Report No. RRTAC 87-8

WASTE DUMP DESIGN FOR EROSION CONTROL

by

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Prepared for

The Reclamation Research Technical Advisory Committee

of

The Land Conservation and Reclamation Council

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of Forestry, Lands and Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The Reclamation Research Program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the Research Program, the Council appointed the Reclamation Research Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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14th Floor, Standard Life Centre
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This report may be cited as:

Chopiuk, R.G. and S.E. Thornton. 1987. Waste Dump Design for Erosion Control. Alberta Land Conservation and Reclamation Council Report #RRTAC 87-8. 50 pp.

Additional copies may be obtained from:

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RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

N/A 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker, and P.F. Polster. 2 vols, 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. H.P. Sims, C.B. Powter, and J.A. Campbell. 2 vols, 1549 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 2 vols, 676 pp.

DESCRIPTION: This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symboints in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarzies the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

** 27. RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp.

DESCRIPTION: Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual included provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

** 28. RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik, and D.G. Walker. 174 pp.

DESCRIPTION: This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area.

** 29. RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (compiler). 218 pp.

DESCRIPTION: Technical papers were presented which describe: the mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

* 30. RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

* 31. RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp.

DESCRIPTION: The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the east slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed.

** 32. RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp.

DESCRIPTION: The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions.

* 33. RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp.

DESCRIPTION: The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

Available from: Publication Services
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Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
*** A $20.00 fee is charged for handling and postage.
N/A Not available for purchase but available for review at the Alberta Environment Library, 14th Floor, 9820-106 Street, Edmonton, Alberta T5K 2J6.

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* Please contact the author for information on these appendices

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ABSTRACT

The Waste Dump Design for Erosion Control study was initiated in 1983. Several foothills/mountain coal mine waste dumps were selected for the purpose of evaluating the effects of final configuration on the amount of surface erosion occurring on those dump surfaces. A series of research plots was established on the reclaimed slopes, and a program to monitor the amount of material movement on the slopes was begun.

The objectives of the program were:

1. To determine the influence of the length and steepness of reclaimed waste dump slopes on erosion;
2. To determine the effect of time and vegetation cover on erosion (i.e., does the age of the material, since reclamation, affect the amount of material movement on the slopes); and
3. To develop, if possible, a model that will predict the effects of those factors contributing to erosion that are within the control of the mine operator, namely slope configuration and nature of material used to cover the slopes.

Data on the movement of the slope surfaces were collected twice in 1983, three times in 1984, and three times in 1985. The total amount of elapsed time between the final measurements obtained in 1985 and the time monitoring began in 1983 was 24 to 26 months.

This report presents a history and outline of the project as well as a discussion of the results of the monitoring program. The analyses which were performed on the data included checks on the frequency distribution, plot means and standard deviations, analysis of variance, t-tests for paired variables, rejection of outliers, and regression. The data were compiled in tables and graphs and placed in Appendices A through K under separate cover. **Due to the large volume of material in these Appendices, they have not been reproduced in this report. Readers should contact the author for information regarding availability of the data in the Appendices.**

In general, the most reliable and dramatic results were obtained from the one slope which was monitored as soon as reclamation was completed. Over the two-year time period that erosion was measured, the total amount of erosion on most other slopes was minimal which made it difficult to establish models or trends of the influence of contributing factors on erosion itself. A general observation of all the results, based on two annual periods of erosion measurement on the slopes, is that there appears to be no need for a great deal of concern about waste dump erosion. Other than for a small initial amount of surface deflation immediately after regrading is complete, no significant amount of material seems to leave the slopes. From knowledge of the nature of the materials involved (i.e., extremely coarse-grained "topsoil" overlying blocky, angular waste rock) one concludes that even measurable erosion is mostly likely redistributed over the slope itself (as evidenced by numerous deposition results of plot measurements). One year after resloping, measured erosion becomes almost insignificant as fine particles have been deposited in voids in the waste rock.

Within the limits of the waste dump design parameters studied, there appears to be no reason to establish design criteria from the standpoint of erosion control. There was also no evidence to support the need for erosion intercepts (dozer cuts located diagonally across the slope face), supported by the results from the long, undisturbed Slope 2 at Tent Mountain.

