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IN SITU SATURATED HYDRAULIC CONDUCTIVITY AND WATER-HOLDING CAPACITY OF UNDISTURBED AND SURFACE-MINED SITES[1]

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ABSTRACT

Water transmission and storage characteristics were examined on undisturbed soil, nonsodic spoil, sodic spoil and topsoil over sodic spoil sites. Bulk density, particle size analysis and soil water content both before and after water application were determined. Restrictions to water movement within the profile were found on the undisturbed and topsoil over sodic spoil areas. Infiltration on the sodic spoil site was minimal due to a disperse surface condition. Saturated hydraulic conductivity of 1.5 inches per hour was measured at the nonsodic spoil location. Identification of soil properties on reclaimed sites to a depth of up to 10 feet may be necessary to determine water transmission and storage characteristics.

INTRODUCTION

The stripping, reshaping and topsoiling activities presently used in surface mining operations may cause significant changes in many pre-mining site characteristics. Variations in both water movement and storage may occur as a result of mining operations. Information on saturated hydraulic conductivities and water-holding capacities of reshaped strip-mine materials is needed for development of improved reclamation procedures.

Saturated hydraulic conductivity describes the rate at which water can move through a thoroughly wetted soil profile. Soil hydraulic conductivity may be used as an aid in calculating infiltration, movement and drainage of water. The quantity of runoff occurring during a rainfall event may also be influenced by hydraulic conductivity.

Water holding capacity is a measure of the amount of water held by a soil against the downward forces of gravity. However, not all of the water held in a soil is available to plants. "Available water" is defined as that portion of water retained between "field capacity" (FC) and "permanent wilting point" (PWP) (Bauer, 1976). FC and PWP values are usually estimated in the laboratory by placing a sample in a pressure plate or membrane apparatus and subjecting it to ⅓ and 15 bar pressure, respectively.

In the present study, saturated hydraulic conductivity (HC) and water-holding capacity of undisturbed and surface-mined sites were determined. An undisturbed rangeland location was selected to serve as a pre-mined condition. Water movement and storage on both nonsodic and sodic spoil materials were examined. A site on which topsoil was placed over sodic spoil was also investigated.

PROCEDURE

The study was conducted at the Indian Head Mine near Zap, North Dakota, in August 1978. Soil analyses, standard soil water characteristics and vegetative cover for the four experimental sites are summarized in Table 1. An undisturbed rangeland area (located with the mine complex) served as a pre-mined condition for comparison with mined areas. The nonsodic spoil site (sodium adsorption ratio (SAR) of approximately seven) was reshaped and seeded in 1972 while reshaping and seeding of the sodic spoil location (SAR = 37) occurred in 1973. The area that was to be topsoiled was reshaped in 1973. The spoil was tilled and approximately 23 inches of topsoil was applied in 1975; the site was seeded to crested wheatgrass in May 1976.

A 10-foot square study area was selected and a trench approximately 3 feet deep was excavated around the perimeter of each site. Two layers of polyethylene sheeting were then placed around the monolith to prevent lateral water movement. The trench was then backfilled and a water-tight wooden dike installed as described by Cassel and Sweeney (1974). Six tensiometers, constructed of PVC tubing (Henderson, 1963), were placed at each location at depths of 0.5, 1, 2, 3, 4, and 5 feet. Each tensiometer was coupled to a mercury manometer with nylon spaghetti tubing (Doering and Harms, 1972). Soil samples for initial water determination were collected approximately 24 hours prior to water application.

Following the addition of sufficient water to wet the profile to a depth of 5 feet, plastic sheets were placed over the plot to prevent evaporation. Soil samples for determination of bulk density and gravimetric water content were taken approximately 72 hours after water application on the nonsodic spoil and topsoil over sodic spoil sites. Soil samples on

Table 1. Soil analyses and vegetative cover on undisturbed soil and surface-mined sites.

