SNOW DRIFTING ON PHOSPHATE MINE DUMPS IN SOUTHEASTERN IDAHO

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by

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Introduction

The phosphate mining area of southeastern Idaho is one of the richest sources of phosphate in the United States. The phosphate is mined using surface techniques where the overburden is stripped away and the ore removed. This leads to the building of large waste dumps which must be carefully managed if erosion is to be minimized and a suitable area for revegetation is to be developed. The purpose of this project was to investigate snow distribution, snowmelt and erosion on the mine waste dumps. The work reported here deals only with snow drift formation and snow redistribution on the waste dumps.

The entire phosphate area is one of north and northwest trending ridges which, when combined with the prevailing winter wind and storm patterns, results in considerable accumulation of snow on the leeward side of the slopes. When waste dumps are constructed so that this snow accumulates on the dump face, there exists the potential for large amounts of erosion. Observations of erosion due to snowmelt have been made in a previous study in this area. During a study of slope stability on the phosphate mine spoil dumps in 1973, Jeppson and others (1974) observed that north facing slopes had large soil loss due to snowmelt whereas the west facing slopes had very little. The reasons given for this difference were: (1) microscale surface slumping of small ridges left from construction occurred under saturated conditions on the north faces but not on the west faces of dumps and (2) that the snowmelt rate had been lower on west facing slopes than on north facing slopes. However, no quantitative study was done to determine the actual erosion rates and their relation to snowmelt. Chacho and Molnau (1979a) measured erosion on these waste dumps. They reported on rill erosion measurements on four waste dumps. West facing dumps had very high erosion, north facing dumps moderate erosion and southwest or south dumps had virtually no erosion. In addition, mass wastage was found on all but the north facing dump during a year of above normal precipitation.

The overall topography and weather patterns in the mining region leads to large scale redistribution of snow. However, drift formation can also be greatly influenced on a smaller scale by local topographic changes. The surface mining process with its accompanying waste dumps produces a terrain of mixed slope length and steepness. The slopes are relatively smooth and offer no obstacle to wind, since all vegetation has been removed. However, many terrain breaks are produced in the form of ridges, flattening of slopes and the meeting of slopes of different steepness.

The distribution of snow over one dump in this mine was studied by Chacho and Molnau (1979b). They found that accumulation and melt patterns were the same during 1978 and 1979 despite large differences in precipitation. No correlation was found between water equivalent during peak periods and slope, distance to the ridge or elevation difference for sites with aspects less than 200°. Schmidt (1970) and Martinelli (1975) briefly described the process by which certain terrain features can affect the location and size of snow accumulation in the form of drifts. The topographic effects on drift formation have been described by Tabler (1974), Tabler and Johnson (1971), Schmidt (1970) and Martinelli (1975) in their studies of the design and location of snowfence to control drifting snow. Tabler (1975) has gone a step further and used regression analysis to model drift formation as a function of topography. This model can be applied to any area but needs to be verified before it can be applied to the waste dumps. Tabler (1979) also developed a model for predicting the water equivalent and density behind snow fences. The application of this model to waste dumps would help in erosion prediction.

The management of mine waste dumps from construction to the final stabilized revegetated slope requires a knowledge of the interaction between snow and the waste dumps. The

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water from melting snow can pose a serious hazard to the stability of the slopes since it is a source of water for subsurface flow and also the source of energy for erosion on the waste dump faces.

Study Area

The results reported in this paper are from drift measurements made on six sites, of which four sites were on waste dumps located in a single mine and two sites were on natural ground in the mining area. The basic criterion for the selection of the dumps was the aspect of the dump face. The sites on natural ground were selected on the basis of their windward slope resembling that of the waste dumps.

The four dump sites, Dumps 5, 6, 7 and 8, are very similar in size and shape. Each is constructed with a long, uniform slope with no breaks from top to bottom. Typically the slopes are about 40-45% and the slope lengths range from 100-300 m. The only major difference between the dumps is the aspect of the dump face which ranged from due south to nearly due west (178° to 235°).

The two sites located on natural ground, the Grays Range site and the Dump 2 Ridge site, are also very similar. Both sites were on ridges with long, even approach slopes which were sagebrush and grass covered, and with very steep leeward slopes which ran into aspen or coniferous tree stands. The Grays Range site had a windward slope of 25 to 33% and an aspect of 235°. The Dump 2 Ridge site had a slope of 15-45% and an aspect of 240°.

Methods

The snow transects were laid out as parallel to the drift causing winds as possible. The full transect was surveyed to obtain ground elevation from which approach and leeward slopes could be determined.

The snow measurements were made along the transects with a Federal snow sampler. When the snow was too deep for the sampler (3 meters) a probe was used to get the depth and the density was determined from measurements on either side of the depth measurements. It was felt that this did not introduce significant error since the densities were quite uniform.

Snow Drift Results

The objective of the drift portion of the overall study was to relate the size of snow drifts to the topography of the disturbed area. The purpose is to give the manager a tool to aid in the determination of the quantity of snow accumulation trapped in topographic catchments occurring both naturally and on restructured land. Examples of where this type of information would be used is in the design of off-dump drainage channels on dump tops or in locating dumps in relation to the natural ground to avoid the accumulation of drifting snow on the dump face and creating a potential erosion hazard.

