THE STUDY OF MINE ROCK EROSION USING SIMULATED RAINFALL AT QUESTA MINE, NEW MEXICO[1]

by

D. Christensen[2], M.J. Reeves, and S. Fortin

Abstract. Open pit operations at a molybdenum mine in northern New Mexico produced over 300 million tons of mine rock between 1968 and 1984. This mine rock was end-dumped into the steep valleys adjacent to the open pit. The mine rock piles typically have angle of repose slopes ranging from lengths of 50 to 600 m. An erosion study was undertaken in support of the development of a mine closeout plan. This paper describes field tests investigating the erosion of mine rock subjected to simulated rainfall. The objectives of the study were to (i) examine the sediment yield rate under varying simulated rainfall intensity and duration; (ii) identify the dominant erosion mechanism on the undisturbed mine rock slopes; (iii) evaluate the effect of antecedent moisture content on the sediment yield rate. The study consisted of two test plots, 4 m in width with a 10 m slope length, subjected to simulated rainfall. The rainfall was introduced at three intensities (48 mm/hr, 80 mm/hr, 108 mm/hr) and three different durations (10 min, 20 min, 30 min). Eroded sediment was trapped in a catchment berm, collected, and dried to determine its mass and grain size distribution. Results show that runoff rill flow was consistent throughout each test but contributed a low sediment yield rate. Mudflows did not occur in every test but dominated the sediment yield rate when they took place. A consistent relationship between the rainfall intensity and sediment yield was not observed. At higher rainfall intensities more erosion occurred when the plot was in a dry condition than when wet, indicating antecedent moisture condition has a large effect on the erosion rate.

Additional Key Words: erosion, rill flow, mudflow, antecedent moisture condition

Introduction

A molybdenum mining operation exists in the Sangre de Cristo Mountains 6 km east of Questa, New Mexico on State Road 38. (See Figure 1) Mining for molybdenum in the Questa area has been on going since the early 1900's. Early underground vein mining gave way to open pit mining of a large, low-grade (0.17%) molybdenum deposit in 1965 continuing until 1981. The mine is presently operating as an underground, block cave mine.

Approximately 350 million tonnes of overburden mine rock were stripped and placed in nine mine rock piles during the open pit production. The piles were constructed by end dumping into the mountain valleys at locations providing the shortest haul distance and elevation change from the area being mined at the time. Wrap-around haul roads were established on pile benches to provide platforms to end-dump material as the open pit increased in depth. This resulted in mine rock piles ranging in height from 50 m to over 600 m with haul road benches at vertical heights of 50 to 200 m.

Objectives

This research work was conducted to create a better understanding of the erosion process present on the angle of repose mine rock piles at the Questa site. The objectives of the simulated rainfall tests were to:

- Examine the sediment yield rate under varying simulated rainfall intensity and duration

[1] Paper presented at the 2001 National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mexico, June 3-7, 2001. Pub. by ASSMR, 3134 Montavesta Rd., Lexington KY 40502.

[2] D. Christensen is a civil engineering graduate student at the Univ. of Saskatchewan, Saskatoon, SK, Canada. M.J. Reeves is a professor of Geological Engineering at the Univ. of Saskatchewan, Saskatoon, SK, Canada. S. Fortin is a geological engineer at Robertson GeoConsultants Inc., Vancouver, BC, Canada.

Proceedings America Society of Mining and Reclamation, 2001 pp 391-398
DOI: 10.21000/JASMR01010391

https://doi.org/10.21000/JASMR01010391

- Identify the dominant erosion mechanism on the mine rock slopes
- Evaluate the effect of antecedent moisture content on the sediment yield rate