Site	SAR[1]	Texture[2]	FC[3]	PWP[3]	Predominate species
			% by weight[4]		
Undisturbed	1	SL	14 (10-18)	6 (4-8)	Kentucky Bluegrass Blue Gramma
Nonsodic Spoil	5	LS	12 (8-15)[5]	5 (3-7)[5]	Crested Wheatgrass
Sodic Spoil	37	SL	14 (10-18)	6 (4-8)	Sweet Clover
Topsoil over Sodic Spoil					Crested Wheatgrass
Topsoil	5	SL	14 (10-18)	6 (4-8)	
Spoil	37	CL	27 (23-31)	13 (11-15)	

[1]SAR = $NA/((Ca + Mg)/2)^{1/2}$, ionic concentration in meq/1.
[2]SL = sandy loam; LS = loamy sand; CL = clay loam.
[3]FC = field capacity, PWP = permanent wilting point.
[4]From Israelsen and Hansen (1962). Normal ranges are shown in parentheses.
[5]Values obtained by interpolation.

the undisturbed and sodic spoil areas were collected approximately 216 hours after water application because of small infiltration rates. On each of the sites, four replicated soil samples were obtained for each 6-inch increment to a depth of 5 feet.

Particle size analysis was determined by the hydrometer method (Day, 1965). Water contents at ⅓ and 15 bars were measured using a pressure plate and membrane apparatus (Richards and Weaver, 1944). For particle size analysis and soil moisture tension determinations, the samples for each depth increment were composited.

Saturated flow conditions will exist when the difference in hydraulic head measured in the upper and lower positions of the profile, H_1 and H_2, respectively, is equal to the profile thickness, L. Saturated HC (K) can then be determined from Darcy's equation for one dimensional flow (Stibbe, Thiel and Taylor, 1970):

$$V = \frac{Q}{AT} = K(H_1 - H_2)/L$$

where V = infiltration rate and Q = volume of water entering the monolith of cross sectional area A in the time interval T. Under steady state conditions the infiltration rate equals HC.

Once saturated conditions developed, as shown by the tensiometers at the 1- and 5-foot depths, additional water of sufficient quantity to fill the square enclosure was added. Water movement through the soil profile continued for a selected period of time. The amount of water required to refill the enclosure was determined allowing calculation of HC. The quantity of water which infiltrated during filling and which evaporated during testing was assumed to be negligible.

RESULTS

Undisturbed Soil

In the Northern Great Plains the predominate land use for much of the area designated for energy development (lignite mining) is rangeland. The undisturbed rangeland site was located on a Flaxton sandy loam (Table 1). Kentucky Bluegrass and Blue Gramma were the predominate plant species found at this location although several other types of vegetation were present.

Water movement under saturated conditions on the undisturbed site was found to be limited. Accurate determination of the small infiltration rate at this location was not possible using the selected experimental measurement technique. The minimal rate of water movement suggests that differences in bulk density or texture could exist within the profile.

Bulk density on the undisturbed site was found to slowly increase through a depth of 3 feet as shown in

Table 2. The presence of more dense soil material would be expected to reduce HC. Differences in texture within the soil profile could also have reduced water movement.

Table 2. Bulk density, particle size analysis, initial water content and final water content versus depth for undisturbed soil.

Depth	Bulk Density[1]	Particle Size			Water Content[1]	
		Sand	Silt	Clay	Initial	Final
(in)	(g/cm³)	--------- % --------			----% by weight----	
0-6	0.99	63	23	14	7.2	36.5
6-12	1.12				8.8	28.9
12-18	1.19				8.5	22.0
18-24	1.35				9.3	20.2
24-30	1.43				10.1	21.7
30-36	1.55				10.5	22.8
36-42	1.53				11.6	19.2
42-48	1.44				12.6	16.4
48-54	1.45				13.8	15.5
54-60	1.53				14.2	15.6

[1]Data are averages of four samples. Initial water content was determined prior to water application and final water content was measured approximately 216 hours after application of water.

Since downward movement of water was impeded at this site, measurement of *in situ* water-holding capacity or HC was not possible. However, soil samples for water content determinations were collected.

Analyses of soil samples obtained in the upper portion of the profile prior to initial water application indicated soil water contents near PWP. The vegetation present at this location would be expected to have a well-established root system. Since soil samples were collected in August (near the end of a growing season), most available water probably had been extracted.

Final water content measurements in the upper portion of the soil profile were found to be much larger than typical FC values reported for coarse-textured materials. Substantial changes in water content between samples collected before and after water application were also noted in the upper soil profile. In contrast, water content changes were small below a 3-foot depth. Water movement through the soil profile appears to have been restricted.

