Water Movement in a Reclaimed Site and Associated Soils at a Mine Site in Western North Dakota

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Water movement through the plant root zone was studied on plots established on several soil types and a reclaimed "soil" profile. Infiltration data were analyzed using the equation $Q = ct^d$ and data from water movement studies were applied to the equation $W = aX^{b+1}T^{-b}$. In soils initial infiltration rates were relatively slow, but the rates sustained for two hours were considered high. Measurements of water content redistribution after flooding indicated that water movement through these soils was unimpeded. A low correlation coefficient resulted when soil water content data from the reclaimed site were "fitted" to the model equation. However, water contents and drainage calculated from the model equation were reasonably good estimates of measured values for the reclaimed site and the undisturbed soils.

Disturbance from strip mining and subsequent reclamation procedures can affect the water movement characteristics of the post mining plant root zone. Soil and shallow overburden materials are removed and stockpiled prior to mining and then respread over shaped overburden materials after mining. Physical characteristics which determine root zone hydrology are likely to be altered in the process. These changes may have important impacts on the quantity of water available for plant use as well as on the quantity of water which may pass through the plant root zone toward groundwater aquifers.

Field plots were established on several soil types and a reclaimed site at the Falkirk Mining Company's mine near Underwood to study plant root zone water movement. At other mines in west central North Dakota, water movement problems after mining and reclamation have resulted because sodic spoil materials, present at these mines, restrict infiltration and drainage (2). However, the overburden materials at the Falkirk Mine site are, in most cases, neither sodic nor saline (7). Thus, if any impediments to water movement were to develop, these likely would result as a consequence of changes in soil and overburden physical properties brought about by disturbance.

In this paper, an attempt is made to characterize the movement of water into and through undisturbed soils and a reclaimed site at the Falkirk Mine site and to determine some of the characteristics of soils important to the determination of plant root zone hydrology. Results from this effort will be compared to those obtained from future studies on reclaimed areas at the Falkirk Mine. This premining characterization, in itself, is of value as a basis for reclamation planning. Desirable characteristics of undisturbed soils can be models for the reconstruction of soil profiles on respread overburden materials (6).

PROCEDURE

Soil water movement was studied at eight sites. These included four of the major soil types in the area and a "soil" reconstructed to simulate a reclaimed soil. The reconstructed "soil" was made by removing the "topsoil" and "second lift suitable plant growth material" and respreading these in the sequence required by current North Dakota State Regulations (5). Prior to replacing the soil materials, rippers were used to disturb an additional 2 to 3 feet of the overburden. This resulted in a reconstructed soil profile 152 cm (5 ft.) deep and structural disturbance to approximately 244 cm (8 ft.). Field work on sites 1 through 6 was accomplished in the autumn of 1978 (Table 1).

At each site a 3.6 m x 3.6 m (12 ft. x 12 ft.) basin was constructed from 0.95 cm (0.39 in.) plywood. The plywood basin was wrapped in plastic to hold water on the plot area, see Figure 1. A neutron probe access tube was installed to a depth of about 2.85 m (9.5 ft.) in the center of each plot. Approximately 7600 l. (2000 gal.) of water was applied to each plot basin, maintaining a head of water for about 2 days. After water had disappeared from the surface, the plots were covered with plastic to prevent evaporation.

Soil water content measurements were made at approximately 30 cm (1 ft.) increments with a Troxler neutron probe. Soil water contents were measured daily for about a week, every other day for the second week and weekly for about 8 more weeks. These data were analyzed to characterize the water movement through these soils using a procedure outlined by Arnold and Dollhopf (1). This procedure involves the use of equation [1].

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Table 1. Chemical and Physical Characteristics of Soils and Reclaimed "Soil" Profile.