1. INTRODUCTION

1.1 BACKGROUND

Most studies related to surface mine hydrology have centred on estimating sediment yield rates and volumes for entire regions and watersheds. Little emphasis has been placed on site-specific analysis of erosion. The commonly-used Universal Soil Loss Equation (USLE) pertains mainly to agricultural land, usually for slopes less than 20 degrees. Published data for slopes in the 20 to 30 degree range are very scarce, hence the need for information directly related to coal mine waste dumps.

Essentially, no information was available on the soil erodibility factor of exposed spoil material. Also, no data on erosion existed for length-slope factors beyond 120 m and 20%.

In 1982, the Coal Mining Research Company (CMRC) undertook a project to determine the slopes that were being achieved through regrading of coal mine waste dumps in the foothills/mountain areas. The second phase of the project involved determining the amount of erosion that could be expected from typical waste dumps in the foothills/mountains. A number of waste dump areas were selected in 1983, monitoring began in August 1983, and continued until October 1985.

1.2 OBJECTIVES

The second phase was designed to examine the effects of the regraded configuration (i.e., slope angle and slope length), waste material characteristics, age since reclamation, amount of precipitation, and vegetative cover on the amount of surface erosion occurring on the resloped faces of the waste dumps. The information will be useful in determining practical guidelines for waste dump reclamation and design. The ultimate goal was to predict the influence of dump configurations and design, including the effects of terraces, on erosion quantities.

2. STUDY AREAS

Plots were established at three mine sites in Alberta: Tent Mountain, located near Blairmore; Smoky River, near Grande Cache; and Cardinal River, south of Hinton. A description of the slope and the plot layout at each location follows.

2.1 SMOKY RIVER

A site map of the research slopes appears in **Figure 1**. Slope cross-sections are shown in **Figures 2 to 5**.

SR1 (No. 8 dump - Figure 2)

- approximately 150 m long;
- resloped to 23 to 26 degrees;
- old, heavily vegetated surface;
- monitoring consists of five transects at approximately equal intervals down the slope;
- 5 erosion pins are located within each transect.

SR2 (Haulroad dump - Figure 3)

- approximately 50 m wide by 100 m long;
- resloped to 20 degrees;
- entire surface is "topsoiled" with vegetation beginning to establish itself;
- surface extremely rough;
- monitoring consists of 25 plots (5 replicates and 5 transects) and 3 additional plots installed to monitor a diagonal diversion trench across the slope;
- the surface materials were described as weathered clay shale, pieces to 1-1/2", med plastic, some silt, and a trace of fine sand, grey, fine roots.