The most successful work done in this subject area has been by Tabler (1975), in which he constructed a multiple linear regression model to predict an equilibrium drift slope as a function of terrain slopes of the catchment area. The equilibrium slope is defined as that snow slope which will exist when a trap has reached saturation. The trap can only reach saturation under theoretical conditions, namely an infinite snow supply. Since this never occurs in nature, the equilibrium slope is a slope which will be approached under field conditions. The usefulness of such a parameter is based on a drift growth pattern where the ultimate depth is approached more quickly than the ultimate length. The drift approaches the equilibrium drift slope in its initial growth stages and as accumulation occurs, the drift grows along near the equilibrium slope but never quite reaching it. This results in a drift with a smooth slope which breaks off sharply in a cornice when the catchment area is far below saturation. In this way, as the drift expands to its maximum size the drift should approach the equilibrium slope predicted by the model.

The model is:

$$Y = 0.25X_1 + 0.55X_2 + 0.15X_3 + 0.05X_4$$

if $X_2, X_3, X_4 < -0.20$ then $X_2, X_3, X_4 = -0.20$

where Y = snow slope over main portion of the drift

X_1 = average terrain slope over a distance of 45 m upwind of the catchment
X_2, X_3, X_4 = ground slopes over distances 0-15 m, 15-30 m and 30-45 m downwind of the trap lip.

Slopes upward in the direction of the wind are taken as positive and slopes downward are negative. For the sites used in this report, the average ground slope of X_1 was assumed equal to the actual slope between the catchment and 45 m upwind since the slopes were nearly uniform in all cases. The variables and definitions of the model are illustrated in Figure 1 for an idealized example.

The study sites included a total of 12 profiles at four transects on natural ground and eight transects on four dumps. The Grays Range site was measured starting in the 1976-77 winter but produced very little data that year due to the drought conditions. The other sites were measured during the 1977-78 and 1978-79 winters from one to four times each year depending on location and weather conditions. The measured and computed drift profiles are shown in Figures 2 through 10. The site terrain data are summarized in Table 1 in the form of Tabler's parameters X_1, X_2, X_3 and X_4 since these are values that can easily be compared from site to site and can be used to compare these data to other locations. Only the maximum profiles for each year at each site are shown in the figures.

TABLE 1: Drift model parameter comparison.

	Tabler's Parameters					Measured Snowslopes				Densities** gm/cm^3	
Site	X_1	X_2*	X_3*	X_4*	Y	1/78	3/78	1/79	3/79	1/78	3/79
D2R-1	0.26	-0.16	-0.35	-0.30	-0.06	0.07	0.05	-0.02	0.06	.44-.45	.41-.47
D2R-2	0.18	-0.26	-0.32	-0.31	-0.11	0.11	0.10	-0.08	0.05	.41-.47	.39-.42
D2R-3	0.35	-0.19	-0.44	-0.11	-0.05	0.03	0.04	0.03	0.02	---	.38-.43
G-2	0.32	-0.54	-0.44	-0.37	-0.07		-0.04		-0.05	.39-.42	---
D5-1	0.30	-0.02	-0.04	-0.06	0.05				0.09	---	---
D5-2	0.40	-0.01	-0.03	0.01	0.09				0.11	---	.34-.46
D5-3	0.33	-0.05	-0.07	-0.04	0.04				0.13	---	---
D7-2	0.47	-0.06	0.13	0.34	0.12	0.15			0.12	---	.42-.47
D8-1	0.39	-0.07	-0.03	0.24	0.07	0.05	0.09		0.11	.46	.34-.40
D8-2	0.40	-0.09	-0.04	0.14	0.05				0.11	---	.36-.40
D6-1	0.48	0.12	0.47	0.66	0.29	0.25	0.28		0.21	---	.38-.46
D6-2	0.46	0.13	0.46	0.85	0.30	0.25	0.34		0.28	---	.37-.47

* Note that for purposes of calculation in Tabler's model those values less than -0.20 are set equal to -0.20.

** Densities are at selected points on drift.

The sites can be placed into three groups based on the leeward ground slope of each site. In this, the off dump sites at the Dump 2 Ridge (D2R-1, D2R-2, D2R-3) and the Grays Range Site (G-2) form a group with large negative leeward ground slopes. All the sites in this group had a negative predicted snow slope ranging from -0.05 to -0.11 as shown in Table 1. The measured slope on the three profiles on the Dump 2 Ridge (Figures 2, 3 and 4) had positive measured snow slopes for peak drift accumulation (3/78, 3/79) ranging from 0.02 to 0.11 but generally in close agreement from year to year at the individual sites. Note that at all three profiles the measured drift profile was greater than the predicted

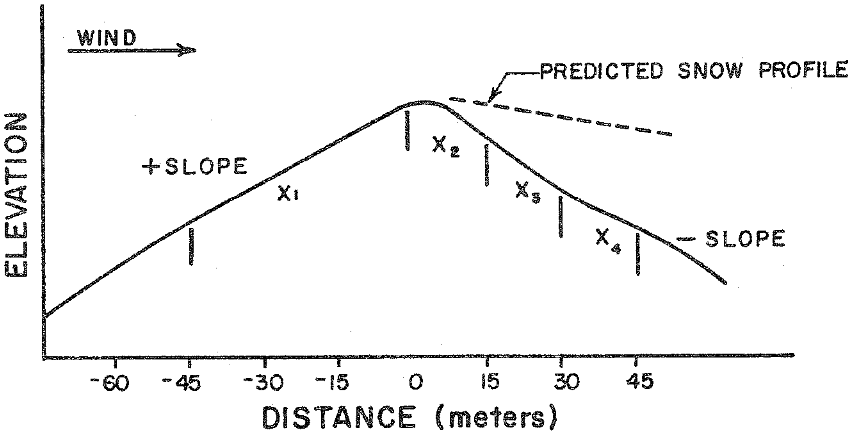

FIGURE 1: Definition sketch of snow drift model variables.

