STATUS OF SOIL WATER IN SURFACE COAL MINELANDS OF WEST CENTRAL NORTH DAKOTA (1989-1992)[1]

by

Padam P. Sharma, F. Scott Carter, and Gary A. Halvorson[2]

Abstract. To understand the effect of landscape position and soil characteristics on temporal and spatial distribution of soil water, we measured soil water contents from 1989 to 1992 at various topographic locations in surface coal minelands of Indian Head Mine near Zap in west-central North Dakota. Transects of neutron probe access tubes were established across comparative landscapes of premine, reclaimed, and abandoned minelands. Soil water versus depth data collected on various transects and tube locations during the four growing seasons were appended and analyzed for coefficient of variation (CV) with time. For semi-arid western North Dakota where growing season potential for evapotranspiration is 2 to 4 times higher than normal rainfall, and deep drainage is negligible, change is soil water content is a function of total infiltration and subsequent evapotranspiration. In this paper, CV is used as an index of temporal variability of soil water contents, and hence, an indicator of water transport and storage capacity of soil. Only in a few abandoned mineland depressional areas which were dominated by non-sodic overburden materials, water moved to > 0.9 m depth during the four years of observation. For all other profiles in abandoned, reclaimed, and undisturbed lands, soil water movement was mostly confined to topsoil-upper subsoil depth (0-0.61 m), and little or no water moved below the subsoil (> 0.90 m). For abandoned minelands, the water movement was dependent upon location, texture, and sodicity of overburden materials. For reclaimed minelands, regardless of topographic position, the soil water movement was restricted to 0.61m from the surface with deeper depths showing less than 5% CV. For premine profiles, the extent of water movement in the root zone depended on the topographic location and the structural attributes of existing land management practice. The observations in this study and many past studies on soil water distribution on reclaimed landscapes suggest that post-mine landscapes, in semi-arid minelands, should be designed with an objective to allow more opportunity for water to infiltrate into the soil. Along with topographic configuration, the infiltration capacity of reclaimed soils need to be improved by alleviating soil compaction during and after reclamation.

[1] Paper presented at the 1993 National Meeting of the American Society of Surface Mining and Reclamation, Spokane, Washington, May 16-19.

[2] Assoc. soil scientists and soil scientist, respectively, with the NDSU/Land Reclamation Research Center, USDA-ARS/Northern Great Plains Research Laboratory, Hwy. 6, South, Mandan, ND 58554. This paper is part of "Western Region - Surface and Root Zone Hydrology Project" supported by the National Mine Land Reclamation Center, West Virginia University, and Bureau of Mines, U. S. Department of Interior.

Proceedings America Society of Mining and Reclamation, 1993 pp 144-154
DOI: 10.21000/JASMR93010144

https://doi.org/10.21000/JASMR93010144

Introduction

Effects of topographic location, slope, and aspect on soil water storage and hence the crop yield have been widely studied for agricultural production systems (Hanna et al., 1982; Ciha, 1984). For post mining systems, the Surface Mining Control and Reclamation Act (SMCRA) requires that post mine landscapes represent approximate original topography and the soils be productive at a level equal to or better than before. Doll et al. (1984) summarized several studies from reclaimed soils of west central North Dakota where topographic positions in the landscape had a significant influence on soil water availability and hence the crop yield on mined land. Wollenhaupt and Richardson (1982) demonstrated that even microtopographic differences can be an important factor in determining soil water storage and crop yields. On the basis of slope measurements of surrounding areas from a point of interest, Halvorson and Doll (1991) developed a topographic factor which provided an empirical tool to quantify water redistribution in the landscape. Above studies have mainly concentrated on the effects of topography on gently rolling pre- and post-mine prairie (post-SMCRA) landscapes.

Prior to the implementation of the SMCRA, many surface mined landscapes in semi-arid, western North Dakota were abandoned with little or no leveling of the overburden materials. The abandoned surface mine lands represent an atypical landscape with alternating knolls and depressions of varying types of coal overburden materials exposed on the surface. Over the years of abandonment, these landscapes have acquired a state of hydro-ecological niche different from that of gently rolling pre- and post-mine landscapes. Information on hydrology of such landscapes is needed to develop scientifically based consensus on whether these landscapes should be reclaimed or left to equilibrate to the forces of nature. The hydro-ecological information from the abandoned mine lands also provide comparative insights into the hydrologic and environmental effects of current land reclamation practices.

