2	28.1	27.7	7.7	20.0	C
30- 55	29.0	28.7	42.3	28.8	13.5	CL
55- 81	26.4	27.8	45.8	32.4	13.4	SCL
81-106	12.2	10.1	77.7	67.3	10.4	SL
106-132	14.2	12.3	73.5	64.0	9.5	SL
132-157	14.2	18.1	67.7	57.4	10.3	SL
4						
0- 12	21.5	32.0	46.5	29.5	17.1	L
18- 40	40.5	31.5	28.0	9.4	18.6	C
50- 75	43.1	35.6	21.2	8.0	13.2	C
75-125	52.3	27.3	20.2	6.2	14.0	C
125-145	25.3	10.8	63.9	51.2	12.7	SCL
145-200	20.1	10.1	69.8	58.5	11.3	SCL
200+	17.6	9.9	72.5	56.1	16.4	SL

Table 2 (continued)

Sample (cm)	Mechanical Analysis					Texture	
	Clay	Silt	Total	% Sand			
				Coarse	Very Fine		
5	0- 13	12.5	20.2	67.3	53.5	13.8	SL
	13- 51	20.2	20.0	59.8	41.8	18.0	SCL
	51-104	20.1	12.6	67.0	51.3	16.0	SCL
	104-132	12.5	7.5	80.0	66.5	13.5	SL
	132-157	20.2	26.0	53.8	28.5	25.3	SCL
	157-183	25.3	28.1	46.6	34.8	11.8	L
	183+	25.2	27.8	47.0	30.8	16.2	SCL
6	9- 12	15.0	27.7	57.3	42.5	14.8	SCL
	12- 48	27.8	27.7	44.5	27.5	17.0	CL
	48-107	25.2	20.1	54.7	40.0	14.7	SCL
	107-132	9.9	7.5	82.6	76.0	6.6	LS
	132-213	20.1	20.1	59.8	55.0	4.8	SCL
	213+	25.2	30.3	44.5	31.5	13.0	L
7	0- 12	9.8	17.8	72.4	64.8	7.6	SL
	12- 45	15.0	10.0	75.0	65.0	10.0	SL
	45- 77	10.3	9.9	79.8	68.8	11.0	SL
	77-117	15.0	15.4	69.6	48.1	21.5	SL
	117-167	10.0	15.6	74.4	53.8	20.6	SL
	167-202	5.0	20.6	75.4	38.8	36.6	LS
	202-220	7.5	15.5	77.0	57.5	19.5	SL
	240+	5.0	12.6	82.4	68.0	14.4	LS
	457-671	2.5	20.1	76.6	64.6	12.0	LS
	762-991	2.5	12.4	80.1	73.1	7.0	LS
8	9- 12	10.0	7.5	82.5	73.3	9.2	LS
	12- 52	10.3	4.7	85.0	76.5	8.5	LS
	52-115	10.0	5.0	85.0	79.0	6.0	LS
	115-142	35.7	49.8	14.5	0.0	14.5	SiCL
	142-172	15.5	17.6	66.9	49.4	17.5	SL
	172	17.5	20.9	61.4	31.9	29.5	SL
	200-217	43.9	46.3	9.8	0.0	9.8	SiC
	217-250	38.7	48.8	12.5	0.0	12.5	SiCL
	250+	41.3	47.0	11.7	0.0	11.7	SiC

Table 2 (continued)

Sample (cm)	Clay	Silt	Mechanical Analysis			Texture
			% Sand			
			Total	Coarse	Very Fine	
9 0- 10	30.4	15.0	54.6	40.0	14.6	SCL
18- 48	52.2	30.9	16.9	0.1	16.8	C
48- 91	52.9	38.4	8.7	0.0	8.7	C
91-127	52.3	42.7	5.0	0.0	5.0	C
127-150	30.7	41.2	28.1	0.1	28.0	CL
150-178	15.3	35.3	49.4	13.4	36.0	L
178-203	31.9	54.3	13.8	6.3	7.5	SiCl
203-244	37.3	58.1	4.6	1.3	3.3	SiCl

Table 3. Chemical properties of the site profiles determined from saturated extracts.

Location	Depth	pH	E.C. mmhos/cm	Sol. cations (me/l)			SAR
				Na	Ca	Mg	
1	0- 20	7.5	.684	1.8	4.2	2.5	1.0
	20- 46	8.3	.608	4.1	1.0	.9	4.2
	46- 74	8.5	2.531	23.3	2.0	4.9	12.5
	74- 98	8.5	5.385	45.1	3.0	24.4	12.2
	98-123	8.1	8.077	53.8	25.8	53.1	8.6
	123-148	8.1	7.538	51.4	25.0	48.8	8.5
	148-173	8.0	7.000	41.6	25.8	38.8	7.3
	173-208	8.1	5.869	38.8	16.2	27.3	8.3
	208-225	8.1	4.900	34.3	11.2	23.6	8.2
2	0- 15	7.8	.668	.9	4.8	1.8	.5
	15- 38	7.8	.786	1.6	5.5	2.6	.8
	38- 63	7.8	5.815	18.0	27.2	58.4	2.8
	63- 88	7.7	8.615	28.8	32.8	78.7	3.9
	88-114	7.6	8.615	20.8	30.0	76.6	2.8
	114-139	7.6	6.838	23.0	24.0	48.0	3.8
	139-165	7.3	7.485	25.0	31.2	69.5	3.5
	165-190	7.2	6.800	29.4	32.4	50.6	4.6
	190-216	7.7	6.462	12.3	28.0	39.8	2.1
216-230	7.8	6.138	17.0	29.0	27.3	3.2	
3	0- 10	6.4	.258	1.9	.5	.7	2.5
	10- 30	7.1	.350	2.9	.8	.6	3.5
	30- 55	7.8	2.510	21.7	4.5	8.0	8.7
	55- 81	8.1	3.554	37.7	4.8	12.4	12.8
	81-106	8.7	1.508	12.3	2.5	3.1	7.4
	106-132	8.7	1.562	20.2	2.5	3.4	11.8
	132-157	8.4	1.430	12.8	1.6	3.6	8.0
	157-170	8.8	1.212	9.1	1.8	2.6	6.1
4	0- 12	6.4	.370	.4	3.6	1.6	.2
	18- 50	7.9	.460	11.2	2.3	5.0	5.9
	50-75	8.2	4.038	24.0	4.5	31.6	5.6
	75-125	8.1	7.030	43.6	20.8	45.3	7.6
	125-145	8.2	7.862	37.0	28.0	90.1	4.8
	145-200	8.5	3.662	28.3	3.5	2.3	16.6
	200-215	8.4	2.690	28.3	2.8	12.3	10.3