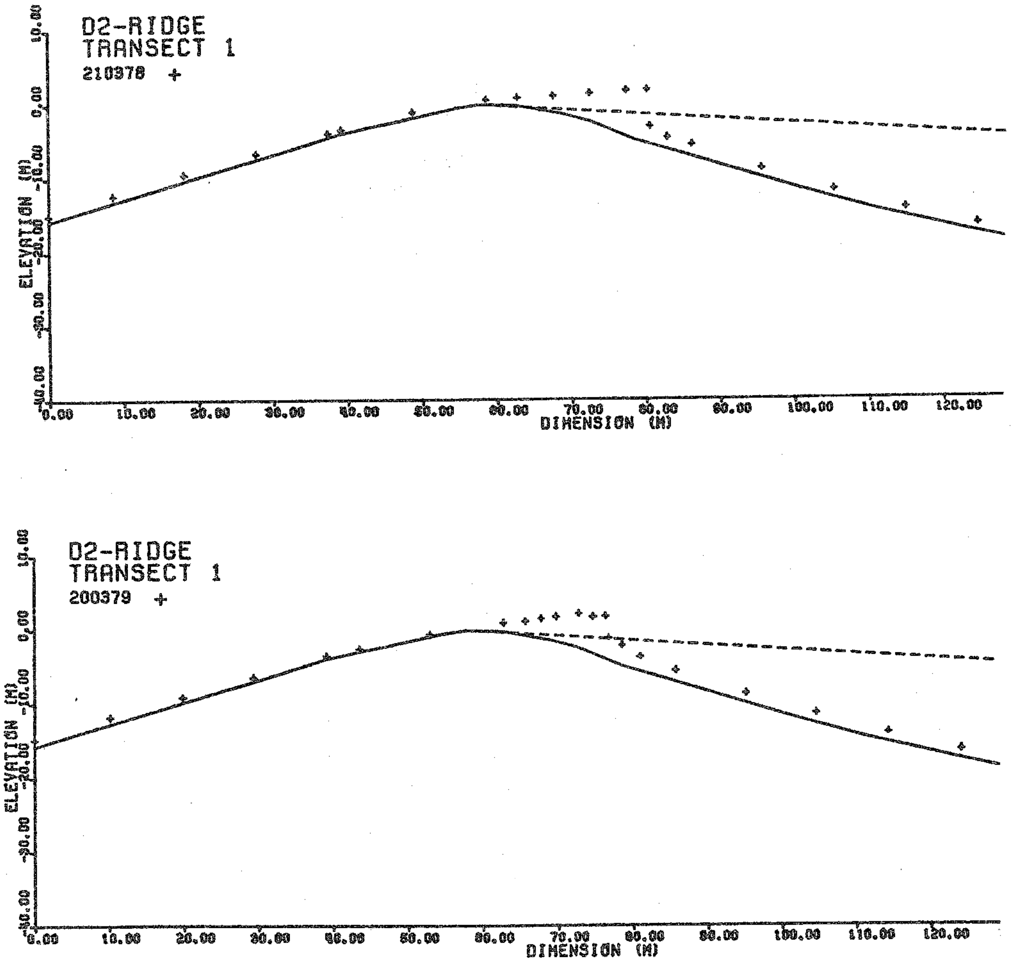

FIGURE 2: Snow profiles. Dump 2 Ridge, Transect 1. 1978, 1979.