Plot	Soil Type	Texture[a/]	Clay (%)	K[b/] (cm/hr)	Sat[c/] (%)	15 bar[c/] (%)	SAR[d/]	EC[e/] (mmho/cm)
1	Bowbells	cl	33	2.1	46	13	1	<1
2	Bowbells	cl	34	3.4	47	13	1	<1
3	Zahl	1	25	18.3	46	13	1	<1
4	Bowbells	1-sil	21	2.1	47	13	4	<1
5	Max	cl	29	0.9	47	13	1	<1
6	Williams	1-cl	29	---	46	12	2	<1
7	Williams-Zahl	cl	30	---	48	--	3	2.2
8	Reclaimed	cl	30	---	47	--	3	1.8

[a/] sil = silt loam; cl = clay loam; 1 = loam
[b/] hydraulic conductivity
[c/] water holding capacity by weight at indicated potentials
[d/] sodium adsorption ratio
[e/] electrical conductivity

Figure 1. Flooded basin on a plot to measure water movement into and through the reconstructed "soil".

$$W = aX^{b+1}T^{-b} \qquad [1]$$

where W = total water content above depth X in cm.
T = time in days from the occurrence of soil water recharge
a,b = constants for any given depth from the surface

By letting $R = aX^{b+1}$ and taking natural logarithms of both sides, this equation becomes:

$$\ln W = \ln R - b \ln T \qquad [2]$$

Equation [2] is the equation of a regression line. By substituting known values of T and measured values of W into equation [2] and working back through equation [1], values of the constants for each depth can be determined. Gardner, Hillel, and Benyamini (4) have presented some theoretical considerations concerning the use of these types of equations to characterize the redistribution of soil water after irrigation.

Infiltration was measured at sites 1 through 6 using the double ring infiltrometer method (3) as shown in Figure 2. Two infiltrometers were installed at each site, one inside and one a few feet outside of each plot. This was done in order to measure infiltration on both wet and dry soils. Infiltrations data were fitted to equation [3]:

Figure 2. Double ring infiltrometer to measure movement of water into reconstructed "soil" surface.

$$Q = ct^d \qquad [3]$$

where Q = infiltration quantity (cm)
t = time (minutes)
c,d = constants

Soil and overburden samples were removed from each plot when access tubes were installed. These samples were analyzed for several physical and chemical properties to discern relationships between those properties and the water movement parameters determined from the water movement experiments.

RESULTS AND DISCUSSION

Table 1 shows several chemical and physical properties of the soil samples obtained from the plots. Textures of all soils were medium or moderately fine. Water retention percentages at saturation and at 15 bars were essentially equal. There were some variations in sodium adsorption ratios and electrical conductivities, but values were not high enough to be considered sodic or saline. The greatest variation was in laboratory determined saturated hydraulic conductivities, K values, but none would be considered excessively slow.

Table 2 shows coefficients of a and b for equation [1] and values of the correlation coefficient, r, for the relationship between lnW and lnT in equation [2] for the upper 152 cm (5 ft.) at each of the sites. The correlation coefficient is a measure of the degree of linear association between the logarithm of the water content, lnW, and the logarithm of time since recharge, lnT. It is also an indication of how well the data fit the model equations. The correlation coefficient was significant at the 0.01 level for plots 1 through 7. Some restrictions to drainage or other factors which are not accounted for in this modeling technique are indicated by the low correlation coefficient value for plot 8.

Table 2. Water Movement Coefficients and Correlation Coefficients for Upper 152 cm.

Plot	Soil Type	Correlation coefficient, r	a	b
1	Bowbells	.78	.323	.022
2	Bowbells	.91	.333	.032
3	Zahl	.98	.302	.034
4	Bowbells	.84	.313	.025
5	Max	.93	.301	.041
6	Williams	.96	.311	.035
7	Williams-Zahl	.62	.329	.019
8	Reclaimed	.42	.348	.012

The water movement coefficients, a and b, shown in Table 2 were used to calculate soil water contents above selected depths at various times. Calculated soil water contents approximately 10 weeks after the simulated recharge events are shown in Table 3. Ten weeks after flooding, water contents in the upper 152 cm of each soil type were nearly equal. Calculated soil water contents were reasonably good estimates of actual soil water contents.