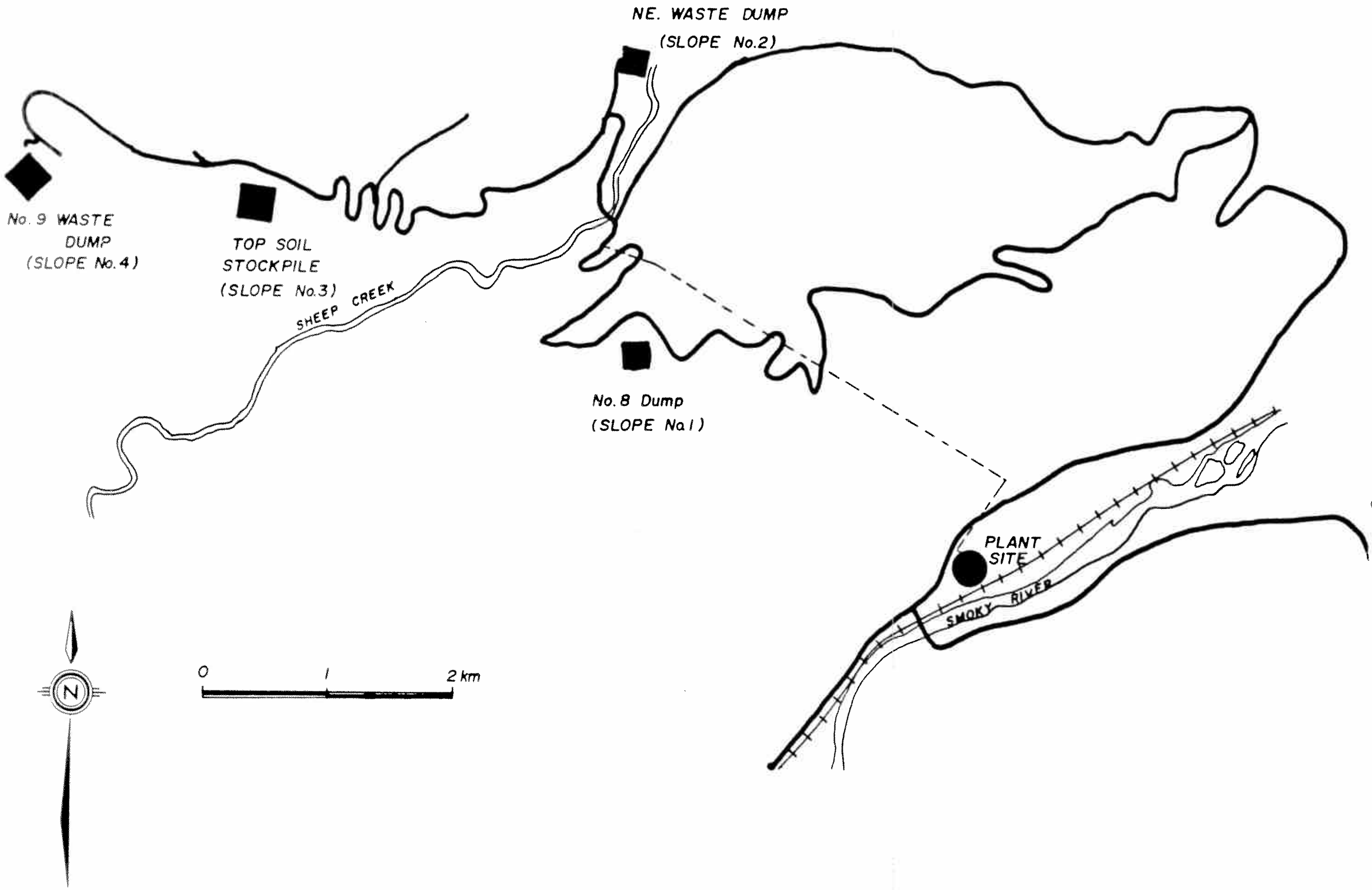


Figure 1. Location of Erosion Research Slopes at Smoky River.