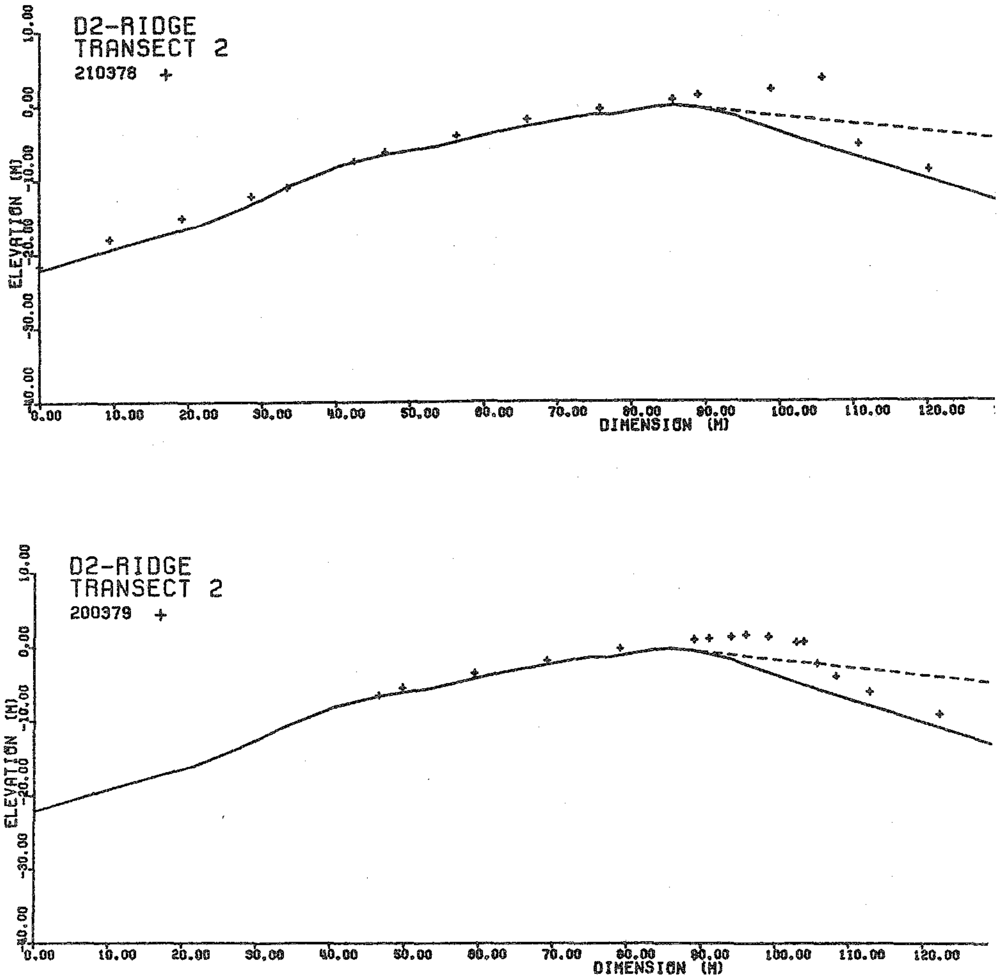

FIGURE 3: Snow profiles. Dump 2 Ridge, Transect 2. 1978, 1979.

drift profile. The Grays Range site (Figure 5) had very good agreement with the predicted profile in both years.

The second group of sites is based on nearly flat or slightly negative leeward ground slopes. The three profiles from Dump 5 (D5-1, D5-2, D5-3), the one profile from Dump 7 (D7-2) and the two profiles from Dump 8 (D8-1, D8-2) fit in this category (Figures 6, 7 and 8). The predicted snow slopes in all cases were positive and ranged from 0.04 to 0.12. The actual profiles were in excess of the predicted in all cases except the Dump 7 site. As can be seen from Figures 6 through 8, the actual profiles seem more rounded at their points of maximum depth than sites in the first group but the predicted profile appears to match the measured profiles much closer than did the sites in the first group. The Dump 7 site (Figure 6) never had a straight slope profile as predicted but was always concave upwards. However, from inspection of the figure, there was close agreement with Tabler's model. The most significant point about this site is that of all the locations only this site never exceeded the profile predicted by the model. There does not appear to be a logical reason for this. Dumps 7 and 8 Transect 1 had a significant rise in the leeward slopes within 45 m of the trap lip but D8-1 had an underpredicted profile just like the others.

The third group consists of the two sites on Dump 6 (D6-1, D6-2) in which the leeward ground slopes are positive (Figure 9). The predicted snow slopes of 0.29 and 0.30 were very close to actual snow slopes which ranged from 0.21 to 0.28 on D6-1 and 0.25 to 0.34 on D6-2. An inspection of the profiles shows very close agreement with the predicted snow slopes on D6-1 and slightly higher accumulations than predicted at D6-2.

The growth in drifts during the year follows the predictable pattern of drift shape, the drift grows to some maximum depth with the profile being an aerodynamic extension of the approach slope. As seen in Figure 10, the January measurement, taken after less than one third of the expected winter precipitation, was already higher than the predicted profile. The February and March measurements are about equal while the May measurement is nearly the same as the January measurement. This particular transect had a very long approach, essentially unobstructed for the entire distance up the slope. There were some trees just over the leeward side of the ridge.