A project entitled "Surface and Root Zone Hydrology of Minelands" was initiated in 1989 to quantify surface and root zone factors that affect infiltration, movement, and retention of water with respect to typical soil profiles in comparative landscape positions of reclaimed, abandoned and undisturbed lands. As a component of the overall study in west-central North Dakota, this paper summarizes the results of soil water contents monitored at pre- and post-mine (reclaimed vs. abandoned) topographic positions at Indian Head Mine of the North American Coal Company near Zap, in Mercer County, from 1989 to 1992.

Experimental Methodology

Figure 1 shows a map of the study site of about 600 ha area which includes adjacent landscapes of abandoned mine lands, reclaimed mine lands and undisturbed lands. The undisturbed and reclaimed landscapes are gently rolling with slopes ranging from nearly level to about 25%. The undisturbed soil in the area mainly consists of Williams loam (*Typic Haploboroll*) with wind and water deposited sediments overlying glacial tills. The reclaimed landscape topsoil and subsoil consists of sandy loam material underlain by silty clay loam minespoil at a depth of about 0.9 m. The abandoned mineland is rugged with steep ridges and depressions. The dominant soil texture is silty clay loam to clay with medium (10-15) to very high (>20) sodium adsorption ratio.

We installed six transects of neutron probe access tubes in June-July of 1989. Three 477, 478, and 262 m long transects were established in abandoned mine lands. Two east-west transects (1 and 2) in the included 16 and 15 access tubes, and a third north-south transect (3) had 13 access tubes. Most of the access tubes in the abandoned