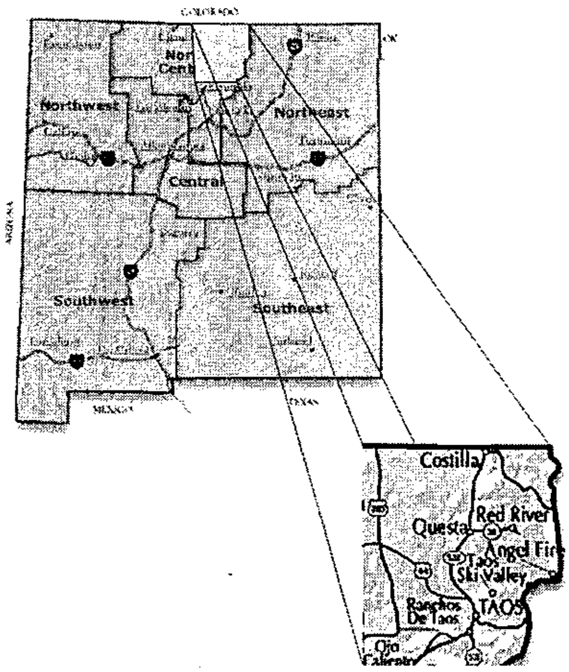

Figure 1. Location of Mine Site (Between Questa and Red River

Erosion Literature Study

Erosion has been extensively studied in Canada and the United States. The majority of these studies have been in the agricultural field leading to the adoption of conservation practices to reduce sediment loss and maintain agricultural productivity. Research has primarily focussed on predicting soil losses from cropland (Gilley et al., 1977).

Zingg (1940) evaluated the effect of slope and slope length on the material lost to erosion for several types of crops and crop rotations. Research work has continued in this area and has led to empirical erosion prediction models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

Erosion research has been extended from the flat slopes of agriculture to the steeper gradients present on mine sites. Typically, slope gradients <10% are examined in agricultural research while mine sites often possess steeper slopes with gradients ranging up to 60 – 80%. Hahn et al. (1985) and Schroeder (1987) quantified the effect of slope steepness (up to 16%) on soil loss of reclaimed spoil from coal strip mining operations. Liu et al. (1994) examined natural hillslopes to observe the effect of slope gradient on soil loss for slopes ranging from 9% to 55%. Erosion losses from mine rock piles under natural conditions have been studied by Sidle et al. (1993) and Kapolka and Dollhopf (2000). Sidle et al. (1993) constructed 15 test plots at 33% and 50% gradients and measured the total erosion for 4.7 years. Kapolka and Dollhopf (2000) studied plots at 25%, 33%, 40%, and 50% gradients to measure the effects of slope gradient and vegetation on soil loss. The study found that maximum erosion occurred at a 40% gradient and declined slightly at 50%. The remainder of the studies concluded that erosion or soil loss increased with an increase in slope steepness.

Rainfall simulators have been used in research studies to provide control to erosion experiments. Simulators such as the one described by Dunne et al. (1980) allow scientists to control the rainfall intensity and duration delivered to the tested area. Rainfall simulators have been widely used in field experiments (Singer and Blackard, 1982, Hartley and Schumann, 1984, and Truman and Bradford, 1993) and laboratory experiments (Goff et al., 1994, Grosh and Jarrett, 1994, and Ghidey and Alberts, 1994) to simulate the effect of factors such as slope gradient, material type, and vegetative cover on soil loss.

Materials and Methods

The erosion test plots were established on mine rock piles composed of mixed volcanics because they are the most erodible material at the Questa site. The mixed volcanics are primarily composed of andesite porphyry rock with minor amounts of other units such as rhyolite dikes or rhyolite tuff (Robertson GeoConsultants Inc., 2000). The term mixed volcanics is used as a general field classification because the extensive atmospheric weathering and hydrothermal alterations have made field classification difficult. The remainder of the piles consist of aplite porphyry, andesite to quartz latite, and rhyolite tuff units. The mine rock piles stand at angle of repose, approximately 1.4 to 1 (horizontal to vertical) steepness or an angle of 36°.

The effects of rainfall were simulated on two erosion test plots lying adjacent to each other on the Sugar Shack Middle mine rock pile. Each test plot measured 4.0 meters wide by 10 meters long on the slope. The 10 meter long slope was selected as it was thought to be of suitable length to induce rill flow and still be manageable to monitor. The 4.0 meter width was demanded by the sprinkler heads used to create the simulated rainfall. The sprinkler heads evenly distribute rainfall to a maximum diameter of 4.5 meters; they were placed 2.46 m on slope from each other to create a rainfall distribution pattern as shown in Figure 2.