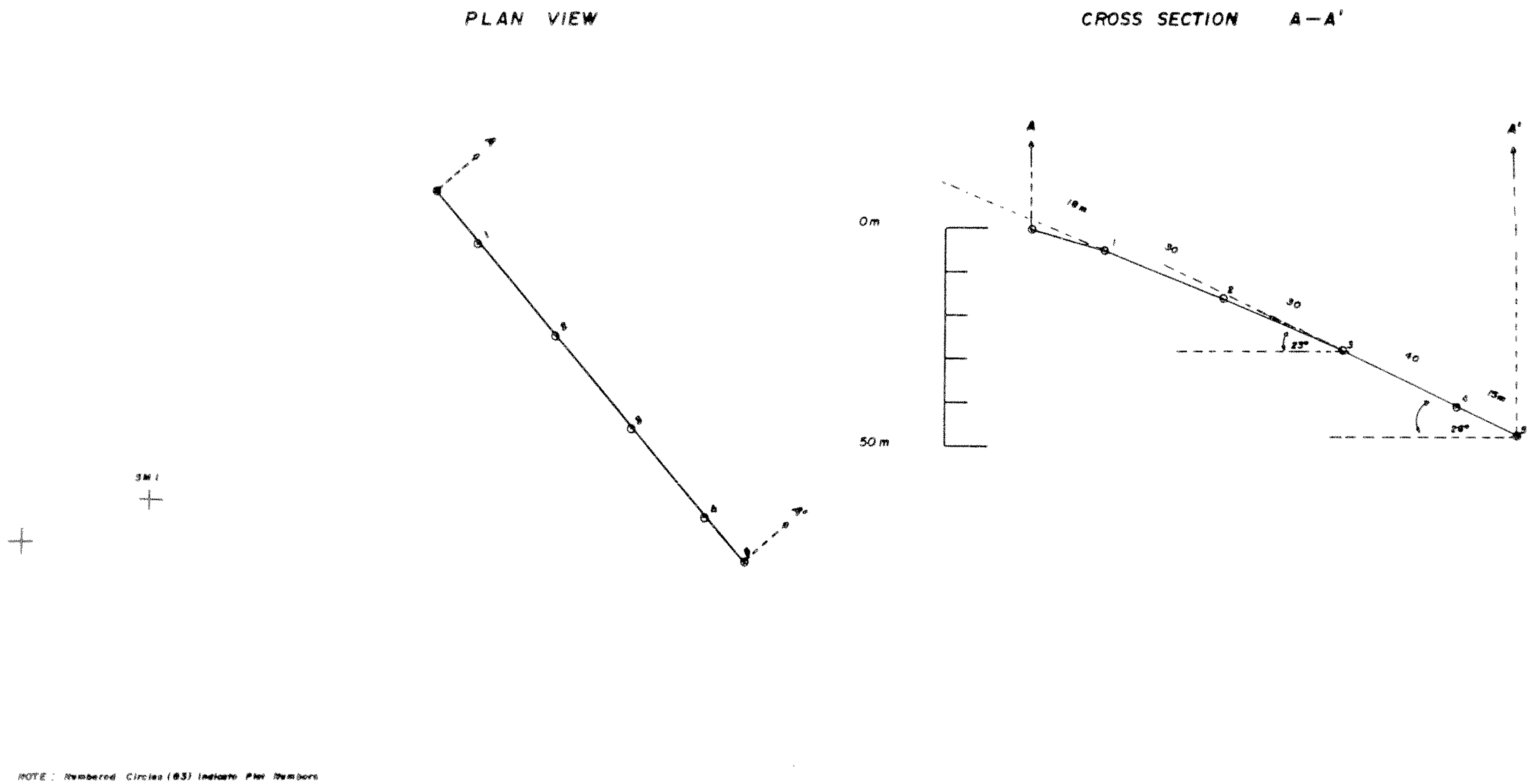


Figure 2. Smoky River No. 8 Spoil Dump Slope 1.