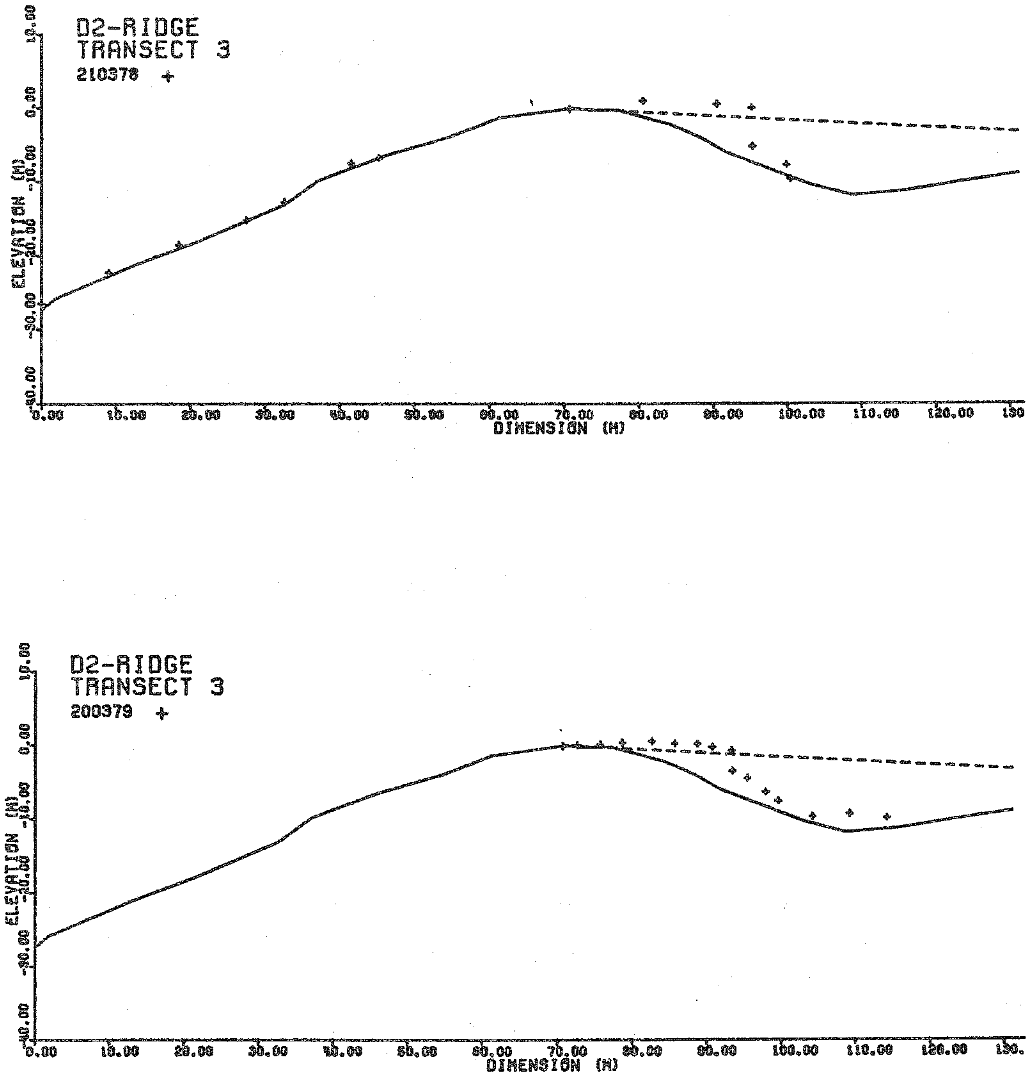

FIGURE 4: Snow profiles. Dump 2 Ridge, Transect 3. 1978, 1979.

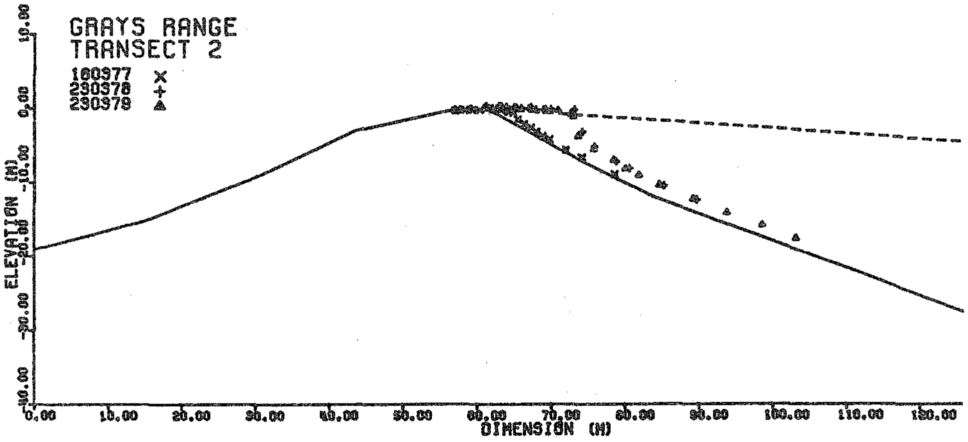

FIGURE 5. Snow profile. Gray's Range transect 2. 1977-1979.

Discussion and Conclusions

In nearly all cases the profiles measured in this study were greater than those predicted by the Tabler model in its present form. This was foreseen by Tabler since the model was developed from data in gentle to moderately rolling terrain. He anticipated that the greater turbulance of more mountainous terrain would cause steeper snow drift slopes. Modification of the model to fit the phosphate mining region was beyond the time limitations of this study. For now, the data provided can be useful in design or management applications. The simplest application is to compute the terrain slopes X_1, X_2, X_3 and X_4 for the location in question, and to compare those values to those in Table 1 to find the best match. By then comparing the matched site's actual slope and predicted slope to the predicted slope of the site in question, an approximate prediction can be obtained.