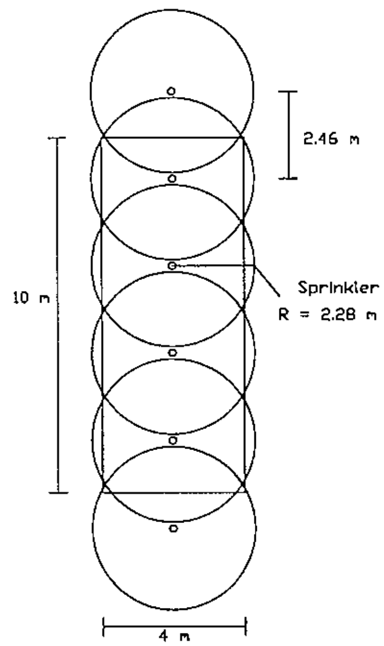

Figure 2. Plan View of the Coverage of the Sprinkler System

The two plots were constructed 30 meters apart from each other on similar materials and slope angles. The first test plot, referred to as TP1, is simply the undisturbed mine rock slope. The slope was left unaltered and care was taken during the setup process not to disturb the surface layer of the test plot area. TP1 was chosen to represent the slope conditions present across the majority of the mine rock piles. The second test plot (TP2) is similar to the first except the top 7.5 to 10 centimeters of the cemented surface layer were removed. TP2 was established to evaluate the effects the cemented surface layer has on the hydrology of the mine rock piles both in terms of infiltration, runoff, and erosion.

The simulated rainfall was delivered using 18 Rainbird sprinkler heads mounted on 19 mm PVC stalks ranging in length from 1.7 to 2.0 m. The sprinkler heads evenly distributed rainfall to a diameter of 4.5 m with the water pressure regulated to 207 kPa (30 psi). The sprinklers were separated into three series of sprinkler heads. Each series was installed parallel to each other up the center of the test plot as shown in Figure 2. 19 mm PVC hosing was used to attach the sprinklers to each other. A three-way valve was installed at the base of test plot allowing control of the water being supplied to the sprinkler heads. By opening one, two, or all three of the valves the rainfall intensity delivered to the test plot could be controlled. The irrigation system was driven by a gas- powered Honda pump supplied by a 11000 liter water tank.

Test Procedure

The test program utilized on the erosion plots examined two variables. The intensity and the duration of the simulated rainfall events was varied with a constant material type and slope angle. Rainfall intensities of approximately 48 mm/hour, 80 mm/hour and 108 mm/hour were used. The tests were run for 10 minutes, 20 minutes, and 30 minutes. Nine tests were run on each test plot, the first test featured the lowest rainfall rate over the shortest duration, the final experiment run saw the highest rainfall intensity continued for 30 minutes. A testing schedule is shown in Table 1.

A catchment berm was constructed at the toe of the slope to trap eroded material. Runoff water was channeled to a 50 mm PVC pipe where the flow rate was monitored. Water samples were taken throughout the test to measure the suspended solids in the runoff water. After the completion of each test, the eroded material on the catchment berm liner was hand shoveled into 20 liter pails for a measurement of the volume. A representative grab sample of the eroded material was collected for laboratory analysis. The contents of the grab sample were dried and weighed to obtain a mass / volume relationship and grain-size analysis. The total sediment yield or erosion was determined by summing the weight of material in the runoff water and the estimated dry weight of the collected eroded material from the catchment berm.

Tests were run early in the morning or late at night to eliminate the influence of wind. An early morning test is shown in Figure 3. The testing schedule was compressed due to time constraints and did not allow drying of the test plot between test runs. Some tests were completed only 30 minutes after the end of the previous tests. Other tests were run after the plot had been allowed to dry during the day or overnight.