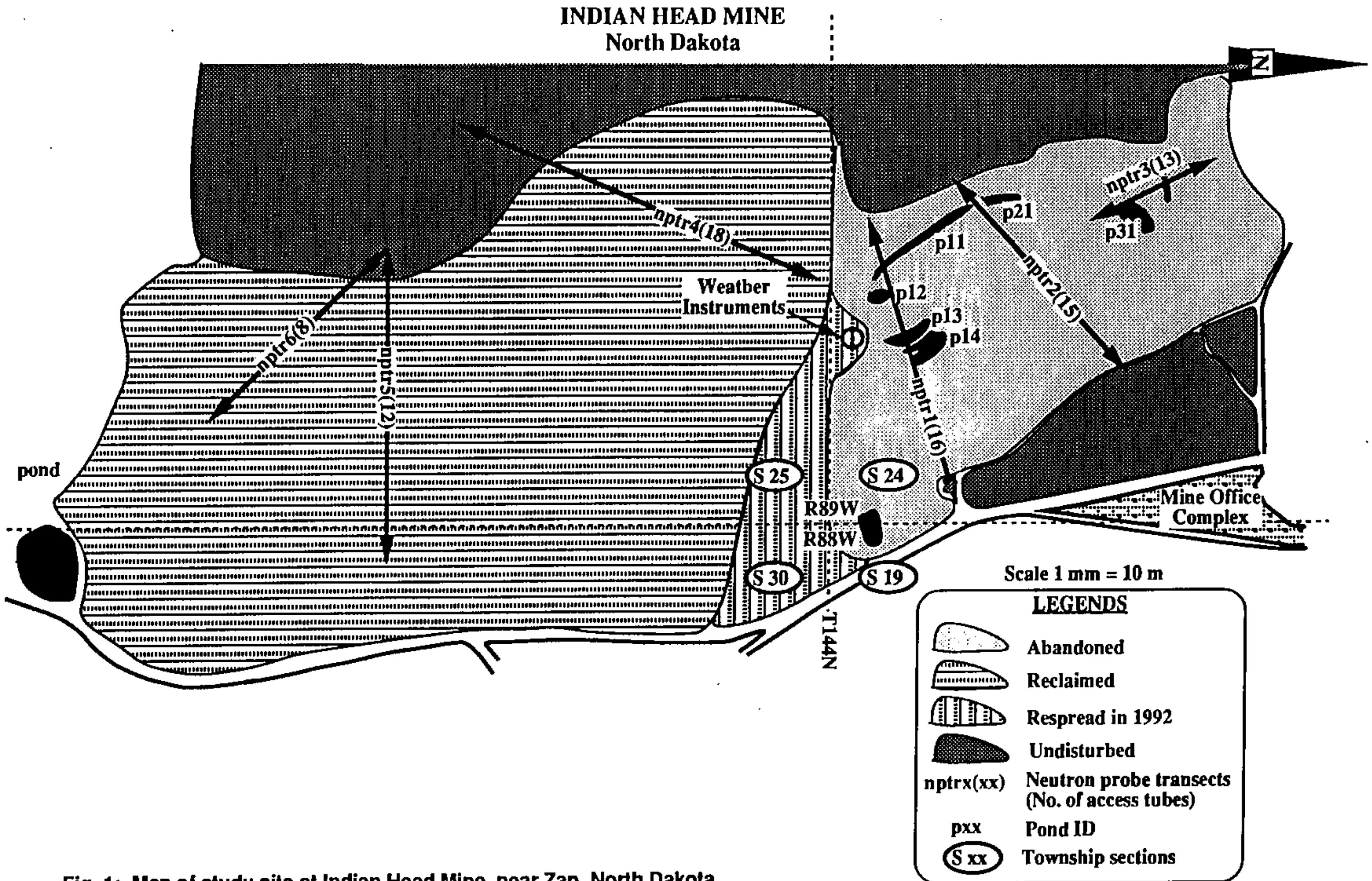

Fig. 1: Map of study site at Indian Head Mine, near Zap, North Dakota

minelands were 2.75 m deep, while those on sites inaccessible to the probe truck were 1.5 m deep. The tubes were not equidistanced from each other, but were located at definite topographic positions.

Three transects (4, 5 and 6) established in the adjacent reclaimed and undisturbed landscape were 817, 676, and 350 m long, and they had 18, 12, and 8 tubes. All tubes, in the reclaimed mineland and undisturbed land were inserted equidistanced from each other (50 m) to a depth of 1.5 m. Each transect ran from reclaimed land (from the toe slope) to undisturbed land (towards the summit).

Neutron probes were read each week during 1989 and every 2 to 4 weeks from April to October in 1990, 1991, and 1992. Soil water data collected at 0.3m depth increments for the four years (1989-1992) from the six transects of the 82 access tubes were appended and analyzed. The soil water content vs. depth data were grouped into three depth increments of 0-0.6 m (0-2ft), 0.6-1.5 m (2-5ft) and 1.5-2.7m (5-9ft), and the overall maximum, minimum, mean, standard deviation, and coefficient of variation (CV) of water contents vs. time at each depth increment were calculated.

For a comprehensive overview of profile characteristics and landscape position effect on soil water status, the temporal CV of soil water is used as an index of the extent of change in soil water storage within a depth increment either by recharge through infiltration and by discharge through evapotranspiration or drainage. For a semi-arid climate where the water table is fairly deep and deep drainage is negligible, almost all of the water infiltrated into the root zone is removed by evapotranspiration. A higher coefficient of variance of soil water content in the root zone indicates a higher amount of infiltration, and hence, a higher capacity of the soil profile to store and transmit water to the roots and to the vadoze zone.

Results and Discussion

Rainfall and Potential Evapotranspiration

The region of west central North Dakota normally (1951-80) receives about 418 mm of annual rainfall of which 357 mm (85%) precipitate between April and October. Snowmelt in the spring and late fall rainfall provide most of the recharge to soil moisture storage. During the months of April to October, the total potential for evapotranspiration is about 1000 mm which, except for immediately after significant summer precipitation events, necessitates that soil water is depleted throughout the summer. Table 1 shows the monthly rainfall amounts measured at the study site during 1989-1992. Except for 1990, the summer time precipitation at the study site was significantly below normal.

The estimated monthly potential open water evaporation amounts are also listed in Table 1. Year 1992 was relatively cooler than other years, and since potential for evapotranspiration does not change very much from year to year, the 1992 ET data represent an average potential for evapotranspiration in the semi-arid climate of western North Dakota. Compared to the normal precipitation, the potential for evapotranspiration in the growing season is about 2 to 4 times higher than the amounts of rainfall. When we compare the monthly ET to actual rainfall amounts during these four years, the dominance of ET in the water balance is very significant. This data also supports the use of CV of soil water content as an indicator to identify profiles that have high capacity for infiltration and hence high potential for removal of water by evapotranspiration.

Coefficient of Variation of Soil Water on Abandoned vs. Reclaimed Landscapes

Figure 2 compares the CV's of soil water contents measured at different topographic positions along two transects, one each from the abandoned mineland and adjoining reclaimed and undisturbed mineland. The CV's of only the first two depth increments