The amount of water in the drift can be estimated once the profile is known by using an average snow density. The range of densities measured on the drifts at the study sites are also shown in Table 1. The densities were not measured across the entire drift profile but only where depths were less than 3 meters (the maximum depth capacity of the equipment used). The snow density of the profile at depths greater than 3 meters has been assumed to

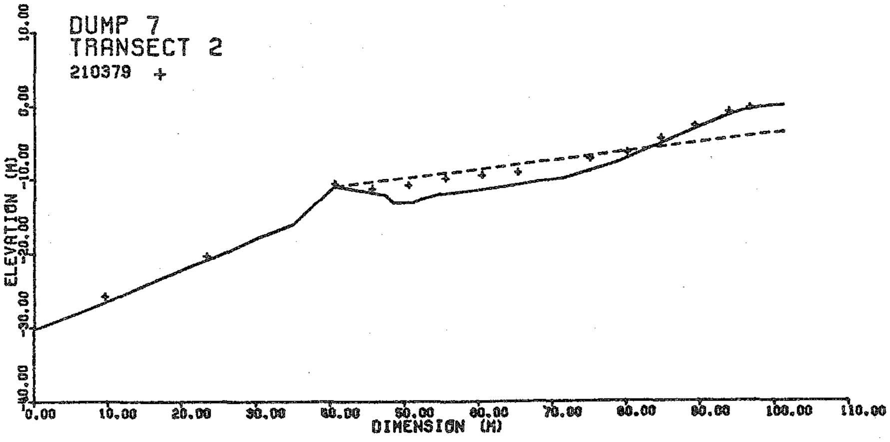

FIGURE 6: Snow profile. Dump 7 transect 2. 1979

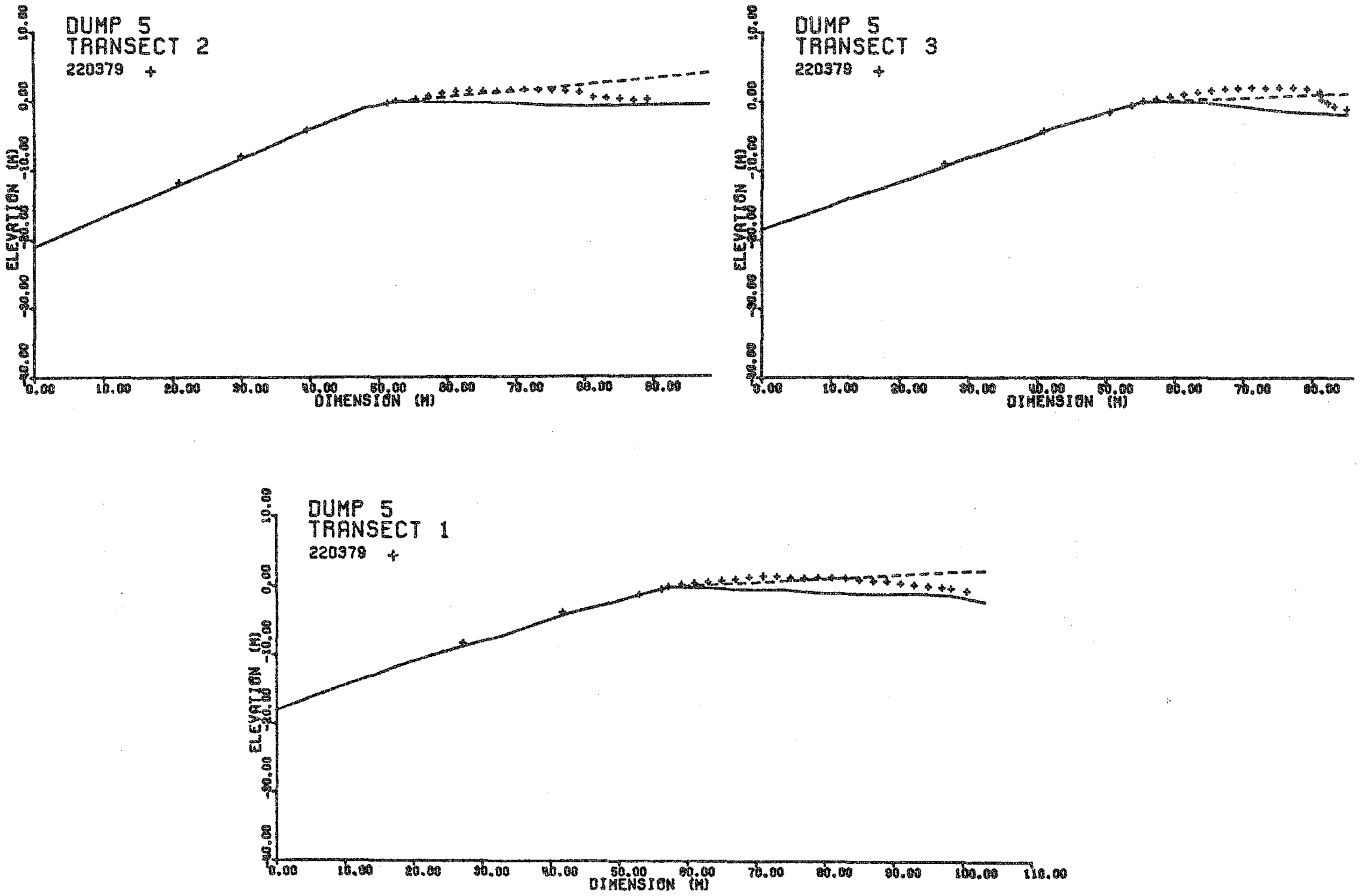

FIGURE 7: Snow profile, Dump 5, transects 1, 2 and 3. 1979.