Table 3 (continued)

Location	Depth	pH	E.C. mmhos/cm	Sol. cations (me/l)			SAR
				Na	Ca	Mg	
5	0- 13	6.1	.573	.3	4.4	1.2	.2
	13- 51	6.7	.188	1.4	2.2	1.3	.7
	51-104	7.1	.268	.7	1.8	1.1	.6
	104-132	8.2	.431	.6	2.4	1.9	.4
	132-157	8.4	.302	.8	1.2	1.6	.7
	157-183	8.4	.339	1.1	1.2	1.6	.9
	183-200	8.4	.307	1.2	1.4	1.6	1.0
6	0- 12	7.5	.657	.6	4.0	1.3	.4
	12- 48	7.6	.366	.7	2.0	.7	.6
	48-107	8.2	.420	2.3	1.4	1.2	2.0
	107-132	8.7	.765	6.7	.5	.3	10.6
	132-213	8.6	.940	10.2	.1	.5	18.6
	213-230	8.3	2.460	24.9	1.5	1.5	20.3
7	0- 12	7.3	.603	.9	.9	7.4	.4
	12- 45	7.6	.328	.5	.5	4.1	.3
	45- 77	7.9	.226	.3	2.8	.9	.2
	77-117	8.2	.447	.8	2.6	1.6	.6
	117-167	8.2	1.066	9.7	4.4	4.3	4.7
	167-202	8.7	1.020	10.1	3.3	2.1	6.8
	202-220	8.4	1.270	8.1	0.8	2.5	6.3
240-255	8.6	.810	6.3	0.8	2.2	5.1	
8	0- 12	7.4	.420	.4	4.2	.8	.3
	12- 52	8.0	.331	1.9	2.8	.8	1.4
	52- 115	8.1	.312	.3	2.2	1.0	.2
	115-142	8.3	.388	.8	1.6	2.3	.6
	142-172	8.4	.360	1.3	.8	2.0	1.1
	172-200	8.4	.460	3.9	.6	2.4	3.2
	200-217	8.4	.920	4.2	1.2	4.2	2.6
	217-250	8.4	1.400	7.8	1.5	3.4	5.0
	250-265	8.4	1.425	9.8	1.5	3.4	6.3
9	0- 10	6.8	.415	1.0	2.0	.7	.9
	18- 48	7.7	2.477	1.1	30.0	11.1	.2
	48- 91	7.9	4.038	5.0	29.5	10.3	1.1
	91-127	8.0	6.678	17.4	27.0	9.8	4.1
	127-150	8.1	6.010	41.1	12.2	4.4	14.3
	150-178	8.3	4.070	34.5	3.8	18.1	10.4
	178-203	8.2	3.800	36.6	3.3	18.1	11.2
	203-244	8.2	3.700	38.5	3.6	18.1	11.7

Table 4. Physical properties of site samples.

Site	Depth (cm)	Bulk Density	% Saturation (cm ³ /cm ³)	% 1/3 Bar (cm ³ /cm ³)	% 15 Bar (cm ³ /cm ³)
1	0- 30.5	1.45	38.33	30.30	18.85
	30.5- 50.0	1.47	41.50	29.65	20.10
	50.0- 76.0	1.32	44.50	34.65	19.14
	76.2-105	1.39	38.67	42.40	19.81
	105-130	1.37	49.50	33.57	15.07
	130-160	1.48	43.50	34.04	20.72
	160-188	1.49	40.00	33.53	17.88
2	0-30.5	1.22	51.00	31.72	14.40
	30.5- 60	1.38	46.60	30.71	11.39
	60 - 82	1.46	42.00	21.90	9.01
	82 -105	1.52	40.00	33.94	11.90
	105-137	1.46	38.67	25.30	8.28
	137-160	1.61	37.00	31.40	9.39
	160-190	1.58	39.00	30.54	13.95
190-205	1.73	20.0	33.74	15.57	
3	0-30.5	1.34	67.13	43.89	31.16
	30.5- 50	1.48	42.00	36.75	23.43
	50 - 78	1.50	39.67	30.50	15.00
	78 -101	1.48	39.00	21.09	9.99
	101-130	1.35	44.67	26.33	10.35
	130-150	1.21	54.00	21.48	9.08
4	0-30.5	1.38	59.34	48.65	27.95
	30.5-55	1.38	52.44	37.72	21.16
	55-80	1.49	53.64	48.67	27.32
	80-110	1.44	41.33	27.36	15.60
	110-138	1.62	33.67	25.38	14.58
	138-165	1.65	32.00	26.40	15.68
	165-185	1.61	29.50	25.36	16.50
	185-203	1.69	43.09	29.58	20.28
5	0-30.5	1.52	40.00	21.78	8.36
	30.5- 55	1.61	37.00	20.93	14.89
	55 - 80	1.58	37.33	21.60	13.95
	80-110	1.59	36.00	18.56	10.87
	110-137	1.56	39.50	18.72	8.97
	137- 165	-	-	-	-
	165-195	1.60	35.50	27.47	12.27
	195- 220	1.73	29.00	21.33	12.98

Table 4 (continued)