Table 1. Summary of Testing Schedule and Erosion Rates for Each Test Plot

Testing on TP #1					Testing on TP #2				
Test #	Date Time	Rainfall Intensity (mm/hr)	Storm Duration (min)	Total Erosion (kg)	Test #	Date Time	Rainfall Intensity (mm/hr)	Storm Duration (min)	Total Erosion (kg)
1	09/04/00 08:30	44.9	10	38.4	1	09/09/00 08:30	55.3	10	27.4
2	09/04/00 09:45	51.6	20	67.9	2	09/10/00 06:30	48.0	20	59.8
3	09/05/00 06:30	40.7	30	99.0	3	09/10/00 07:30	50.4	30	136
4	09/06/00 06:30	76.5	10	143	4	09/10/00 22:30	83.0	10	82.9
5	09/06/00 07:45	87.9	20	299	5	09/11/00 06:45	78.9	20	124
6	09/06/00 19:30	84.1	30	370	6	09/11/00 08:00	68.9	30	166
7	09/07/00 08:30	105.8	10	290	7	09/11/00 21:30	117.2	10	217
8	09/08/00 06:45	106.7	20	194	8	09/12/00 06:30	108.2	20	174
9	09/08/00 07:45	104.2	30	322	9	09/12/00 07:30	105.8	30	279

Figure 3. Simulated Rainfall Test on TP1

Results and Discussion

A summary of the total sediment yield from the test plots for each of the 18 simulated rainfall tests is shown in Figure 4. It was assumed that all sediment eroded from the plots was delivered to the catchment berm as no deposition of material on the slope was visually evident during the test.

The testing schedule did not allow proper investigation of the first objective of the simulated rainfall tests. Each of the simulated rainfall events on the test plots did not begin from a common soil moisture condition. The results of the effects of rainfall intensity and duration on erosion were influenced by the antecedent moisture condition and can not be properly compared to each other.

The erosion from TP1 was always greater than TP2 with the exception of the low intensity 30 minute simulation. The removal of the cemented layer at surface on TP2 reduced the total erosion experienced by the test plot. The test plots were constructed adjacent to each other, however due to the high variability of mine rock deposits it is possible TP2 had a higher rock content at surface. During the testing process, the rill channels on TP2 area became rock lined, possibly reducing the amount of erosion. Increased rock content in the rill channel increases the shear resistance of the channel material reducing the amount of material eroded by rill flow. The cemented surface layer that was removed from TP2 was a finer grained material than the soil beneath. It is possible that the higher erosion rates experienced on TP1 were the result of the finer grained soil layer being removed after rainfall was sufficient to break the cohesion of the cemented layer.

Generally, total sediment yield increased with increased rainfall intensity and duration. Test results from TP1, however, show that the highest sediment yield occurred on the 30 minute medium intensity tests rather than the high intensity tests. TP2 showed increased erosion with increased storm intensity except for the 20 minute test at the highest storm intensity.