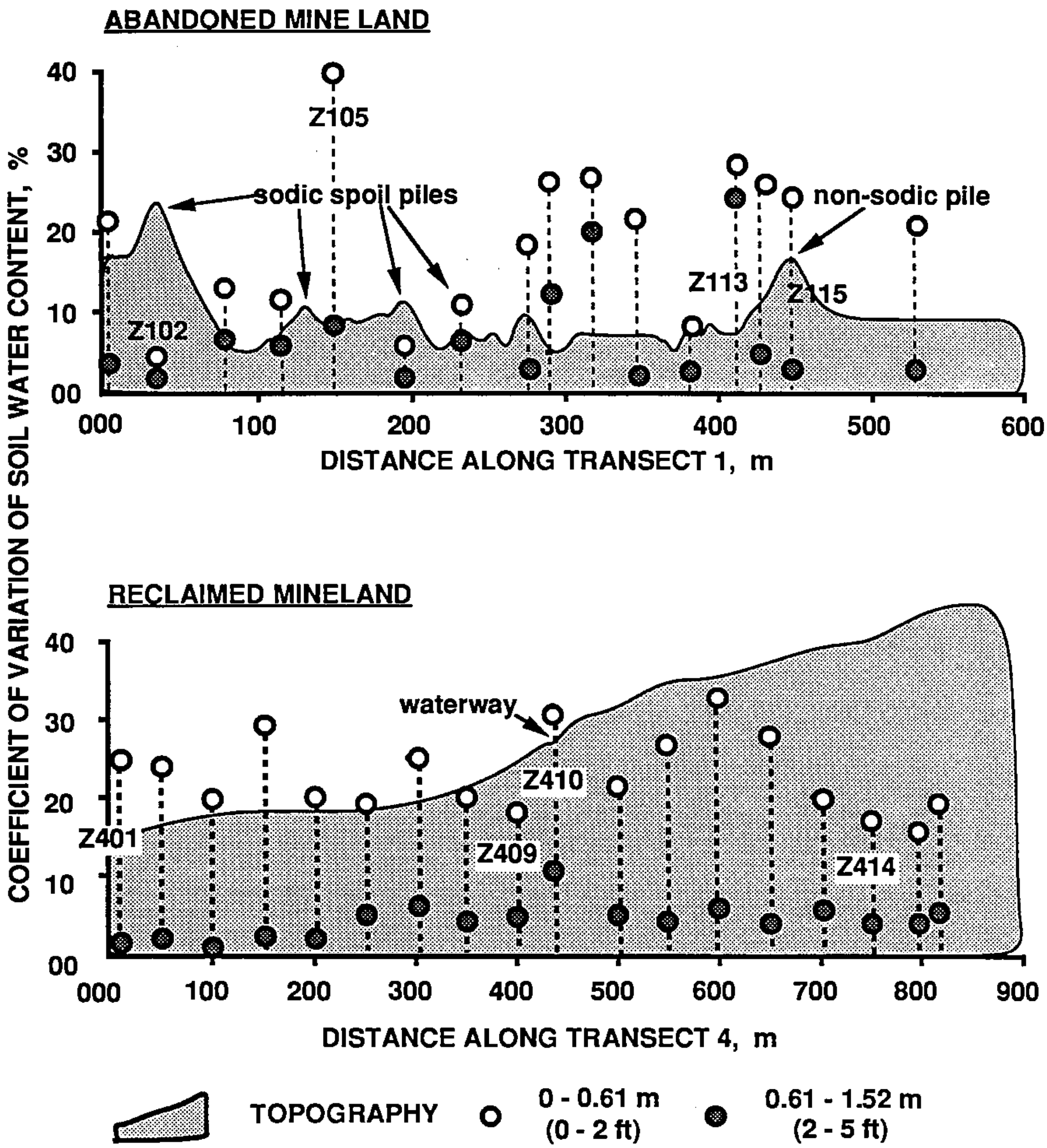

Fig. 2 :Coefficients of variation of soil water measured at different landscape positions along two transects of abandoned mineland and reclaimed mineland at Indian Head Mine during 1989 to 1991.

Table 1: Monthly summer precipitation and potential evapotranspiration (PET) at Indian Head mine, in west-central North Dakota (1989-92).

	Rainfall amounts (mm)					Estimated PET (mm)
Month	**Normal[1/]**	**1989**	**1990**	**1991**	**1992**	**1992[2/]**
April	39	62	10	0	16	78
May	57	61	77	35	22	200
June	90	48	153	58	64	181
July	59	39	43	27	39	183
August	49	41	29	75	25	174
September	43	14	38	75	10	128
October	21	8	7	0	1	80
Total	**358**	**273**	**357**	**270**	**176**	**1024**

1/ North Dakota Agricultural Statistics, 1991 (1951-1980).
2/ Potential open water evaporation calculated by Penman method (Penman 1948).

are illustrated in the figure. Except for few tube sites in good structured depressions in abandoned mineland, the CV's of the third depth increment (5-9ft) were less than 5% in all 82 tube sites in the study area.