Nonsodic Spoil

Soil analyses on the nonsodic site indicate the presence of a loamy sand spoil material (SAR = 5). The bulk density and particle size analyses shown in Table 3 indicate the existence of a relatively uniform profile. A dense cover of crested wheatgrass was found at this site.

An HC of 1.5 inches per hour was measured on the nonsodic spoil. Approximately 176 gallons of water were found to have infiltrated into the profile over a 114-minute period. Water movement did not appear to be restricted at this site.

Water storage characteristics were also found to be relatively uniform with depth at the nonsodic spoil location. FC measurements agree closely with values reported in Table 1 for materials with loamy sand texture. Initial measured water content was generally within the range reported for PWP. As was the case on the undisturbed site, most of the available water was probably extracted by vegetation.

Sodic Spoil

A sparse stand of sweet clover was found at the sodic spoil site. For soils with a dispersed surface

Table 3. Bulk density, particle size analysis, soil water characteristic, initial water content, *in situ* field capacity and available soil water versus depth for nonsodic spoil.

Depth	Bulk Density[2]	Particle Size			Water Content[1]: Soil Water Tension (bar)				Available Water	
		Sand	Silt	Clay	⅓[3]	15[3]	Initial[2]	*In Situ* Field Capacity[2]	⅓ to 15 bars	*In Situ* F.C. to 15 bars
(in)	(g/cm³)	---------- % ----------			---------- % by weight ----------				------ inches ------	
0-6	1.23	79	14	7	10.0	5.0	5.0	13.1	0.37	0.60
6-12	1.39	79	11	10	8.2	4.1	4.5	10.0	0.34	0.49
12-18	1.34	83	12	5	7.7	4.6	5.3	9.9	0.25	0.43
18-24	1.39	81	11	8	8.2	4.3	7.7	11.8	0.33	0.63
24-30	1.45	84	11	5	7.4	3.8	7.3	10.7	0.31	0.60
30-36	1.46	81	9	10	7.6	4.2	6.4	11.3	0.30	0.62
36-42	1.29	80	15	5	8.2	4.3	7.9	12.2	0.30	0.61
42-48	1.42	83	9	8	4.9	3.3	8.9	10.9	0.14	0.65
48-54	1.42	84	11	5	4.4	3.8	7.8	10.7	0.05	0.59
54-60	1.48	82	10	8	5.4	3.7	6.9	11.9	0.15	0.73
								TOTAL	2.54	5.94

[1]Initial water content was determined prior to water application and *in situ* field capacity was measured approximately 72 hours after application of water.
[2]Data are averages of four samples.
[3]Data are averages of two samples.

condition such as found at this location, vegetative cover is usually limited since water movement into dispersed soil materials is typically small.

Infiltration on the sodic spoil site was found to be very limited due to the dispersed surface condition. Accurate measurement of the small infiltration rate found at this location was not possible. As shown in Table 4, initial water content measurements taken below a 6-inch depth generally indicate values equal to or greater than FC. Since these samples were collected near the end of the growing season, root water extraction would appear to have been minimal. Because of large standard deviations in measured water contents, final water content values in some cases were less than initial measurements.

Table 4. Bulk density, particle size analysis, initial water content and final water content versus depth for sodic spoil.

Depth	Bulk Density[1]	Particle Size			Water Content[1]	
		Sand	Silt	Clay	Initial	Final
(in)	(g/cm³)	----------%----------			-----% by weight-----	
0-6	1.16	58	25	17	9.4	25.0
6-12	1.43				15.0	14.7
12-18	1.43				20.2	17.8
18-24	1.36				14.8	17.6
24-30	1.26				17.6	15.1
30-36	1.20				20.4	19.1
36-42	1.27				18.1	28.9
42-48	1.29				19.0	33.6
48-54	1.39				24.7	23.0
54-60	1.25				24.1	18.6

[1]Data are averages of four samples. Initial water content was determined prior to water application and final water content was measured approximately 216 hours after application of water.

Water movement into the spoil appears to have occurred in a nonuniform fashion. The spoil material at this location consisted of a heterogeneous mixture of fragmented geologic materials. Water flow would be expected to follow a tortuous path through the profile moving between disperse spoil particles. Excess quantities of water appear to have accumulated at various locations within the profile.