Table 3. Measured Water Contents (W_m) Compared to Those Calculated (W_c) for the Upper 152 cm.

Plot	W_m (cm)	W_c (cm)	Difference[a/] (cm)	Correlation Coefficient, r
1	50.40	49.81	-0.59	.79
2	50.98	51.68	0.70	.91
3	46.50	46.83	0.33	.98
4	47.21	48.39	1.18	.84
5	47.36	46.88	-0.48	.93
6	48.12	48.31	0.19	.96
7	49.10	50.70	1.60	.62
8	51.80	53.30	1.50	.42

a/ minus sign indicates underestimation.

Since the plots were covered to prevent losses due to evapotranspiration, decreases in soil water content over time can be considered as losses due to drainage below the 152 cm depth. Thus, the difference between the soil water content at the time of the recharge event and that at any time, T, is an estimate of the amount of water which has drained below the plant root zone. Calculated drainage losses after 76 to 84 days are shown in column 5 of Table 4. These results, including the reduced drainage from the reclaimed site, compare well with those obtained by Arnold and Dollhopf (1) at a Montana strip-mined site. The last

Table 4. Calculated Soil Water Drainage from the Upper 152 cm.

Plot	Time (days)	W_i[a/] (cm)	W_f[b/] (cm)	Calculated[c/] drainage (cm)	Measured[c/] drainage (cm)
1	84	54.93	49.81	5.12	3.28
2	82	59.56	51.68	7.88	7.42
3	82	54.43	46.83	7.60	7.62
4	82	54.00	48.39	7.61	7.52
5	82	54.49	46.88	7.61	6.81
6	81	56.25	48.31	7.94	6.68
7	78	54.50	49.10	5.40	5.10
8	76	54.60	51.80	2.80	2.60

a/ Soil root zone water content one day after recharge event
b/ Soil root zone water content at time in column 2
c/ After time in column 2

column in Table 4 shows measured drainage losses below 153 cm. These values were determined by subtracting the soil water contents measured at the times indicated in column 2 from those measured one day after the conclusion of the recharge event.

It is emphasized that these water movement plots are only simulations of natural conditions. The amount of water added was much greater than is added in almost any natural precipitation event which would occur in North Dakota, although water available for infiltration may be greater in some areas where runoff collects. Evapotranspiration loss has not been considered, but this should not be a serious omission for the nongrowing season. The data obtained seem to fit the mathematical description well and the descriptive equations developed can be of great value to make comparisons between sites. One reclaimed "soil" was studied so general conclusions about the applicability of this model equation on reclaimed sites are limited. For the reclaimed site, investigated here, the low value of the correlation coefficient indicates that equations [1] and [2] are not applicable. Arnold and Dollhopf (1) had much more success applying these equations to reclaimed "soils" in Montana. Additional studies are needed to test this technique's applicability to reclaimed "soils" in North Dakota.

Results of the application of the double ring infiltrometer data to equation [3] are shown in Table 5. Values of the correlation coefficient all exceed 0.99 so it is concluded that equation [3] provides an excellent mathematical description of infiltration in these soils. Infiltration in every case is greater in dry than wet soils because they have less of their soil water reservoir already filled. Infiltration measurements were obtained for the initial two hours after the application of water so only upper soil profile characteristics are reflected in the infiltration rates. The intercept parameter, c, is relatively low for all soils studied indicating slow initial rates of infiltration. The d parameter indicates the rate of water entry into the soil on a longer term basis, up to two hours. These values are all relatively high. The high sustained rates of infiltration plus the excellent "fit" of the data to the infiltration equation indicate that water flow through the upper horizons is unimpeded in these soils.