The top graph of Transect 1 (Fig. 2) in the abandoned mineland shows that for all the depths on the spoil piles the water movement is insignificant (CV <5%). For depressions near the spoil piles, the topsoil depth increments show good signs of water accumulation but very low movement to deeper depths. For depressions and level slope areas near good quality topsoil or subsoil piles, water moved to deeper depths. The water movement is higher in these areas due to availability of runon water from adjacent areas and higher infiltration capacity of these soils than the depressions near the sodic spoil piles (Sharma et al. 1993).

The lower graph of Transect 4 (Fig. 2) shows the coefficients of variation of soil water contents measured at the 18 tube locations in the reclaimed mineland landscape. Throughout this and the other two transects in the reclaimed landscape (data not shown), water movement was restricted to the top depth (0-0.6m) increment only. The CV's for subsoil depth were less than 5% for the entire transect. Except for a tube on a constructed waterway which showed a CV of 11% at the subsoil depth, the soil water data from reclaimed landscape indicate that, regardless of topographic position, water movement into reclaimed profiles was confined to topsoil and upper subsoil depth only. During these four years of observation, deeper movement of water was limited mainly due to lack of sufficient rainfall coupled with lower infiltration capacity of reclaimed soils (Sharma et al. 1993).

Soil Water vs. Depth at Specific Topographic Locations

Figure 3 shows examples of soil water content distribution with depth and time for four typical topographic sites of Transect 1 from the abandoned mine lands. The upper half of Fig. 3 represents data from summit positions while the lower half shows data from depressional areas. On the summits, tube Z102 is located on a highly sodic spoil clay material (SAR > 20.0) while the tube Z115 is located on non-sodic, topsoil-subsoil mixed material. On the toe slopes, tube Z105 is located in the vicinity of sodic spoil piles, while tube Z113 is located in a non-sodic overburden sediment depositional area. Site Z102 does not support any vegetation, while sites Z105, Z113 and Z115 support