Site	Depth (cm)	Bulk Density	% Saturation (cm ³ /cm ³)	% 1/3 Bar (cm ³ /cm ³)	% 15 Bar (cm ³ /cm ³)
6	0-30.5	1.36	37.67	28.56	19.95
	30.5-55	1.52	36.50	25.66	13.30
	55-76	1.58	34.5	27.26	14.62
	76-100	1.51	38.00	21.14	9.44
	100-140	1.54	35.00	16.94	7.70
	140-160	1.46	38.50	25.19	18.25
	160-180	1.34	38.00	26.13	13.74
	180-215	1.45	38.67	22.48	7.98
7	0-30.5	1.45	40.00	18.13	10.15
	30.5-50	1.44	39.00	19.68	10.80
	50-76	1.46	39.00	19.47	10.95
	76-105	1.39	40.00	28.26	11.12
	105-130	1.33	43.67	21.28	7.09
	130-157	1.48	40.00	18.50	8.88
	157-190	-	-	-	-
8	0-30.5	1.51	39.00	13.09	8.05
	30.5-56	1.54	39.67	14.63	8.98
	56-85	1.59	35.00	12.72	5.57
	85-100	1.57	39.00	12.56	7.07
	110-137	1.53	43.18	35.45	17.85
	137-160	1.64	41.00	34.17	16.95
	160-190	1.56	35.00	24.18	8.58
	190-222	1.73	39.79	42.82	28.98
9	0-30.5	1.42	41.00	32.00	-
	30.5-55	1.43	40.00	28.84	16.20
	55-76	1.57	39.00	29.83	18.06
	76-107	1.61	47.49	41.06	21.74
	107-137	1.75	44.60	39.08	20.13
	137-160	1.75	47.25	43.75	25.38
	160-190	1.81	39.82	35.75	19.91
	190-215	1.80	57.60	41.63	28.35

in Table 4 from those in Tables 2 and 3. The samples of Table 4 were obtained in a soil tube in order to obtain bulk densities whereas those in Tables 2 and 3 are disturbed samples taken on the basis of some visual profile characteristics. The tube samples were obtained in 30 cm increments which resulted in inaccurate horizon splitting.

The bulk densities are normal for productive soils of the area. Bulk densities above about 1.7 to 1.8 grams per cubic centimeter may retard root growth; our experience with natural soil peds of this range of bulk densities indicates most of the root growth is between peds (Brady, 1974). Except for site 9, bulk densities of over 1.7 grams per cubic centimeter were obtained from below 190 cm which is below the major rooting zone.

The water holding characteristics corresponded very well to the textures. Samples from sites 3, 4, and 9 that were classified as clay held considerably more water at the three potentials than did other samples. The surface 30 cm sample of sites 3 and 4 and the lower depth from site 9 are unusual in that the saturation percentage is much higher than other samples. These data indicate that the clays of this zone tend to be of the swelling type which would restrict water movement and infiltration. Data in EPA Report number R-893727 shows swelling clay contents in equal and greater amounts throughout the study area, therefore, some other soil characteristic (perhaps clay particle size) is causing an impermeable soil layer on sites 3, 4, and 9.

Water Infiltration

The parameters of the infiltration equations (equations 1 and 2) describing quantity of water entering the soil and depth of movement as a function of time are shown in Table 5 and 6.

The depth-time data (Table 5) are subject to considerable error since it is difficult to define the exact depth of a moving wetting front with the neutron equipment. Also, in those soils with very rapid water movement, sites 2 and 8, the coefficients were determined from only 3 to 4 data points. The method does, however, show differences (and similarities) between sites. The magnitude of the f parameter signifies the rate at which the water initially moved into the soil. The magnitude of the e parameter is an indication of early water movement; uniform soils with large pores should have a large e . This is generally true, sites 2, 5, 6, 7, and 8 tend to be sandy. The e of 3 and 4 is small, indicating restricted water entry into the soil; these two sites contain considerable clay in the top 30 cm and also had the high saturation percentages indicating swelling clays. The e values of sites 1 and 9 are intermediate. These two sites contained considerable clay in the surface 30 cm but did not have the high saturation percentage of sites 3 and 4. Thus, the early infiltration estimate (parameter e) corresponds well with the texture and saturation percentage data. Sites 3 and 4 did not become wet during the infiltration process below about

Table 5. Parameters for the equation $d = e t^f$, relating depth of infiltrating water as a function of time. As can be seen from the equation, e is the intercept at a very short time, f is the slope of the line and R^2 is an indication of the goodness of fit, and DM is the depth of water movement in the infiltration phase.

Site	e	f	R^2	DM-CM
1	32.7	.267	.876	135
2	61.4	.285	.970	>240
3	14.9	.282	.893	45
4	7.9	.314	.481	30
5	111.4	.184	.944	>240
6	62.7	.289	.892	>240
7	55.8	.671	.979	>180
8	92.4	.476	.990	>240
9	21.5	.369	.904	>165

Table 6. Parameters for the equation $Q = a t^b$, relating the quantity of infiltrated water as a function of time. As can be seen from the equation, a is the intercept at a very short time, b is the slope of the line, and R^2 is an indication of the goodness of fit.

Site	A	B	R^2
1	6.677	.265	.895
2	14.081	.286	.925
3	1.216	.403	.822
4	442	.670	.573
5	18.945	.205	.857
6	4.502	.479	.951
7	10.927	.689	1.00
8	22.243	.576	1.00
9	2.804	.303	.489

30 and 45 cm, respectively. Certainly water entering these two soils is not transmitted readily toward a groundwater table.

Parameters describing the quantity of water, as estimated from the neutron data, entering the soil as a function of time are shown in Table 6. Again, in those sites with very rapid infiltration where water reached to the bottom of the neutron access tube in a short time the parameters are based on limited data points. The magnitude of b signifies the early rate of water accumulation. The magnitude of a is an indication of early quantity of infiltration. Sites 2, 5, 7, and 8 infiltrated a very significant quantity of water in a very short time. The surface zone of sites 3, 4, and 9 restricted early water entry. In those cases where depth of water penetration was not so rapid that only a few data points were obtained, the fit of the data, R^2 , can be useful in describing water movement in the system. In deep, uniform, non-swelling soils the equation will, characteristically, fit obtained Quantity-time data very well; i.e., an R^2 greater than .90. Quantity-time infiltration data that do not have a high R^2 generally indicate lateral rather than vertical movement or swelling clays. Sites 3, 4, 9, and perhaps 5 have R^2 's of less than about .9. The restricting tendencies of 3 and 4 have been previously discussed; the saturation percentage of site 9 does not indicate swelling clay in the upper part of the profile, but the high clay content in the profile might result in lateral rather than vertical movement. In site 5 the very sandy

layer at about 100 cm might well have resulted in data not fitting the equation; but, downward water movement should not be permanently restricted in this profile.