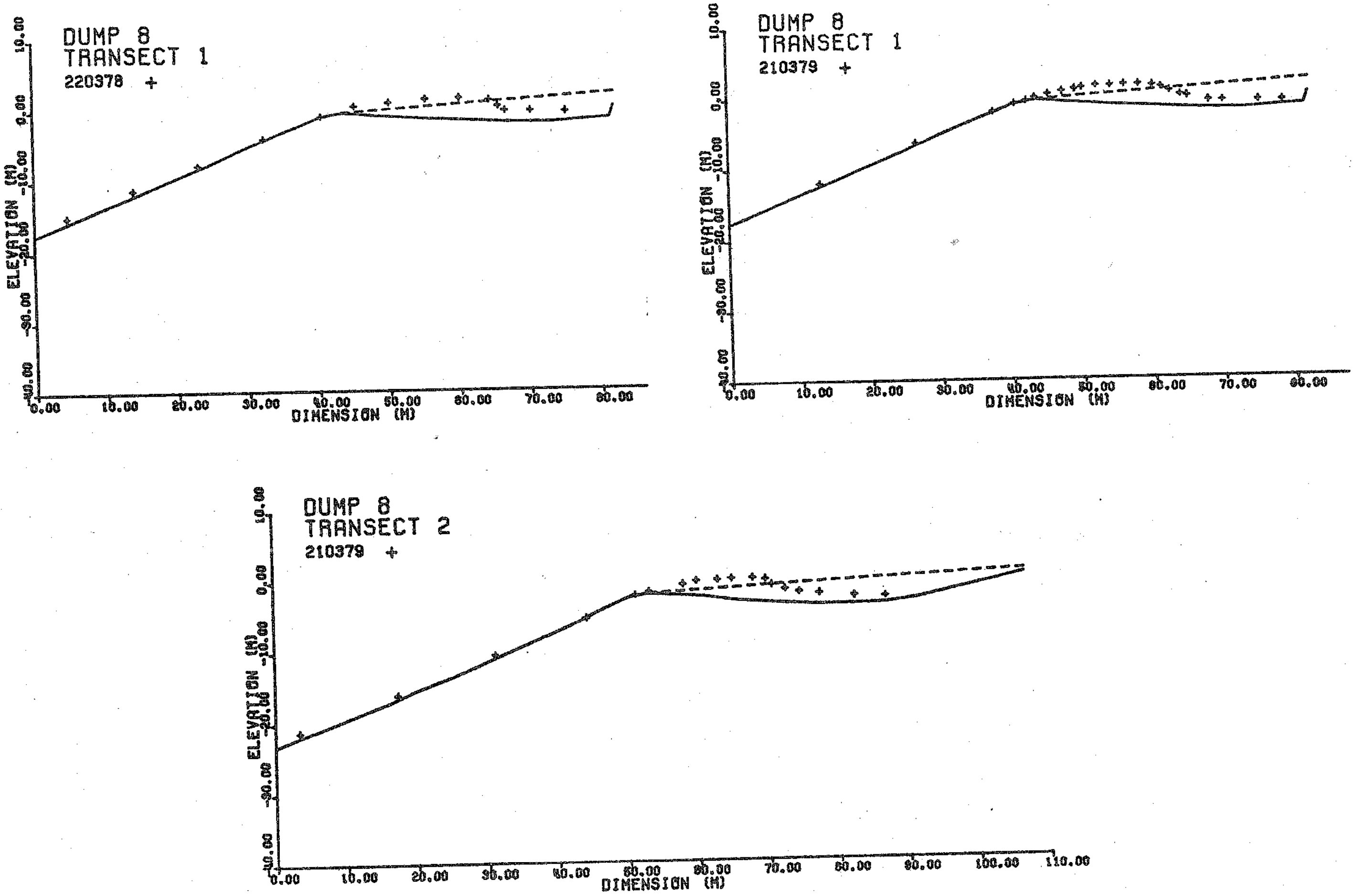

FIGURE 8: Snow profiles. Dump 8 transects 1 and 2. 1978, 1979.