Topsoil over Sodic Spoil

At the topsoil over sodic spoil site, approximately 23 inches of sandy loam topsoil material was placed over a sodic spoil (SAR = 37). A dense cover of crested wheatgrass was present. The topsoil material appeared to have been of sufficient quality and depth to have provided a suitable plant growth medium.

A limited infiltration rate was also found to exist at the topsoil over sodic spoil site. The sodic clay loam spoil appeared to restrict downward water movement. At this location, accurate measurement of HC was not possible.

Initial water content measurements shown in Table 5 for the topsoil material indicate values within the PWP range. In contrast, water content appeared to be equal to or greater than FC below the 6-inch depth on the spoil material. It appears that root water extraction within the spoil was minimal.

Table 5. Bulk density, particle size analysis, initial water content and final water content versus depth for topsoil over sodic spoil.

Depth	Bulk Density[1]	Particle Size			Water Content[1]	
		Sand	Silt	Clay	Initial	Final
(in)	(g/cm³)	----------%----------			-----% by weight-----	
Topsoil						
0-6	1.33	55	26	19	5.0	19.5
6-12	1.42				5.5	18.3
12-18	1.33				5.8	19.2
18-24	1.45				6.1	17.9
Spoil						
0-6	1.39	31	38	31	10.9	21.6
6-12	1.46				14.5	19.3
12-18	1.29				19.9	18.8
18-24	1.24				20.4	20.1
24-30	1.48				21.6	20.8
30-36	1.28				22.5	25.5

[1]Data are averages of four samples. Initial water content was determined prior to water application and final water content was measured approximately 72 hours after application of water.

Following water application, water content of the topsoil material appeared to have been above FC. Substantial changes in water content were limited to the top foot of the spoil material. As was true on the sodic spoil site, excess quantities of water appear to have accumulated at various locations within the profile. Large standard deviations in measured water contents of the spoil material were also found.

For water movement to occur from the coarse-textured sandy loam topsoil material into the finer-textured clay loam spoil, the topsoil material must first become saturated (or nearly so). This requirement appears to have been satisfied at this location, however, water movement appears to have occurred in a nonuniform fashion.

DISCUSSION

HC was measured only at the nonsodic spoil site. HC measurements were not made at the other locations because of small infiltration rates. The experimental technique described by Cassel and Sweeney (1974) would probably be best suited for coarse-textured materials for which unrestricted vertical water movement occurs.

The nonsodic and sodic spoil sites were selected to represent water transmission extremes. HC of the coarse-textured, nonsodic spoil area was found to be much higher than at the sodic spoil location where HC could not be easily measured. Hillel (1971) reported an infiltration rate of less than 0.04 inches per hour for sodic soils (Table 6). The presence of well-aggregated or cracked soils or a crust may significantly affect infiltration rates.

Table 6. Final infiltration rate for selected soil types.[1]

Soil Type	Final Infiltration Rate
	(in/hr)
Sands	>0.8
Sands and Silty Soils	0.4-0.8
Loams	0.2-0.4
Clayey Soils	0.04-0.02
Sodic Clayey Soils	<0.04

[1]From Hillel (1971).

Previous studies in western North Dakota have also shown infiltration on sodic spoils to have been limited (Gilley **et al.**, 1976). The most significant change in water storage was found to occur within the top few inches of the spoil profile. Tillage of sodic spoil prior to topsoil placement was found to produce little effect on increased water flow into the spoil medium (Gilley, Gee and Bauer, 1977).

Subsurface soil characteristics were found to greatly influence infiltration on both the undisturbed and topsoil over sodic spoil sites. The surface material on both of these areas was of sandy loam texture. As can be seen from information presented by Israelsen and Hansen (1962) in Table 6, the sandy loam surface material would be expected to have a relatively large infiltration rate. However, infiltration on these sites was reduced because of restrictions to water movement occurring within the profile. Thus, if water movement is to be accurately estimated on reclaimed sites, identification of soil properties within the profile is required.