SUMMARY

Infiltration, water retention, and drainage characteristics were determined for several soils commonly occurring in the area of the Falkirk Mine site near Underwood. Data were compared to those collected from a reclaimed site. The soils were generally non-sodic and non-saline. Infiltration and water movement through them was generally unimpeded. The infiltration equation, $Q = ct^d$, provided excellent results in describing infiltration into all of the soils investigated. Initial infiltration was relatively slow but infiltration in two hours was high in all plots. The equation, $W = aX^{b+1}T^{-b}$ adequately described water movement through the undisturbed soil profiles and measurements of water retention compared favorably with water retention calculated from the equation. Calculations of drainage indicate that the amount of water draining below the plant root zone from any one of the undisturbed soil profiles was greater than that draining from the reclaimed "soil." Additional studies are needed to determine infiltration, water movement and drainage characteristics of profiles resulting from the reclamation of strip-mined lands.

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Continued on Page 20

Table 5. Measured infiltration Quantity (Q_m) Compared with Calculated Infiltration Quantity (Q_c) after 120 Minutes.

Soil	Q_m (cm^3/cm^2)	Q_c (cm^3/cm^2)	Difference (cm^3/cm^2)	Equation Constants c	Equation Constants d
Wet soils					
Bowbells[a]	7.30	7.30	0.00	.108	.937
Zahl	2.67	2.71	0.04	.019	1.079
Max	4.69	4.95	0.26	.100	8.15
Williams	2.15	2.13	0.02	.187	.528
Dry soils					
Bowbells[a]	15.87	16.03	0.16	.329	.787
Zahl	7.57	7.41	0.16	.101	.897
Max	5.33	5.31	0.02	.162	.733
Williams	3.25	3.28	0.03	.106	.717

[a] Average of three plots

Table 5. Erosion, Runoff and Infiltration for Rainfall Simulation Study of a Revegetated Surface Mined Site.[a/]

Surface Treatment	Run[b/]	Soil Loss, tons/acre	Runoff in.	Ratio of Soil Loss to Runoff, % by weight	Infil-tration in.	Infiltration Rate, in./hr.[c/]
Undisturbed	Init + Wet	1.4	0.8	1.2	3.8	1.6
Harvested	Init + Wet	2.7	1.9	1.3	2.7	1.1
Bare[d/]	Init + Wet	6.0	1.7	2.8	2.9	1.5
Mulched[d/]	Init + Wet	2.0	2.0	0.8	2.6	1.0
Undisturbed	Initial	0.6	0.4	1.1	1.9	1.6
Harvested	Initial	1.4	1.0	1.3	1.3	1.0
Bare[d/]	Initial	3.0	0.7	3.1	1.6	1.2
Mulched[d/]	Initial	1.1	0.8	1.0	1.5	1.1
Undisturbed	Wet	0.8	0.4	1.3	1.9	1.5
Harvested	Wet	1.3	0.9	1.2	1.4	1.2
Bare[d/]	Wet	3.0	1.0	2.5	1.3	1.7
Mulched[d/]	Wet	0.9	1.2	0.5	1.1	0.8

[a/] Plots were 13.3 by 72.6 ft. on a 10.4 percent slope.

[b/] Initial and wet runs lasted 60 minutes; application intensity 2.3 iph.

[c/] Data are averages of two replications.

[d/] Average rate during the last 3 minutes of the runs.

SUMMARY

Erosion and runoff resulting from simulated rainfall were measured on a revegetated surface mined site with undisturbed, harvested, bare and mulched surface treatments. Sediment production from bare topsoil plots was over 200 per cent larger than the harvested treatment. A ½ ton per acre surface mulch reduced soil losses by 66 per cent over bare conditions. Runoff was smallest on the undisturbed plots, averaging 17 per cent of applied rainfall. Runoff rates from harvested and mulched treatments were similar.

This study demonstrates the need for rapid establishment of protective vegetative cover on topsoiled sites. A surface mulch can serve to effectively control erosion during the critical period of grass establishment. Erodibility of recently topsoiled areas is significantly reduced as vegetation becomes established on surface mined areas.

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Continued from Page 8

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