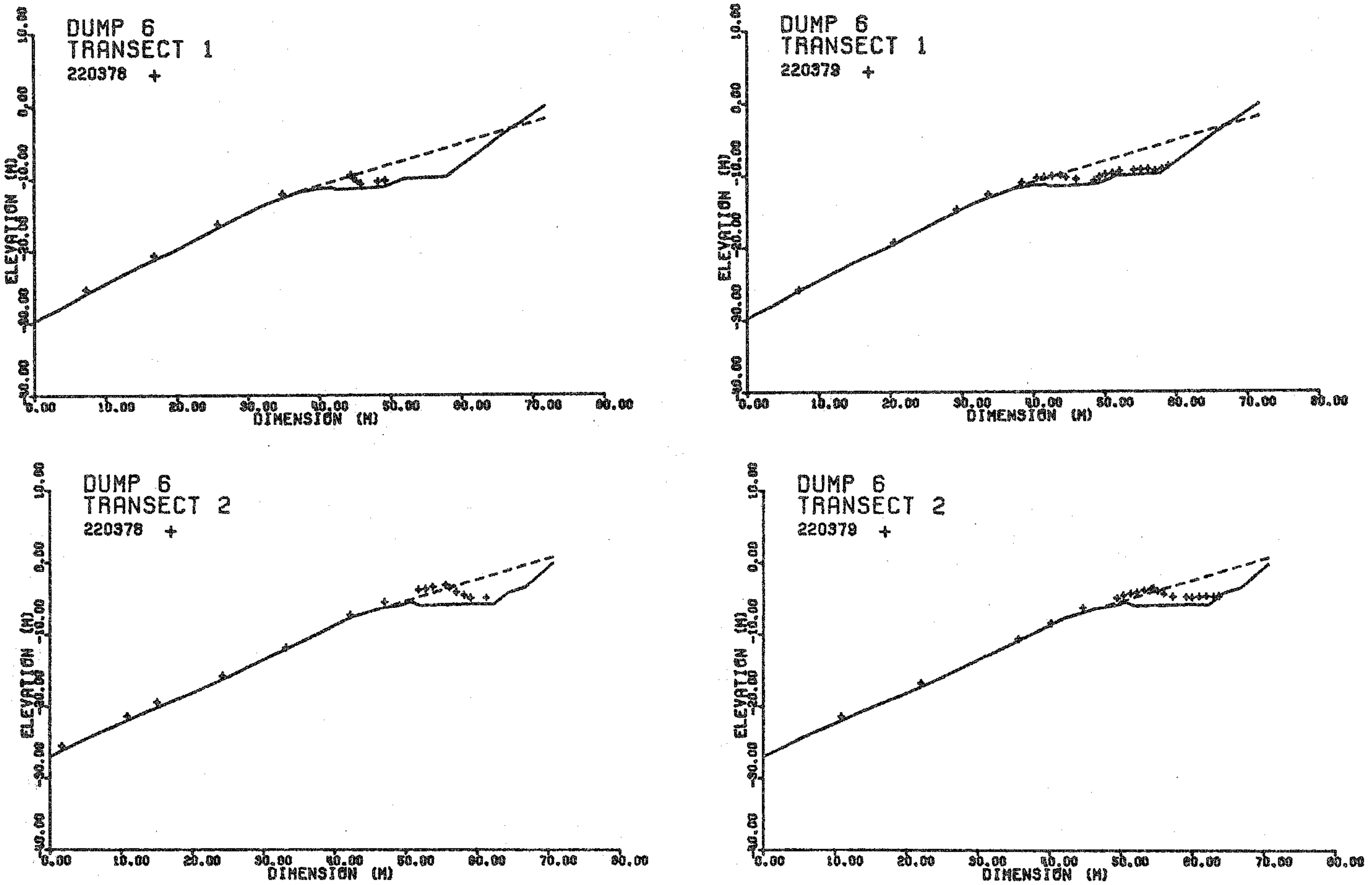

FIGURE 9: Snow profiles. Dump 6 transects 1 and 2. 1978, 1979.

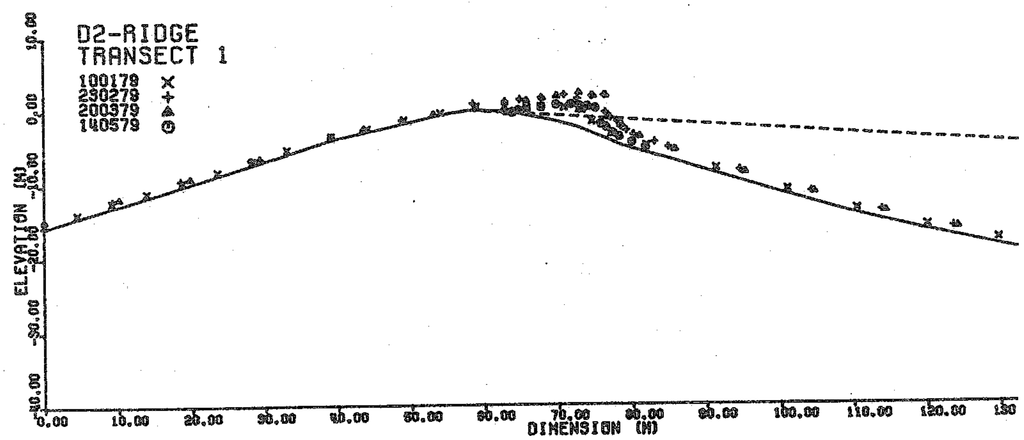

FIGURE 10. Growth and ablation of snow drift during 1979. Dump 2 Ridge.

be in this range and most likely are at the upper limits. The densities for all drifts during the two years of measurements ranged from 0.34 to .47 gm/cm^3. A good average value to be used over the whole drift profile would be about .45 taking into account that the greater depth profile would have a higher density.

The lateral extent of the drift must be computed at incremented distances across the face of the catchment area. Further investigations into drift formation in the phosphate mining area should continue the drift profile prediction as a function of topography and should investigate the areal extent of the drift formation. This can probably be most efficiently studied through the use of aerial photographs to determine areas of drift formation quickly and over a large region. This approach would also require field reconnaissance to get the snow measurements. This technique has been proposed by Radok (1977) and could be used in conjunction with an aerial photography study of erosion in the mining area.

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