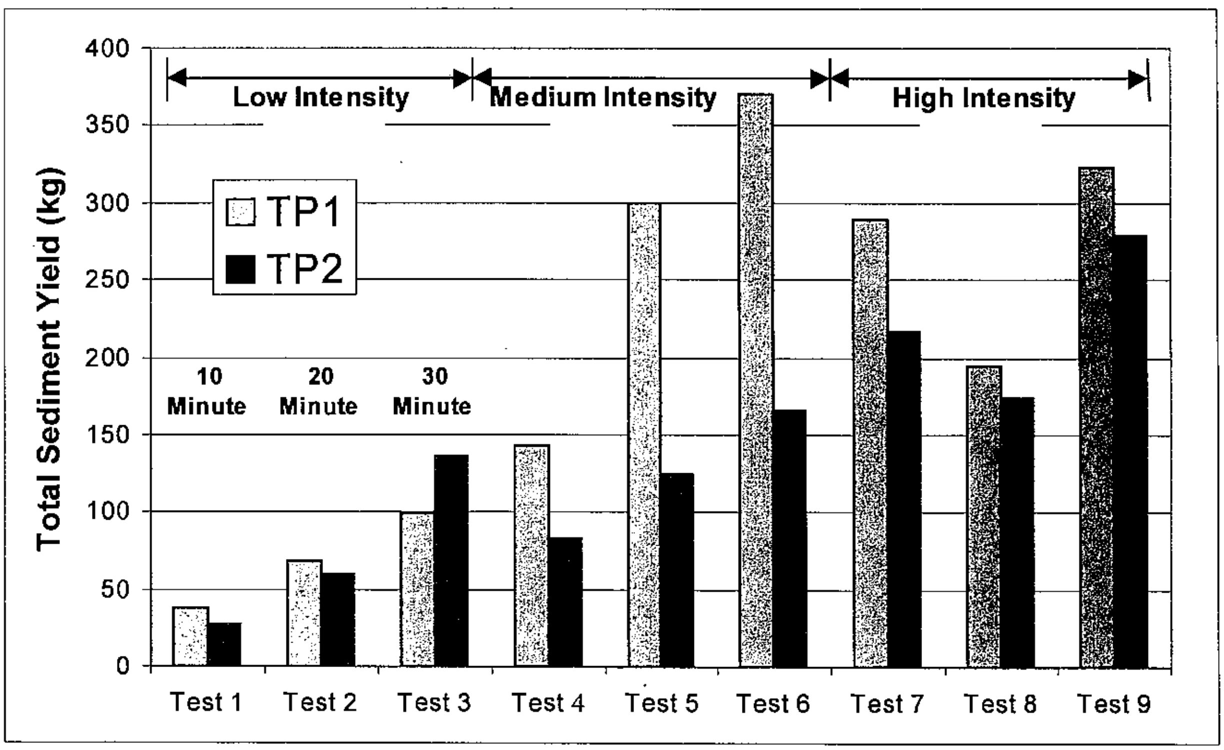

Figure 4. Total Sediment Yield for Each Test on TP1 and TP2

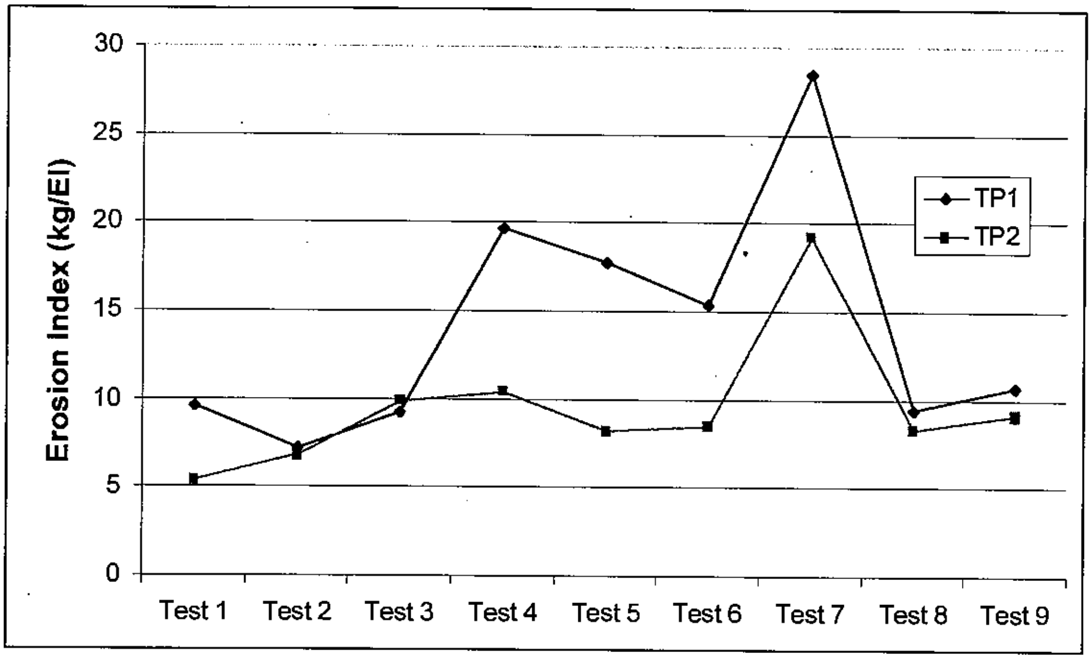

Figure 5. Grain Size Envelopes for Each Test on TP1

Wischmeier (1959) developed a rainfall erosion index for use in the Universal Soil Loss Equation. The EI parameter, the product of the rainfall energy and maximum 30 minute intensity, relates total erosion to the total energy introduced by the rainfall activity. In the simulated rainfall tests completed with factors such as slope angle, slope length, and material type kept constant, the erosion experienced should have a direct relationship to the rainfall intensity and duration. The EI parameter includes both the total rainfall amount experienced in the test and the intensity, allowing all the tests for each plot to be compared. If the erosion occurring is attributable only to total rainfall, the total erosion divided by the EI parameter should be roughly equivalent for each test. As shown by Figure 5, this relationship is not true for TP1 or TP2 and other factors such as antecedent moisture condition are controlling the amount of erosion that is occurring.