Based on the infiltration data in Table 6 for Q and t as a function of time, considering both the parameters and the fit of the data, one would not expect sites 3, 4, and 9 to transmit significant water toward the water table. Water applied to sites 2, 5, 7, and 8 would be expected to move relatively rapidly toward the groundwater; in these sites movement is rapid enough so that a considerable amount of added water might escape below the root zone even during active plant transpiration. Water added at sites 1 and 6 would move beyond the root zone given time, but if added during active plant growth, it might be transpired before it could move below the root zone.

Profile Drainage

Parameters for equation 3 on Table 7 describing the unsaturated drainage from the "root zone" are given in Table 7. Since sites 3 and 4 did not wet during infiltration below about 40 cm, no drainage occurred at these sites. The drainage data were obtained over a period of about two months, thus these parameters are based on many data points. It is difficult to specify an acceptable R^2 in these data; perhaps an R^2 of .60 or above is adequate to give confidence in use of the parameters for prediction purposes. A low R^2 may indicate one of several possibilities:

Table 7. Parameters of the drainage equation $w = \alpha x^{\beta+1} t^{-\beta}$ for selected profile depths.

Site	α	β	R^2
1- 90cm	.363	.0277	.711
-105cm	.350	.0269	.684
-120cm	.337	.0156	.384
2- 90cm	.364	.053	.897
-105cm	.365	.050	.885
-120cm	.363	.046	.877
5- 90cm	.320	.012	.463
-105cm	.319	.018	.757
-120cm	.317	.021	.784
6- 90cm	.324	.018	.512
105cm	.327	.018	.586
120cm	.325	.020	.666
135cm	.322	.024	.744
7- 90cm	.264	.097	.862
-105cm	.261	.098	.895
-120cm	.259	.101	.917
-135cm	.255	.103	.933
8- 90cm	.225	.059	.845
-105cm	.221	.068	.947
-120cm	.220	.080	.928
-135cm	.223	.091	.929
9- 90cm	.361	.017	.577
-105cm	.358	.019	.610
-120cm	.357	.019	.579

1) the assumption of a unit gradient is not valid; 2) horizontal rather than vertical water drainage; 3) no drainage below a depth because of an impermeable horizon, or; 4) marked profile textural differences that make the drainage process very complex.

The relatively uniform profiles of sites 2, 7, and 8 showed high R^2 indicating that the assumptions for application of the drainage equation were met. The R^2 for sites 5, 6, and 9 were considerably lower. The textural horizon variations at these sites was significant and the drainage process was undoubtedly complex. At these sites the assumptions of the drainage equation were not well met. However, reasonable estimates of the quantity of water drainage to below the depths shown can (in my opinion) be made with the parameters. The very low R^2 for the 120 cm depth of site 1 is difficult to explain. The textural variation within the profile was not unusual. However, the saturated water content (Table 3) of the 105 to 130 cm depth was higher than normal. EPA Report number R-803727 shows that swelling clays dominate the area, therefore, downward water movement was prevented and this resulted in very slow drainage or lateral water movement. The fact that the SAR in about the 90 cm depth at this site is relatively high (about 12.0) supports this supposition.

The magnitude of the alpha parameter is a relative estimate of the very early drainage after infiltration ceases, or, conversely, no quantity of water retained when infiltration ceases and drainage starts.

The α values shown are significantly less at sites 7 and 8 than the other sites. This should be expected considering the sandy texture and low water holding capacity of these sites.

The magnitude of beta (β) provides a relative estimate of the rate of long drainage; the higher this number the more rapid is drainage from this profile. Sites 7 and 8 have very high values indicating that water collected in the profile during infiltration would quickly drain to below the root zone. Site 2 has moderately high β values. The β values of the other sites are in the 0.010 to 0.030 range indicating relatively slow drainage.

The drainage equation number 3 is exponential in form. Thus, most of the drainage occurs early after the profile is filled. At sites 7, 8 and 2 most of the drainage would occur in a very short time period; infiltrating water would probably escape to beyond the root zone even in the presence of growing plants. These three sites would be expected to transmit significant quantities of water toward the water table any time that infiltrating water reached the depths shown. Drainage is significantly slower at the other sites. During long periods with little evapotranspiration these sites, with the exception of sites 1, 3 and 4, would contribute significant quantities of water to deep drainage. However, the relatively slow drainage from these sites would allow much of the water to be transpired if water were added during active plant growth. Site 1 does drain but, based on the previous discussion,

it appears that drainage is very slow and is probably dominated by lateral movement at about the 120 cm depth. It is unlikely that significant water infiltrating this site moves towards a water table.

Laboratory Water Flow Analysis

K of equation 5 describes the rate of saturated water flow through a soil. Pore size is the most important soil property controlling K. Thus K is highly dependent upon texture and the tendency of the soil to swell and, thus, reduce pore size. Hydraulic conductivities (K) of samples from the study area are shown in Tables 8 and 9. Table 10 provides a set of general standards by Smith and Browning (1946) for saturated hydraulic conductivity. It must be noted that even with the very slow class, i.e., $K = 0.01$ cm/hr, over a long period of time a great deal of water can be moved.

Table 8 shows the hydraulic conductivities for disturbed samples collected in the field on the basis of visual profile characteristics. Table 9 shows the undisturbed soil hydraulic conductivities which were collected in a soil tube where each sample was limited to approximately 20 to 30 cm.