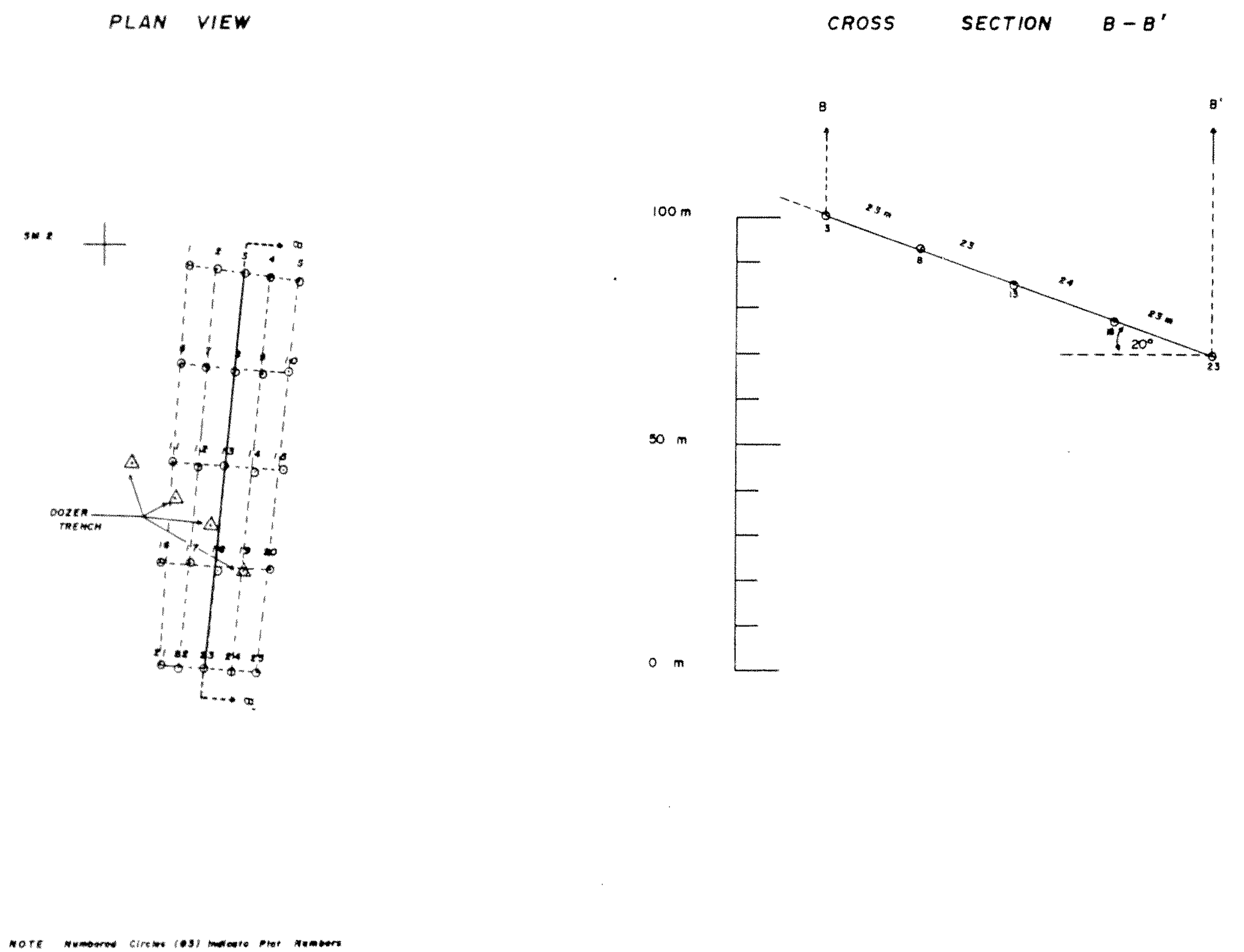


Figure 3. Smoky River NE Waste Dump Slope 2.

SR3 (Topsoiled stockpile - Figure 4)

- approximately 40 m long;
- natural angle of repose, 33 to 36 degrees;
- old weathered surface;
- 16 plots (4 replicates and 4 transects);
- 5 erosion pins in each plot of replicates 1 and 4.

SR3A (Topsoil stockpile adjacent to SR3)

- approximately 40 m long;
- natural angle of repose, 33 to 36 degrees;
- freshly regraded material (1984);
- 4 clusters of 5 erosion pins were installed at 10 m intervals down slope, however material sloughed down the slope, covering the pins.

SR4 (No. 9 dump - Figures 5 and 6)