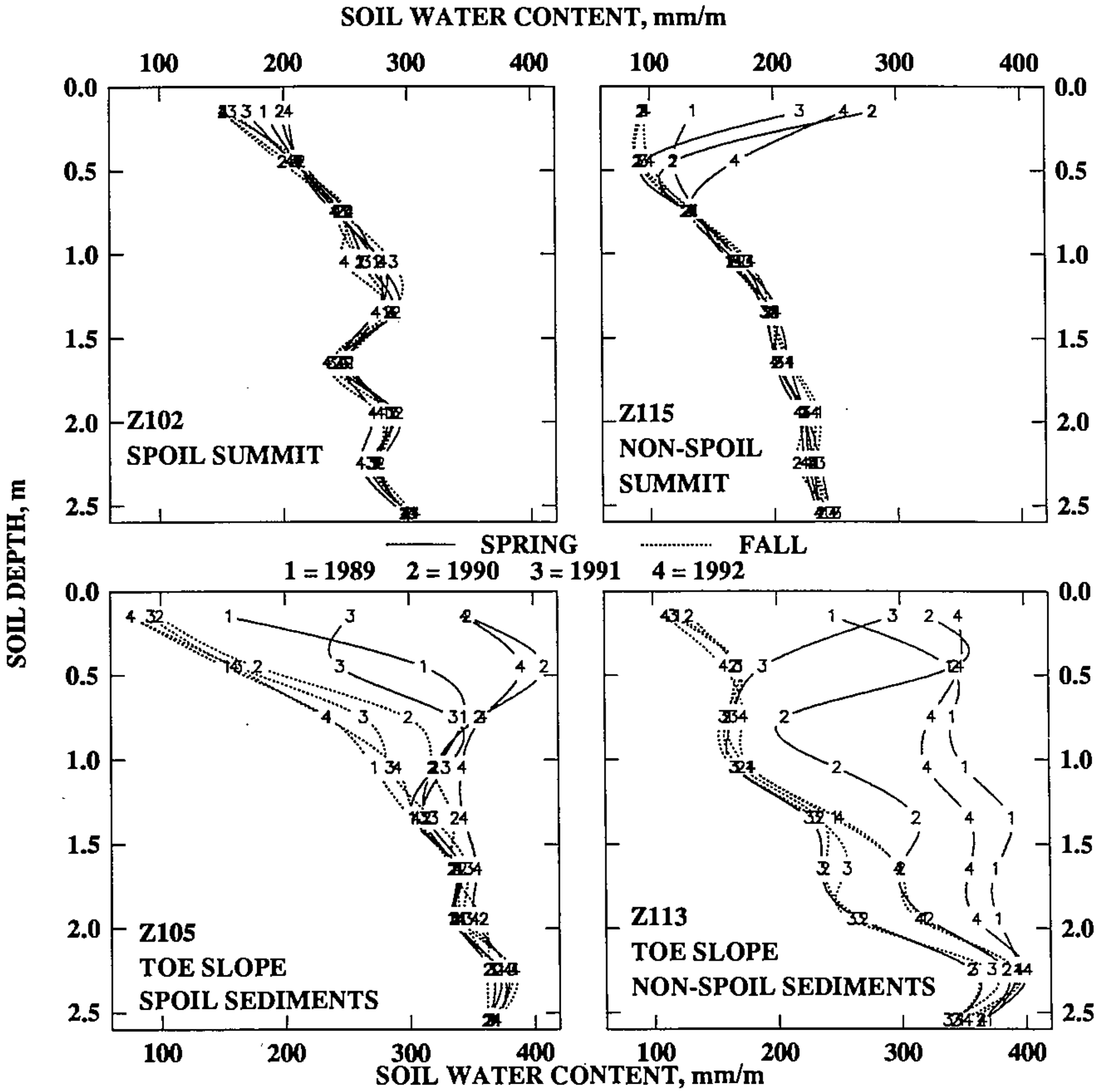

Fig. 3: Soil water content vs. depth at four typical abandoned mine sites.

varying densities of natural grass vegetation. The solid lines represent higher water contents typical of spring and early summer months, while the dotted lines represent typical drier water contents during late summer and early fall months.

Figure 3 shows that soil water readings at tube Z102, a sodic-spoil knoll position (see Fig. 2 for tube locations), show little or no change in water content for the last four years. Compared to that tube Z115, a non-sodic spoil knoll position, shows response of infiltration of water to a depth of about 0.75 m. This demonstrates the effect of sodic spoil clay material in restricting water flow though the profile.

In contrast to the knoll positions illustrated in upper half of Fig. 3, the tubes in depressions, as shown in lower half of Fig. 3, depict greater fluctuations in soil water both at topsoil and subsoil depths. The subsoil in non-spoil depression (tube Z113) shows higher recharge than at depression in the vicinity of sodic-spoil piles (tube Z105) even though the latter site possibly received more runon water from the adjoining upslope areas. The controlling factor for infiltration of water in the depressional areas is the hydraulic conductivity of deposited materials by erosion from steeply sloping overburden piles in the vicinity.

These examples and other data from abandoned minelands suggest that subsoil and vadose zone recharge occurs at localized depressions where sufficient runon water is available from surrounding areas. For rapid movement of water through these profiles, these depressions should also contain non-sodic coarse textured sediments with relatively high hydraulic conductivities. For depressions with sodic-clay sediments, the swelling of clay particles restricts the flow of water to deeper depths. The above data help explain the ground water quality observations of Groenewold et al. (1984) who showed that the soluble salt concentrations under abandoned spoil areas remain quite constant over time, and leaching toward the groundwater table is restricted to very small isolated depressional areas where ponding occurs.

Fig. 4 shows the soil water content vs. depth data for four topographic locations in Transect 4 of the reclaimed and undisturbed landscape. The upper half of the graph shows data for the reclaimed portion of the landscape at toe slope (Z401) and shoulder slope (Z409) positions. These two examples, and data from other tubes in between, show that, regardless of topographic location, the soil water movement was restricted to topsoil and subsoil depth only (<0.9 m).

Tube Z414 near the summit area of Transect 4 in the undisturbed Williams loam also show similar water contents to that of reclaimed soils down below. Only one tube (Z410) in the entire transect showed water movement to deeper depths due to its location in a constructed waterway.

Table 2 shows the amounts of over-winter recharge calculated for typical topographic positions for the abandoned, reclaimed and undisturbed mineland sites exemplified in Figs. 3 and 4. The winter of 1989-90 was very dry with no apparent effect of topographic position or the land type. The relatively higher amounts of over-winter recharge data of 1990-91 and 1991-92 demonstrate that both soil profile characteristics and its position in the landscape affect the soil water storage. In the abandoned minelands, the sodic spoil summit position (Z102) shows the least recharge, and as expected, the non-spoil depression position (Z113) shows the most recharge. Except for the waterway (Z410), the data from the reclaimed minelands show the least effect of topographic position. For the undisturbed profiles where infiltration capacity of soils is not restrictive, the location has a significant effect on the amount of soil water in the root zone.