The disturbed K's are largely a function of texture. The undisturbed saturated flow is a function of natural structure in addition to texture and swelling. Natural structure might be very dense with only

Table 8. Hydraulic conductivities of disturbed samples collected from the field sites.

Depth (cm)	K(cm/hr)	Depth (cm)	K(cm/hr)
<u>Site 1</u>		<u>Site 2</u>	
0- 20	2.06	0- 15	15.0
20- 46	.148	15- 38	4.09
46- 74	.0942	38- 64	.186
74- 99	.090	64- 89	.115
99-124	.263	89-114	.378
124-150	.104	114-140	.171
150-175	.870	140-165	.152
175-208	.0557	165-190	.249
208+	.538	190-216	.105
<u>Site 3</u>		<u>Site 4</u>	
0- 10	.0825	0- 13	.68
10- 30	.0367	18- 51	.310
30- 56	.452	51- 76	.199
56- 81	.133	76-127	.389
81-107	4.99	127-147	8.59
107-132	6.30	147-203	10.5
132-157	6.97	203+	10.4
157+	13.0		
<u>Site 5</u>		<u>Site 6</u>	
0- 11	8.31	0- 13	1.28
13- 51	20.8	13- 48	.951
51-104	4.80	48-107	2.61
104-132	16.6	107-132	35.2
132-157	3.57	132-213	1.77
157-183	2.9	213+	.0508
183+	4.76		

Table 8 (continued)

Depth (cm)	K(cm/hr)	Depth (cm)	K(cm/hr)
<u>Site 7</u>		(meters) <u>Site 7 -Deep Samples</u>	
0-13	8.11	4.6- 6.7	7.87
13- 46	16.8	7.6- 9.9	7.56
46- 79	13.7	12.2-14.9	1.61
79-119	1.85	18.3-21	1.44
119-170	4.31	*26.5-26.7	.0348
170-206	20.5	*48.6-48.8	.0025
206-244	4.0	*49.4	.000714
244+	26.2		
<u>Site 8</u>		(cm)	<u>Site 9</u>
0- 13	6.41	0- 10	2.88
13- 53	17.7	18- 48	2.46
53-117	11.0	48- 91	.588
117-145	.333	91-127	1.57
145-175	13.7	127-150	1.13
175-203	2.53	150-178	2.02
203-220	.120	178-203	.146
220-255	.241	203-244	.0272
255+	.296		

*Shale.

Table 9. Haudraulic conductivities of undisturbed samples obtained from each site.

Depth (cm)	K(cm/hr)	Depth (cm)	K(cm/hr)	Depth (cm)	K(cm/hr)
<u>Site 1</u>		<u>Site 4</u>		<u>Site 7</u>	
0- 31	.72	0- 31	.007	0- 31	8.22
31- 52	.61	31- 56	.11	31- 50	5.81
53- 76	.04	56- 82	.08	50- 76	4.24
76-104	.08	82-110	.10	76-104	2.99
104-132	.90	110-139	.22	104-130	3.76
132-152	.17	139-166	.15	130-157	5.39
152-168	.32	166-203	.07	157-193	.83
168-188	.19				
<u>Site 2</u>		<u>Site 5</u>		<u>Site 8</u>	
0- 31	8.09	0- 31	6.61	0- 31	13.24
31- 26	3.88	31- 57	4.95	31- 56	12.61
61- 81	.87	57- 76	2.03	56- 85	23.11
81-107	.39	76-110	1.80	85-110	12.84
107-137	.41	110-137	2.68	110-137	2.20
137-163	.13	137-165	.55	137-164	.45
163-190	.05	165-195	.60	164-190	.17
190-206	.0006	195-221	.39	190-223	.01
<u>Site 3</u>		<u>Site 6</u>		<u>Site 9</u>	
0- 31	.04	0- 31	4.26	0- 31	.02
31- 56	.04	31- 56	2.56	31- 54	.39
56- 79	.48	56- 76	.23	54- 76	.05
79-102	2.16	76-105	1.47	76-107	.03
102-130	1.64	105-140	2.89	107-137	.007
130-155	5.37	140-160	.14	137-162	.004
		160-180	.14	162-190	.005
		180-216	3.11	190-218	.001
				229-262	.000

Table 10. Permeability classes of Smith and Browning (1946) for saturated subsoils

Class	Hydraulic Conductivity K, cm/hr	Comments
Extremely slow	0.00254	So nearly impervious that leaching process is insignificant.
Very slow	.00254 - .0254	Poor drainage results in staining; too slow for artificial drainage.
Slow	.0254 - .254	Too slow for favorable air-water relations and for deep root development.
Moderate	.254 - 2.54	Adequate permeability
Rapid	2.54 - 25.4	Excellent water holding relations as well as excellent permeability
Very rapid	25.4 +	Associated with poor water holding conditions.

many small pores and thus have a low K. Or, it might contain many large pores and cracks and thus have high K.

In general, the data of Tables 8 and 9 correspond nicely with the textural data of Table 2. Sites 7 and 8 are sandy and have rapid permeability. Sites 2, 5 and 6 are generally medium textured and have moderate permeability. Sites 3, 4, and 9 have clay layers at various depths and these zones have low permeability. The silty clay zone in site 1 has low saturated permeability. In general, the clay content at all locations except 3, 4, and 7 increases with depth and the saturated hydraulic conductivity decreases with depth. Sites 3 and 4 become more permeable with depth but this matters little because of the low permeability at the surface.

There are many significant relative differences between the disturbed and undisturbed permeability data. Perhaps the most striking is the indicated relatively high permeability of the disturbed samples of sites 4 and 9. Apparently the grinding of these samples resulted in high permeabilities. Undisturbed samples are difficult to obtain, but with soils high in clay, undisturbed samples may not give even an indication of the hydraulic conductivity. In these soils, natural field structure is very important in determining water movement; when this structure is destroyed water flow is increased.

At site 7 deep soil samples were obtained at depths from 4 to 49 meters. In the 4 to 21 meters range hydraulic conductivities were

fast. When shale was encountered at 26 meters, the hydraulic conductivities decreased to the very slow range and eventually to the extremely slow range at 48 meters, below the coal seam.