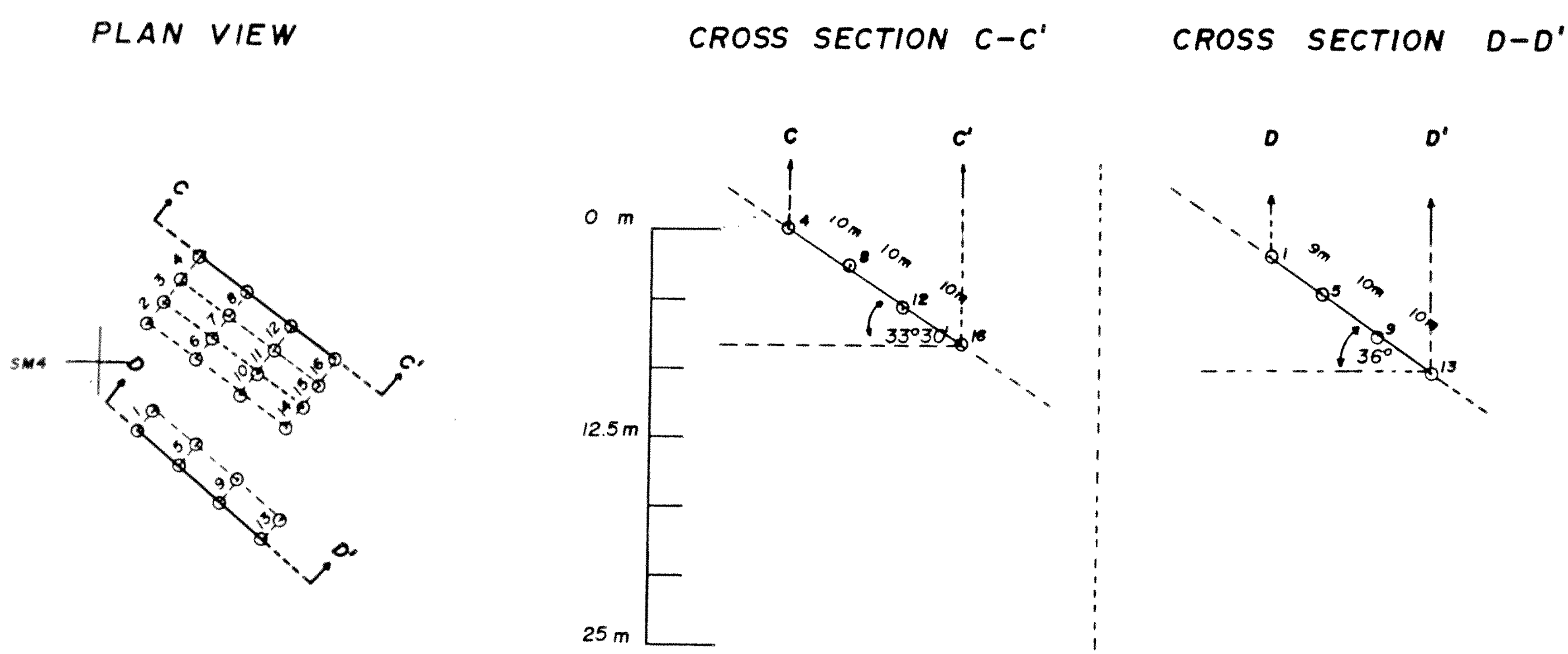
- newly resloped and topsoiled surface (1984);
- approximately 120 m long;
- resloped to an angle of about 23 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4;
- the materials were described as weathered sandstone with a trace of silt, fine grained, low plastic fines, dry, loose, sandstone inclusion, dense, well-cemented, fine-grained. Clay shale inclusion, grey, med plastic, hard. Dilatancy test: slow.

2.2 TENT MOUNTAIN

A site map of the research slopes appears in **Figure 7**. Slope cross-sections are shown in **Figures 8 to 12**.

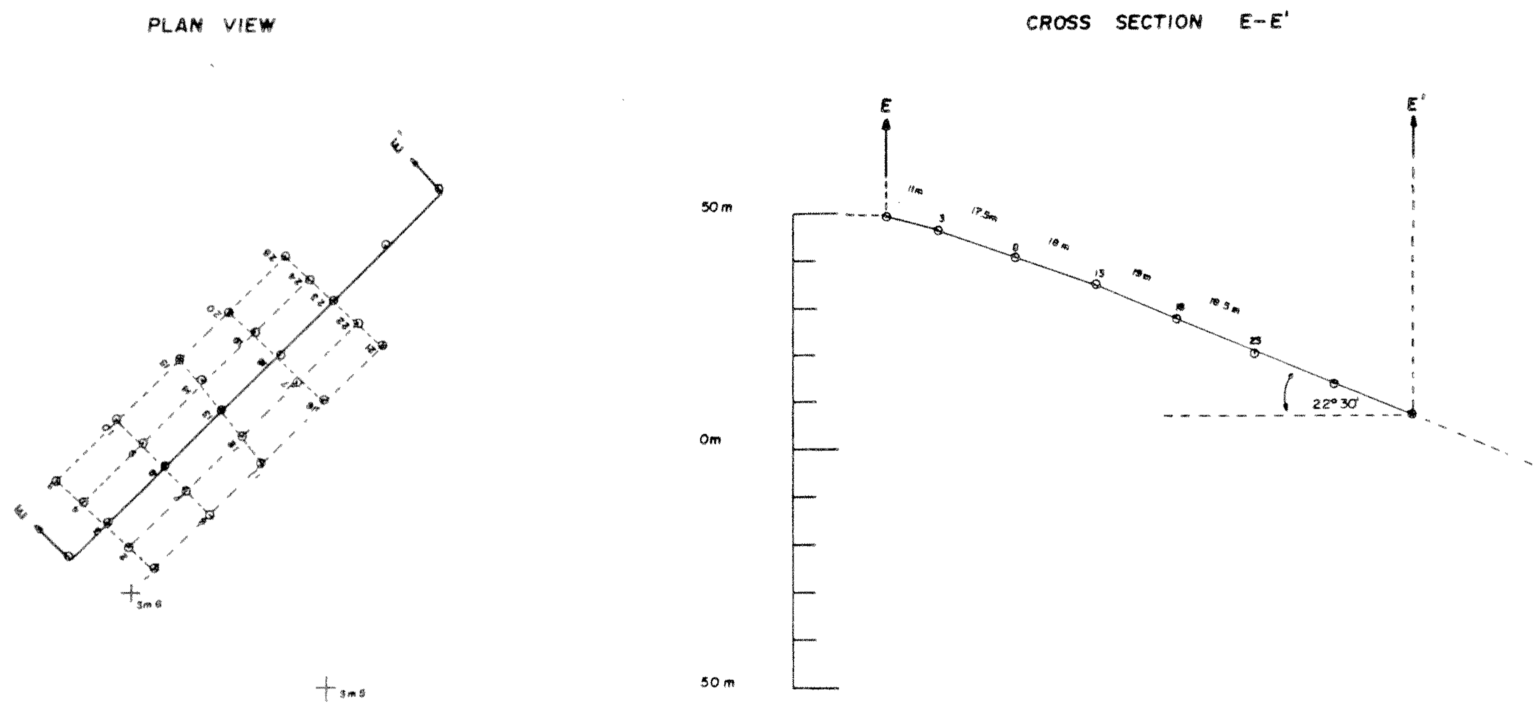
TM1 (Ungraded slope - Figure 8)