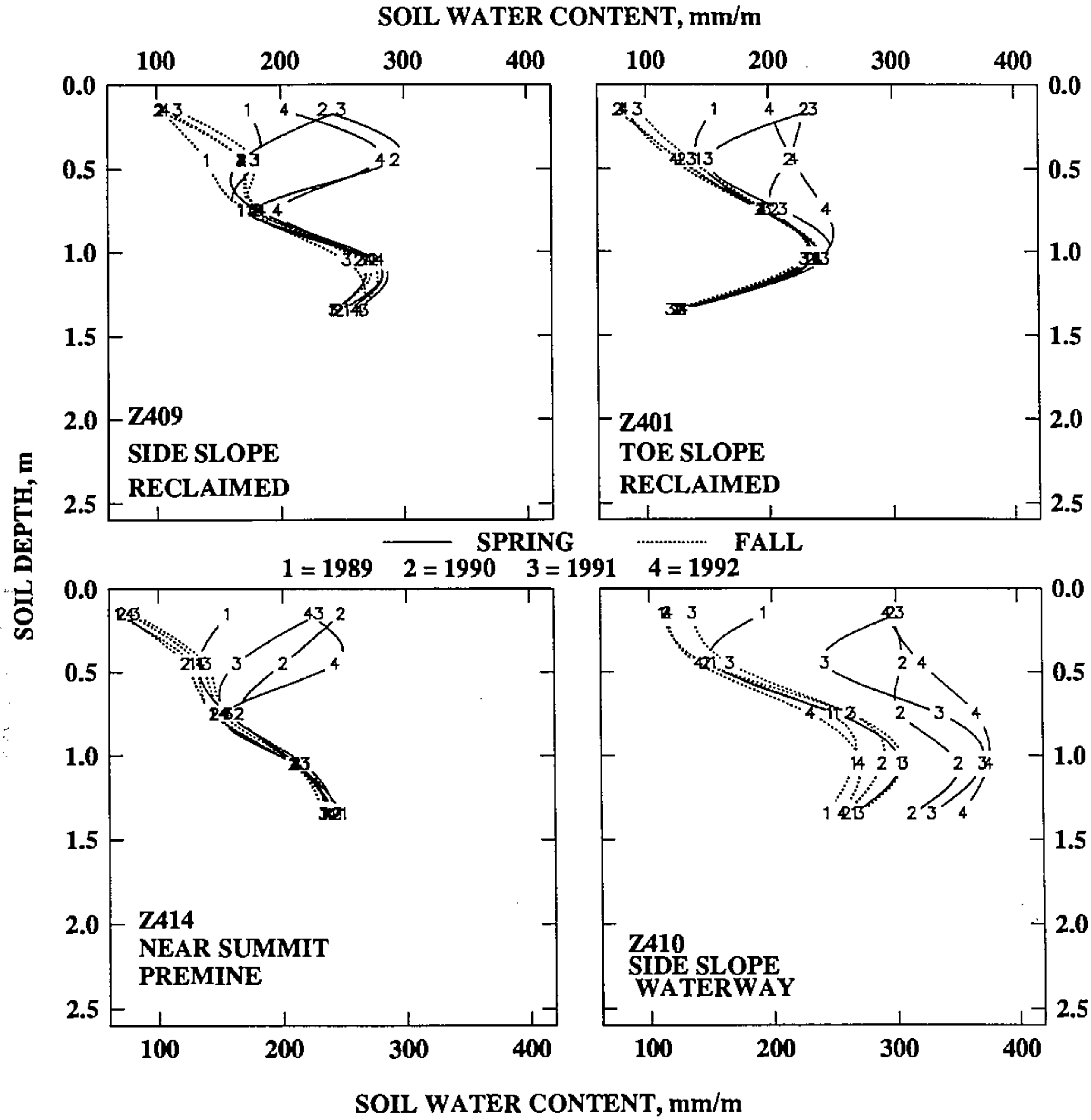

Fig. 4: Soil water content vs. depth at selected reclaimed and premine profiles.

Table 2: Late fall and over winter recharge of soil water (0-1.52 m) at selected tube sites of Indian Head mine in west central North Dakota (1989-1992)

Access Tube	Land Type	Profile Description	Topographic Location	Change in Soil Water (mm/m) 1989-90	1990-91	1991-92
Z102	Abandoned	sodic spoil	summit	4	8	11
Z105		sodic spoil	depression	8	59	157
Z115		non-sodic	summit	2	33	60
Z113		non-sodic	depression	10	46	178
Z409	Reclaimed	perennial hay	shoulder	13	36	58
Z401		perennial hay	toeslope	4	51	60
Z410		perennial hay	waterway	7	108	126
Z414	Premine	perennial hay	shoulder	13	54	56
Z110	Premine	undisturbed	toeslope	7	151	113

Summary

Analysis of four years of soil water data from comparative landscape positions of reclaimed and abandoned mineland transects at the Indian Head mine showed general lack of subsoil recharge during 1989-1992. The observation in this study and that of previous soil water distribution studies by Schroeder and Bauer (1984), Schroeder et al. (1986) and Schroeder and Halvorson (1988) on reshaped, vegetated spoil and nearby undisturbed grassland sites demonstrate that little, if any, water percolates beyond the rooting zone at either the spoil or the undisturbed sites at higher locations. At any location during the growing season, total soil water in the root zone decreases over time, due to upward movement by unsaturated flow in response to gradients created by evapotranspiration.