On contact with the shale layer at 26 meters the soil water probably begins to move in a lateral direction. One could assume that the top of the shale layer supports a water table at some point along the geological shale formation.

Hydraulic conductivity tests run on each soil increment for all sites, with the exception of certain levels or horizons in sites 4 and 9, supports the field drainage data and the physical and chemical data gathered on the same locations. Sites 4 and 9 presented conflicting data between disturbed and undisturbed hydraulic conductivities, but when compared with other recorded evidence, the undisturbed conductivities seem correct and the disturbed conductivities look either in error, or soil disturbance may significantly increase hydraulic conductivities.

SUMMARY AND CONCLUSIONS

A study was initiated in May, 1976, on the site of the future East Decker Mine near Decker, Montana to measure and determine soil water movement in natural soils. Sites were chosen to reflect common geomorphic land types in the field. These included ridge tops terraces, depressions, and floodplains.

Mathematical models were used to describe the rate of infiltration, the quantity of water infiltrated as a function of time, and the unsaturated soil water movement through the soil profile. Although the depth-time, and quantity-time data exhibited considerable error, those sites (2, 5, 7, and 8) with large pores and uniform soils indicated early water movement and those sites (1,3,4, and 9) with constricting soil layers (evidence of considerable clay) indicated restricted water entry. Similarly, the parameters describing the quantity of water entering the soil profile indicated significant amounts of water in those sites (2, 5, 7, and 8) that did not restrict water entry.

Profile drainage was shown to occur readily on sites 2, 7, and 8 where water could easily pass to the groundwater table. On sites 5, 6, and 9 where textural differences in the soil profile and evidence of expanding clays indicated water restriction, profile drainage was reduced. These sites could contribute to the groundwater table during long periods with little evapotranspiration. Sites 1, 3, and 4 exhibited

such restrictive water entry that no drainage occurred at these sites. Further study was needed to determine the reason for the restricted or impermeable soil layers.

It is unlikely that water movement through the profile is a major source of water in the coal seam and this is because of a variety of reasons which are:

1. The deep sample on site 7 showed a shale layer over the coal seam that was virtually impermeable which could encourage lateral water movement.
2. Soils in the depressions or valleys tended to have low water transmission properties.
3. The uplands which exhibited high transmission properties did not collect enough water to pass the root zone.

The only time water is likely to reach the coal seam is during periods of a heavy precipitation and water can drain through the upland soils.

The deepsoil samples taken on site 7 showed a shale layer immediately above and below the coal seam (26 and 48 meters, respectively). The impermeability of the shales shown by the hydraulic conductivities probably stopped all water movement.

In the laboratory hydraulic conductivities were run on disturbed and undisturbed soil samples. The results supported the field infiltration and drainage findings and each profile's soil physical and chemical characteristics. The disturbed hydraulic conductivities also displayed

faster permeabilities through the clay zones in the soil profiles than the undisturbed hydraulic conductivities. The scale of soil particle size ranges created by mining compared to those created by the laboratory are different, but in either case the structure is destroyed and the textures are mixed and the result enhances water movement.

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APPENDIX

Site 1

Soil: Keiser silty clay loam

Classification: Ustallic Haplargid - fine - silty, mixed Mesic family.

Location: 1225'S, 25'W. NE Corner Sc. 17 T9S R40E

Profile description:

- A₁ 0-1" Light brownish gray (10yr6/2 when dry) heavy silt loam; dark grayish brown (10yr4/2 when moist); vesicular fine platy structure; soft when dry; very friable when moist; slightly sticky and slightly plastic when wet; many unstained sand grains.
- B₂₁^t 1-7" Brown (10yr5/3 with 5/2 coats when dry) heavy silty clay loam; dark brown (10yr4/3 with 3/2 coats when moist); strong fine and medium prismatic separating easily to strong fine blocks; very hard when dry; friable when moist; sticky and plastic when wet.
- B₂₂^t 7-10" Brown (10yr5/3 when dry) silty clay loam; dark brown (10yr4/3 when moist); strong medium prismatic structure separating easily to strong fine blocks; very hard when dry, very friable when moist; sticky and plastic when wet; moderate effervescence.
- B₃^{ca} 10-22" Light olive brown (2.5y5/4 when dry) silty clay loam; olive brown (2.5y4/4 when moist); moderate medium prismatic structure separating to strong fine blocks; very hard when dry; very friable when moist; slightly sticky and slightly

plastic when wet; strong effervescence with a few soft masses of segregated lime.

- C₁ca 22-30" Light olive brown (2.5y5/4 when dry) heavy silt loam; a few thin strata of loam and light silty clay loam; olive brown (2.5y4/4 when moist); weak coarse prismatic structure; hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; strong effervescence with a few seams of lime and gypsum.
- C₂cs 30-46" Light olive brown (2.5y5/3 when dry) silt loam; loam and light silty clay loam stratified; olive brown (2.5y4/4 when moist); hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; moderate effervescence; few seams of gypsum.
- C₃ 46-66" Light yellowish brown (2.5y5/3 when dry) silt loam; light silty clay loam and loam stratified; olive brown (2.5y4/4 when moist); hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; moderate effervescence; few seams of gypsum.
- C₄cs 66-84" Light yellowish brown (2.5y5/3 when dry) silt loam and silty clay loam stratified; olive brown (2.5y4/4 when moist); hard to very hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; moderate effervescence; few seams of gypsum.

C₅cs 84-102" Light yellowish brown (2.5y6/3 when dry) clay loam; light olive brown (2.5y5/4 when moist); massive; very hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; moderate effervescence; few seams of gypsum.