Erosion occurred by two mechanisms during the test; rill flow and mudflows or mass wasting. Rill flow occurred when runoff was initiated. Runoff water collected in the pre-existing rills and flowed down the hillslope carrying sediment. Mudflows occurred when the side walls of the rills oversteepened and failed into the channel partially blocking the flow. When these 'dams' are breached mudflows are initiated down the gully. The flowing mass is a mixture of coarse and fine materials that flows like a heavy fluid. Both of these processes contributed to the total sediment yield experienced from the test plots.

Rill flow was present at all times after runoff was initiated. The amount of rill flow present depended on the flow characteristics such as flow depth and velocity of the water in the rills. Material deposited by rill flow was consistent over the span of the tests. Higher rainfall intensities brought higher runoff values, increased the transport capacity of the rill flow and increased sediment yield due to rill flow.

Mudflows did not occur in every rainfall simulation test, however, when they did occur, the mudflows eroded much more material than what was transported by rill flow. Therefore, mudflows dominated the magnitude of erosion in the tests, the test runs with the highest total sediment yield had a high incidence of mudflows. Test 7 for both TP1 and TP2 had the highest number of mudflows and their effect is reflected in the high erosion shown in Table 1 and rates in Figure 5.

The effect of the mudflows can be seen in the grain-size distribution curves obtained from the representative samples taken after each test. Figure 6 shows the results of the grain size analysis for TP1.