Power **et al.**, (1974) reported that small grains exhibit significant root growth and activity into 4 feet of soil. Grass roots in the western portion of North Dakota were found to extend well into the fifth or even sixth foot while penetration of alfalfa roots may reach depths greater than 8 feet. On reclaimed sites with established grass cover in western North Dakota, Schroeder and Bauer (1983) seldom measured changes in water storage below a 4-foot depth. Since water movement is influenced by underlying soil properties, identification of soil characteristics on reclaimed sites to a depth of up to 10 feet may be necessary.

Water-Holding Capacity

In situ water-holding capacity was measured only on the nonsodic spoil site. Because of restrictions to downward water movement, measurements of water-holding capacity were not possible at the other locations. Analyses of soil samples collected on sites with restricted drainage indicate water content values above FC.

On the nonsodic spoil site, values for available water calculated using *in situ* FC measurements were considerably higher than those determined using the ⅓ bar pressure plate method (Figure 1). Cassel and Sweeney (1974) reported similar results for other coarse-textured soils. Thus, the method used to make soil water determinations appears to significantly affect estimated available water.

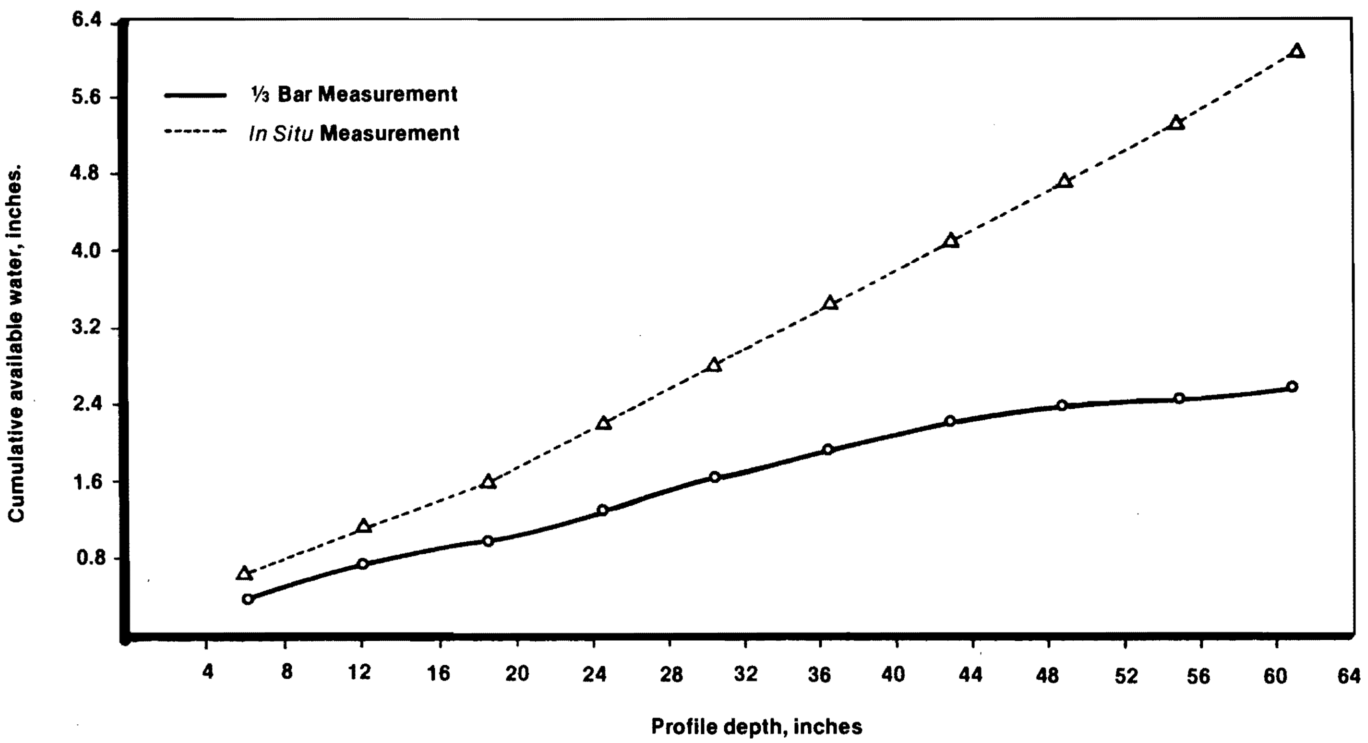

Figure 1. Cumulative available water in the top 5 feet as measured by the pressure plate and membrane method and the *in situ* method.