Site 2

Soil: Sperlin loam

Classification: Ustic torriorthents - coarse - loamy, mixed
(calcareous) Mesic

Mapping Unit: Sperlin-Wibaux loams

Location: 150'S, 150'E, W¼ Corner, Sec. 7 T9S R41E

Profile Description:

- A₁₁ 0-2" Reddish brown (5yr5/4 when dry) light loam; dark reddish brown (5yr3/4 when moist); weak fine granular structure; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet;
- A₁₂ 2-8" Reddish brown (5yr4/4 when dry) light loam; dark reddish brown (5yr3/4 when moist); weak medium and coarse prismatic structure separating to weak fine and medium subangular blocks; slightly hard when dry; very friable when moist; slightly sticky and nonplastic.
- C_{1ca} 8-18" Reddish brown (5yr5/4 when dry) light loam; reddish brown (5yr4/4 when moist); weak medium and coarse prismatic structure; separating to weak subangular blocks; slightly hard when dry; very friable when moist; slightly sticky and nonplastic when wet; very strong effervescence with a few seams of lime.

- C₂₁a 18-30" Light brown (7.5yr6/4 when dry) light loam; reddish brown (5yr5/4 when moist); massive; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet; very strong effervescence; few weathered sandstone fragments.
- C₃ 30-36" Light brown (7.5yr6/4 when dry) fine sandy loam; reddish brown (5yr5/4 when moist); massive; soft when dry; very friable when moist; nonsticky and nonplastic when wet; very strong effervescence; few sandstone fragments.
- R Hard baked sandstone.

Site 3

Soil: Valent loamy sand

Classification: Ustic torripsamments - mixed, Mesic.

Mapping Unit: Valent-Tullock loamy sands

Location: 170'W, 65'N, Center Sec. 12 T9S R40E

Profile Description:

- A₁ 0-8" Grayish brown (10yr5/2 when dry) loamy sand; dark brown (10yr3/3 when moist); single-grain; loose; nonsticky and nonplastic.
- A_C 8-18" Grayish brown (10yr5/2 when dry) loamy sand; dark brown (10yr4/3 when moist); single-grain; loose; nonsticky and nonplastic.
- C₁ 18-30" Yellowish brown (10yr5/6 when dry) loamy sand; dark yellowish brown (10yr4/6 when moist); soft, very friable, nonsticky and nonplastic.
- C₂ 30-60" Light olive brown (2.5y5/4 when dry) light loamy sand, or sand; olive brown (2.5y4/4 when moist); soft, very friable, nonsticky and nonplastic; some resistance to auger. Probably strongly weathered weakly consolidated sandstone.

Site 4

Series: Nelson fine sandy loam

Classification: Ustic Torriorthents-coarse-loamy, mixed (calcareous)
Mesic family.

Location: Sec 9 T9S R40E about 900 feet north and 1000 feet east
of SE corner.

Profile Description:

A₁₁ 0-2¹/₂" Dark brown (10yr4/3) loamy fine sand; very dark grayish brown (10yr3/2 when moist); loose, very friable, nonsticky, and slightly plastic; clear, smooth boundary.

A₁₂ 2-10" Dark brown (10yr4/3) loamy fine sand; dark brown (10yr3/3 when moist); slightly hard, friable, slightly sticky and slightly plastic; clear, wavy boundary.

C₁ 10-17" Pale brown (10yr6/3) light sandy clay loam; brown (10yr5/3 when moist); hard, friable, slightly sticky and plastic; slightly effervescent; gradual, wavy boundary.

C_{2ca} 17-24" Pale brown (10yr6/3) loamy fine sand; brown (10yr5/3 when moist); hard, friable, slightly sticky and slightly plastic; strongly effervescent; common, fine lime mottles; abrupt, wavy boundary.

C 24+" Sandstone.

Common fine roots penetrate to the bedrock.

Site 5

Soil: Nelar loam

Classification: Ustic torriorthents coarse - loamy, mixed (calcareous)
Mesic.

Mapping Unit: Nelar loam

Location: 100'S, 100'E, Center Sec. 7 T9S R41E

Profile Description:

- A₁ 0-8" Reddish brown (5yr4/4 when dry) light loam; dark reddish brown (5yr3/4 when moist); moderate fine and very fine granular structure; soft when dry; very friable when moist; nonsticky and nonplastic when wet; few flat fragments.
- C_{1ca} 8-30" Light reddish brown (5yr6/3 when dry) light loam; reddish brown (5yr4/3 when moist); weak coarse prismatic structure; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet; very strong effervescence with a few threads of lime; few lime coated angular fragments.
- C₂ 30-40" Reddish brown (5yr5/4 when dry) light loam and fine sandy loam; reddish brown (5yr4/4 when moist); massive; soft when dry; very friable when moist; nonsticky and nonplastic when wet; strong effervescence; few lime coated angular fragments.

C₃ 40-60" Red (2.5yr5/5 when dry) light loam and fine sandy loam; reddish brown (2.5yr4/4 when moist); massive; soft when dry; very friable when moist; nonsticky and nonplastic when wet; about 5 percent by volume of fine angular sandstone and scoria fragments.

Site 6

Soil: Terry sandy loam

Classification: Ustalic Haplargids - coarse - loamy, mixed, Mesic

Mapping Unit: Terry-tassel sandy loams

Location: 1000'S, 390'W, N¼ corner Sec 12 T9S R40E

Profile Description:

A₁ 0-8" Grayish brown (10yr5/2 when dry) light sandy loam; dark brown (10yr3/3 when moist); single-grained; loose when dry and moist; nonsticky and nonplastic when wet.

B₂ 8-20" Yellowish brown (10yr5/4 when dry) sandy loam; dark yellowish brown (10yr4/4 when moist); moderate coarse prismatic structure; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet.

B₃ 20-24" Olive yellow (2.5y6/5 when dry) sandy loam; light olive brown (2.5y5/5 when moist); weak coarse prismatic structure; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet.

C_{1ca} 24-30" Olive yellow, weakly consolidated sandstone bedrock.

Site 7

Soil: Sperlin gravelly loam

Classification: Ustic torriorthents - coarse - loamy, mixed
(Calcareous) Mesic.