There was some movement of water at localized depressional areas in the abandoned minelands. For abandoned minelands, the main constraint to water movement is the presence of sodic minespoil materials on the surface. This constraint has been overcome in the post-SMCRA reclaimed soils by placement of varying depths of top soil and subsoil materials on top of the sodic spoils. However, during the reshaping and soil replacement work by earth moving equipment, layering and compaction are added as additional constraints to water flow. These factors limit the movement of water in the reclaimed soils primarily due to reduction in amount of macropores (Potter et al., 1988) and associated decrease in hydraulic conductivities (Sharma et al., 1993). The higher water content data at the water way position indicates that the second constraint to increased soil water storage in the reclaimed profile is the general lack of opportunity for runon water to accumulate and infiltrate into the soil due to creation of continuously rolling and smooth post-mine topography.

Literature cited

Ciha, A. J. 1984. Slope position and grain yield of soft white winter wheat. Agron. J. 76: 193-196.
http://dx.doi.org/10.2134/agronj1984.00021962007600020007x

Doll, E. C., S. D. Merrill, and G. A. Halvorson. 1984. Soil replacement for reclamation of stripmined lands in North Dakota. North Dakota Agric. Exp. Stn. Bull. 514.

Groenwold, G. H., R. D. Koob, and E. C. Murphy. 1984. Hydrogeochemical characteristics of abandoned surface mines in North Dakota - Implications with respect to reclamation. p. 145-190. In: National Symp. and Workshops on Abandoned Mine Land Reclamation, Bismarck, ND. 21-22 May. N. D. Public Service Commission, Bismarck, ND.

Halvorson, G. A., and E. C. Doll. 1991. Topographic effects on spring wheat yields and water use. Soil Sci. Soc. Am. J. 55: 1680-1685.
http://dx.doi.org/10.2136/sssaj1991.03615995005500060030x

Hanna, A. Y., P. W. Harlan, and D. T. Lewis. 1982. Soil available water as influenced by landscape position and aspect. Agron. J. 74: 999-1004.
http://dx.doi.org/10.2134/agronj1982.00021962007400060016x

Penman, H. L. 1948. Natural evapotranspiration from open water, bare soils and grass. Proc. R. Soc. London Ser. A. 193:120-145.

Potter, K. N., F. S. Carter, and E. C. Doll. 1988. Physical properties of constructed and undisturbed soils. Soil Sci. Soc. Am. J. 52: 1435-1438.
http://dx.doi.org/10.2136/sssaj1988.03615995005200050043x

Schroeder, S. A., and A. Bauer. 1984. Soil water variation in spoil and undisturbed sites in North Dakota. Soil Sci. Soc. Am. J. 48: 656-659.
http://dx.doi.org/10.2136/sssaj1984.03615995004800030037x

Schroeder, S. A., and G. A. Halvorson 1988. Soil water depletion under crops on reclaimed and undisturbed soils. J. Environ. Qual. 17: 130-134.
http://dx.doi.org/10.2134/jeq1988.00472425001700010020x

Schroeder, S. A., J. W. Enz, and A. Bauer. 1986. Over winter soil water accumulation in vegetated reclaimed mineland spoil. North Dakota State Univ. Land Recl. Res. Ctr. Technical Report No. 6.

Sharma, P. P., F. S. Carter, and G. A. Halvorson. 1991. Profile scale characterization of infiltration and preferential flow. Agronomy Abstracts, ASA, Madison, WI. pp. 231.

Sharma, P. P., F. S. Carter, and G. A. Halvorson. 1993. Infiltration of water into mineland soil profiles of North Dakota. Paper presented at the NMLRC Symposium 93, Collinsville, IL, April 20-23. National Mine Land Reclamation Center, West Virginia University, Morgantown, WV.

Wollenhaupt, N. C. and J. L., Richardson. 1982. The role of topography in revegetation of disturbed lands. p. C-2-1-C-2-11. In Mining and reclamation of coal mined lands in the northern Great Plains. Proc. Billings, MT. Montana Agric. Exp. Stn. Res. Rep. 194, Bozeman.