Water-holding capacity for coarse-textured materials such as those found on the nonsodic spoil site is limited. Crops with a large water consumptive requirement or shallow rooting depth would probably not be productive at this location. Because of its relatively deep rooting depth and abilty to sustain water stress, crested wheatgrass appears to be well suited for this location.

SUMMARY AND CONCLUSIONS

Information on HC and water-holding capacity of reshaped strip-mined materials are needed for development of improved reclamation procedures. Saturated flow through 10-foot square soil monoliths was measured. Soil samples for water content determinations were collected before and after water application.

Water movement and storage within an undisturbed soil, nonsodic spoil, sodic spoil and topsoil over sodic soil were measured. HC in the undisturbed soil, sodic spoil and topsoil over sodic spoil was found to be minimal. At the nonsodic spoil location, a saturated hydraulic conductivity of 1.5 inches per hour was measured.

Initial water content on the undisturbed soil, nonsodic spoil and topsoil over sodic spoil was near PWP. At the sodic spoil location, initial water content below 6 inches was found to be greater than FC. Bulk density, particle size distribution and water storage characteristics were found to vary little in the top 5 feet of the nonsodic spoil profile.

Because of restrictions to drainage occurring within the profiles, final water content on the undisturbed and the topsoil over sodic spoil sites was larger than FC. Water movement within the sodic spoil appeared to have occurred in a nonuniform fashion since excess quantities of water were found at various locations within the profile.

If HC and water-holding capacity are to be accurately estimated in reclaimed soils, characerization of the soil profile is required. Restrictions to water movement occurring below the root zone may significantly affect permeability and storage characteristics. Identification of soil properties on reclaimed sites to a depth of up to 10 feet may be necessary.

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REFERENCES

1. Bauer, A. 1976. Effect of soluble salts on soil water availability. North Dakota Ag. Exp. Stn. Farm Res. 33(5):9-14.
2. Cassel, D.K. and M.D. Sweeney. 1974. *In situ* water-holding capacities of selected North Dakota soils. North Dakota Ag. Exp. Stn. Bulletin 495.
3. Day, P.R. 1965. Particle fractionation and particle size analysis. **In** Methods of Soil Analysis. American Society of Agronomy Monograph No. 9, Part 1. Ed. C.A. Black. Madison, Wisconsin.
4. Doering, E.J. and J.P. Harms. 1972. Improved mercury well for multiple tensiometer systems. Soil Sci. Soc. Amer. Proc. 27:239-245.
5. Gilley, J.E., G.W. Gee, A. Bauer, W.O. Willis and R.A. Young. 1976. Water infiltration on surface-mined sites in Western North Dakota. North Dakota Ag. Exp. Stn. Farm Res. 34(2):32-35.
6. Gilley, J.E., G.W. Gee and A. Bauer. 1977. Effects of tillage on water movement into surface-mined materials. North Dakota Ag. Exp. Stn. Farm Res. 34(4):28-29.
7. Henderson, D.W. 1963. Tensiometer construction with plastic materials. Soil Sci. Soc. Amer. Proc. 27:239-240.
8. Hillel, D. 1971. Soil Water-Physical Principles and Processes. Academic Press, Inc., New York, New York.
9. Israelsen, O.W. and V.E. Hansen. 1962. Irrigation principles and practices. 3rd Edition. John Wiley, Inc., New York, New York.
10. Power, J.F., W.O. Willis, F.M. Sandoval, and J.J. Bond. 1974. Can productivity of mined land be restored in North Dakota? North Dakota Ag. Exp. Stn. Farm Res. 31(6):30-32.
11. Richards, L.A. and L.R. Weaver. 1944. Moisture retention by some irrigated soils as related to soil-moisture tension. J. Ag. Res. 69:215-235.
12. Schroeder, S.A. and A. Bauer. 1984. Soil water variation in spoil versus undisturbed sites in North Dakota. Soil Sci. Soc. Amer. J. "In press."
13. Stibbe, E., T.J. Thiel and G.S. Taylor. 1970. Soil hydraulic conductivity measurement by field monoliths. Soil Sci. Soc. Amer. Proc. 34:952-954.