Mapping Unit: Sperlin - Wibaux gravelly loams

Location: 730'N, 1035' W, E $\frac{1}{4}$ Corner, Sec 12 T9S R40E

Profile Description:

- A₁ 0-4th Reddish brown (5yr5/3 when dry) light loam; dark reddish brown (5yr3/3 when moist); weak fine granular structure; soft when dry; very friable when moist; nonsticky and nonplastic when wet; 5 percent by volume fine angular sandstone and scoria fragments in mass but about 40 percent of surface covered by fragments.
- C₁ 4-20" Reddish brown (5yr5/4 when dry) light loam; reddish brown (5yr4/4 when moist); massive; soft when dry; very friable when moist; nonsticky and nonplastic when wet; about 5 percent lime coated fragments; strong effervescence.
- C₂ 20-32" Light reddish brown (5yr6/3 when dry) light loam or fine sandy loam; reddish brown (5yr4/4 when moist); massive soft when dry; very friable when moist; nonsticky and nonplastic when wet; about 10 percent by volume small lime coated angular sandstone fragments; strong effervesence.
- R 38"+ Hard, baked sandstone which is shattered in upper part.

Site 8

Soil: Stoneham loam

Classification: Ustollic Haplargid - fine - loamy, mixed, Mesic.

Mapping Unit: Stoneham loam

Location: 550'N, 135'W, SE Corner Sec 12 T9S R40E

Profile Description:

- A_p 0-4" Grayish brown (10yr5/2 when dry) loam; dark grayish brown (10yr4/2 when dry); moderate fine and medium granular structure; slightly hard when dry; very friable when moist; slightly sticky and slightly plastic when wet.
- B₁ 4-6" Grayish brown (10yr5/2 when dry) heavy loam; dark grayish brown (10yr4/2 when moist); moderate medium prismatic structure separating to moderate fine and medium blocks; hard when dry; very friable when moist; slightly sticky and plastic when wet.
- B_{2t} 6-10" Brown (10yr5/3 when dry) light clay loam; dark brown (10yr4/3 when moist); strong medium prismatic structure separating to strong fine and medium blocks; very hard when dry; friable when moist; sticky and plastic when wet.
- B_{3l} 10-15" Pale brown (10yr6/3 when dry) heavy loam; brown (10yr5/3 when moist); strong medium prismatic structure separating to moderate medium and coarse blocks; hard when

dry; very friable when moist; slightly sticky and plastic when wet; moderate effervescence.

B₃₂ca 15-22" Light brownish gray (10yr6/2 when dry) loam; grayish brown (10yr5/2 when moist); moderate medium prismatic structure separating to moderate fine and medium blocks; strong effervescence; common soft masses of segregated lime.

C₁ca 22-32" Light brownish gray (10yr6/2 when dry) loam; dark grayish brown (10yr4/2 when moist); weak coarse prismatic in upper and massive in lower part; hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; strong effervescence; few soft masses of segregated lime.

C₂ 32-60" Grayish brown (10yr5/2 when dry) loam and silt loam stratified; dark grayish brown (10yr4/2 when moist); hard when dry; very friable when moist; slightly sticky and plastic when wet; strong effervescence.

Site 9

Soil: Olney fine sandy loam

Classification: Ustollic Haplargid - fine - loamy, mixed Mesic family.

Location: 2250'E, 1395'N SW Corner Sec 9 T9S R40E

Profile Description:

- A₁ 0-5" Grayish brown (10yr5/2 when dry) light fine sandy loam; dark grayish brown (10yr4/2 when moist); weak very fine granular structure; soft when dry; very friable when moist; non-sticky and nonplastic when wet.
- B₂₁^t 5-11" Brown (10yr5/3 when dry) light sandy clay loam; dark brown (10yr4/3 when moist); strong medium prismatic structure; very hard when dry; very friable when moist; slightly sticky and slightly plastic when wet.
- B₂₂^t 11-14" Brown (10yr5/3 when dry) heavy fine sandy loam; dark brown (10yr4/3 when moist); moderate medium and coarse prismatic structure; hard when dry; very friable when moist; slightly sticky and nonplastic when wet.
- B₃ 14-20" Brown (10yr5/3 when dry) heavy fine sandy loam; dark brown (10yr4/3 when moist); moderate medium and coarse prismatic structure; slightly hard when dry; very friable when moist; slightly sticky and nonplastic when wet; moderate effervescence.

- C₁ca 20-34" Grayish brown (2.5y5/2 when dry) fine sandy loam; dark grayish brown (2.5yr4/2 when moist); weak very coarse prismatic structure; slightly hard when dry; very friable when moist; nonsticky and slightly plastic when wet; strong effervescence with many soft masses in upper 6 inches and common soft masses of segregated lime in lower part.
- C₂ca 34-45" Light brownish gray (2.5y6/2 when dry) fine sandy loam; dark grayish brown (2.5y4/2 when moist); massive; slightly hard when dry; very friable when moist; nonsticky and slightly plastic when wet; strong effervescence with a few soft masses of segregated lime, few fine flat sandstone fragments.
- IIC₃ 45-56" Light olive brown (2.5y5/4 when dry) light clay loam; olive brown (2.5y4/4 when moist); massive; hard when dry; very friable when moist; slightly sticky and slightly plastic when wet; weak effervescence; with a few soft masses and seams of lime; few thin lenses of loam.
- C₄ 56-68" Light olive brown (2.5y5/4 when dry) fine sandy loam; olive brown (2.5y4/4 when moist) massive; slightly hard when dry; very friable when moist; nonsticky and nonplastic when wet; moderate effervescence; few fine flat sandstone fragments.

C₅ 68-90" Light yellowish brown (2.5y6/4 when dry) silt loam and light silty clay loam stratified; light olive brown (2.5y5/4 when moist); massive; very hard when dry; very friable when moist; sticky and plastic when wet; strong effervescence.

Site 10

Alluvial Land

Fluvaquent

Alluvial land is a nearly level to gently sloping, unconsolidated mixture of variably textured soil material, gravel, cobbles, and stones. It occurs on narrow flood plains and in unland drainageways, and forms alluvial fans at the mouths of drainageways. Typically, the deposits are not old enough for soil horizons to have developed. Drainage is variable, and shallow pools are common after flooding and heavy rainfall.