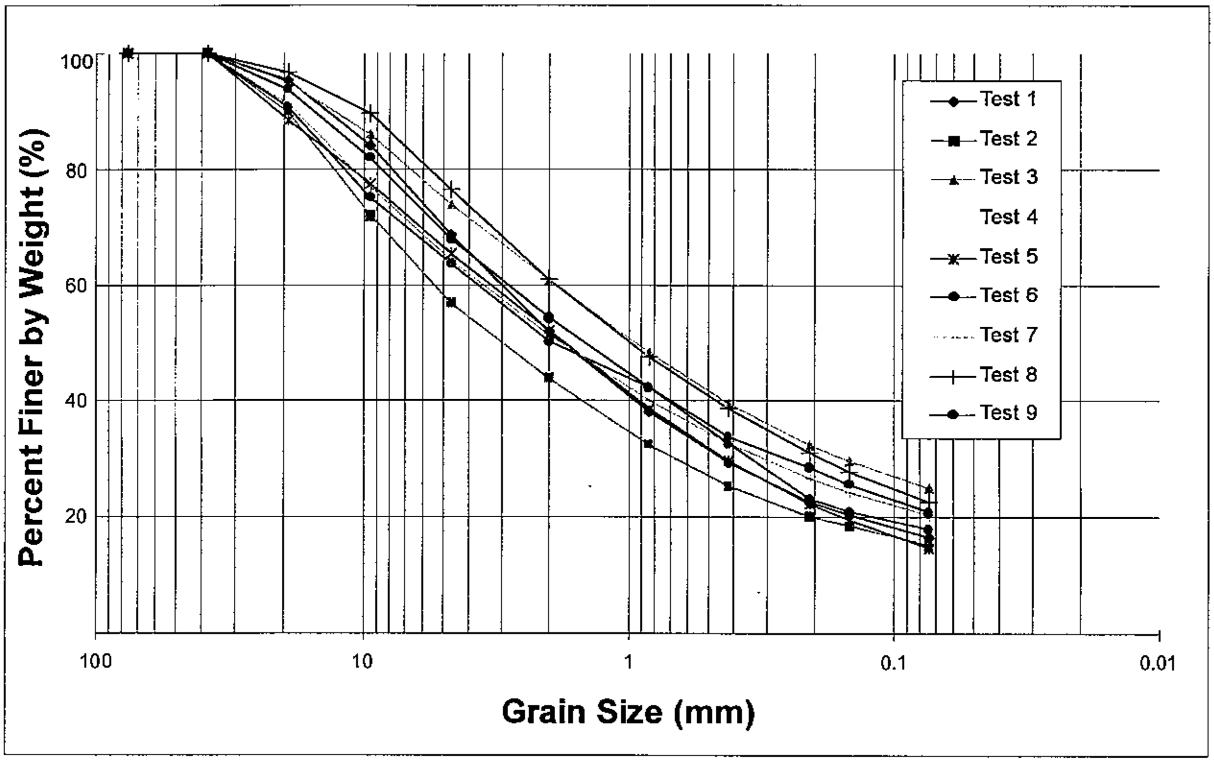

Figure 6. Grain Size Envelope for Tests on TP1

Mudflows result in coarser grain size curves than rill flow, which generally consists of finer material easily caught up in runoff water. Tests 3, 8, and 9 which had low indexed erosion values as shown in Figure 4 produced curves on the fine end of the grain size curve envelope. Tests with higher erosion rates and more instances of mudflows therefore have distributions on the coarse end of the grain-size curve envelope.

Antecedent moisture conditions influenced the amount of sediment yielded from the plots during each test run. Investigations of the effect of antecedent moisture conditions has shown a tendency for increased initial water content to decrease the total soil loss. Hahn et al. (1985) performed back to back tests in which a dry soil was subjected to 50 minutes of rainfall, allowed to dry for 30 minutes, and then exposed to rainfall for 30 more minutes. The erosion rate of the second test was found to be less than the test with the initially dry soil.

If the 18 tests completed are split into "dry" and "wet" antecedent moisture conditions (a "dry" condition occurs when the plot was allowed to dry for greater than 2 hours between tests) the average indexed erosion for "dry" tests is 15.4 kg / EI and "wet" is 11.9 kg / EI for TP1. The difference is not as apparent for TP2 with "dry" tests having an average of 9.75 kg / EI and "wet" tests 9.17 kg / EI.

Test 7 for each test plot was a "dry" test and experienced the highest incidences of mudflows and the highest erosion rate. This could be attributed to cracks developing in the material as it dries. When the material is subjected to high rainfall rates shortly after, water enters the cracks and rapidly decreases the strength of the soil causing it to slump or slough into the rill channel where it is transported down the slope.

Conclusions and Recommendations

Simulated rainfall erosion tests were completed at the Questa molybdenum mine. A total of 18 tests were run on two test plots on the mixed volcanics angle of repose mine rock slopes. Factors contributing to erosion such as material type, slope angle, and slope length were kept constant to examine the effect of rainfall intensity and duration on erosion losses.

A consistent relationship between the total storm energy (EI), as defined by Wischmeier (1959), and soil loss was not observed. Test results from TP1 show that the highest sediment yield occurred on the 30 minute medium intensity tests rather than the high intensity tests. TP2 showed increased erosion with increased storm intensity except for the 20 minute test at the highest storm intensity. These results were influenced by the constrained testing schedule that did not allow a common initial soil moisture condition for each of the tests.

Erosion occurred by two mechanisms during the testing process; rill flows and mudflows. Rill flow erosion occurred consistently when runoff was present. The rill flow detached and transported fine materials and deposited them at the toe of the slope. Mudflows did not occur consistently but when they were present they dominated the magnitude of soil loss during each experimental run. The mudflows were a mixture of fine and coarse material that flowed down the slope like a heavy fluid.

Antecedent moisture conditions influenced the magnitude of erosion experienced during the testing process. Tests that started from a "dry" condition (greater than 2 hours between tests) were shown to have a higher erosion rate than "wet" tests. It is possible that the drying of the test plot creates small cracks in the soil which are inundated with water during subsequent testing and cause failures into the rill channel.

Acknowledgements

The authors would like to acknowledge the research funding provided by the Natural Science and Engineering Research Council for this project. A special thanks to Geyza Lorinczi and Anne Wagner for their approval of the project and help in preparation of the simulated rainfall erosion test plots.

Literature Cited

Dunne, T., Dietrich, W.E., and Brunengo, M.J. 1980. Simple, Portable Equipment for Erosion Experiments Under Artificial Rainfall. Journal of Agricultural Engineering. Vol 25: pp. 161-168.

Gilley, J.E., Gee, G.W., Bauer, A., Willis W.O., and Young, R.A. 1977. Runoff and Erosion Characteristics of Surface-Mined Sites in Western North Dakota. Transactions of the ASAE. Vol 20: pp. 697-700, 704.
https://doi.org/10.13031/2013.35631

Goff, B.F., Bent, G.C., and Hart, G.E. 1994. Influence of Rainfall Intensity on the Interrill Erodibility of Two Rangeland Soils. Transactions of the ASAE. Vol 37: pp. 1445-1448.
https://doi.org/10.13031/2013.28226

Grosh, J.L., and Jarrett, A.R. 1994. Interrill Erosion and Runoff on Very Steep Slopes. Transactions of the ASAE. Vol 37: pp. 1127-1133.
https://doi.org/10.13031/2013.28186

Hahn, D.T., Moldenhauer, W.C., and Roth, C.B. 1985. Slope Gradient Effect on Erosion of Reclaimed Soil. Trans. of the ASAE. Vol 28: pp. 805-808.
https://doi.org/10.13031/2013.32342

Hartley, D.M., and Schuman, G.E. 1984. Soil Erosion Potential of Reclaimed Mined Lands. Transactions of the ASAE. Vol 27: pp. 1067-1073.
https://doi.org/10.13031/2013.32923

Kapolka, N.M. and Dollhopf, D.J. 2000. Effect of Slope Gradient and Plant Growth on Soil Loss On Reconstructed High Altitude Slopes. Proceedings of the 2000 Billings Land Reclamation Symposium. Billings, MT. pp. 75-84.

Liu, B.Y., Nearing, M.A., and Risse, L.M. 1994. Slope Gradient Effects on Soil Loss For Steep Slopes. Trans. of the ASAE. Vol 37: pp. 1835-1840.
https://doi.org/10.13031/2013.28273

Robertson GeoConsultants Inc. 2000. Interim Background Study of Questa Mine, New Mexico. Report No. 052008/6 prepared for Molycorp Inc., June 2000.

Schroeder, S.A. 1987. Slope Gradient Effect on Erosion of Reshaped Spoil. Soil Science Society of America Journal. Vol 51: pp. 405-409.
https://doi.org/10.2136/sssaj1987.03615995005100020027x

Sidle, R.C., Brown, R.W., and Williams, B.D. 1993. Erosion Processes on Arid Minespoil Slopes. Soil Science Society of America Journal. Vol 57: pp. 1341-1347.
https://doi.org/10.2136/sssaj1993.03615995005700050030x

Singer, M.J., and Blackard, J. 1982. Slope Angle-Interrill Soil Loss Relationships for Slopes up to 50%. Soil Science of America Journal. Vol 46: pp. 1270-1273.
https://doi.org/10.2136/sssaj1982.03615995004600060030x

Truman, C.C., and Bradford, J.M. 1993. Relationships Between Rainfall Intensity and the Interrill Soil Loss-Slope Steepness Ratio as Affected by Antecedent Water Content. Soil Science. Vol 156: pp. 405-413.
https://doi.org/10.1097/00010694-199312000-00005

Wischmeier, W.H. 1959. A Rainfall Erosion Index for a Universal Soil – Loss Equation. Proceedings of the Soil Science Soc. of America. Vol 23: pp. 246-249.
https://doi.org/10.2136/sssaj1959.03615995002300030027x

Wischmeier, W.H., and Smith, D.D. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. USDA, Agricultural Handbook No. 537. U.S. Government Printing Office, Washington D.C.

Zingg, A.W. 1940. Degree and Length of Land Slope as It Affects Soil Loss in Runoff. Agricultural Engineering. Vol 21: pp. 59-64.