- approximately 150 m long;
- natural angle of repose, 37 to 38 degrees;



NOTE: Numbered Circles (⊙3) Indicate Plot Numbers

Figure 4. Smoky River Topsoil Stockpile Slope 3.



NOTE: Numbered Circles (83) Indicate Plot Numbers

Figure 5. Smoky River No. 9 Spoil Slope 4.

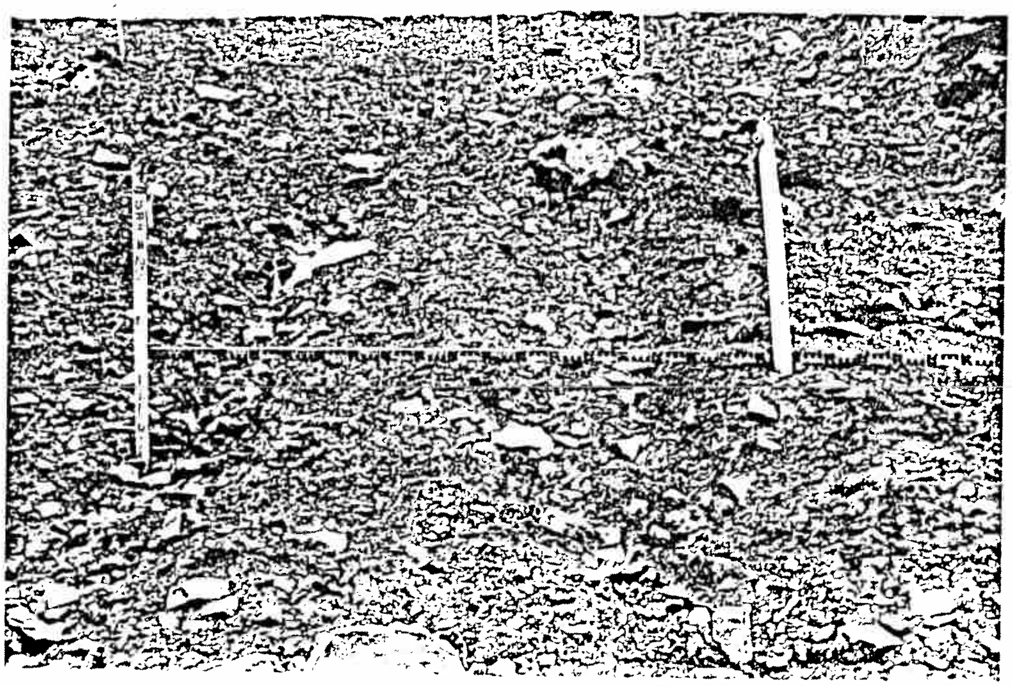


Figure 6. Photograph of Plot 25 on Smoky River Slope 4.

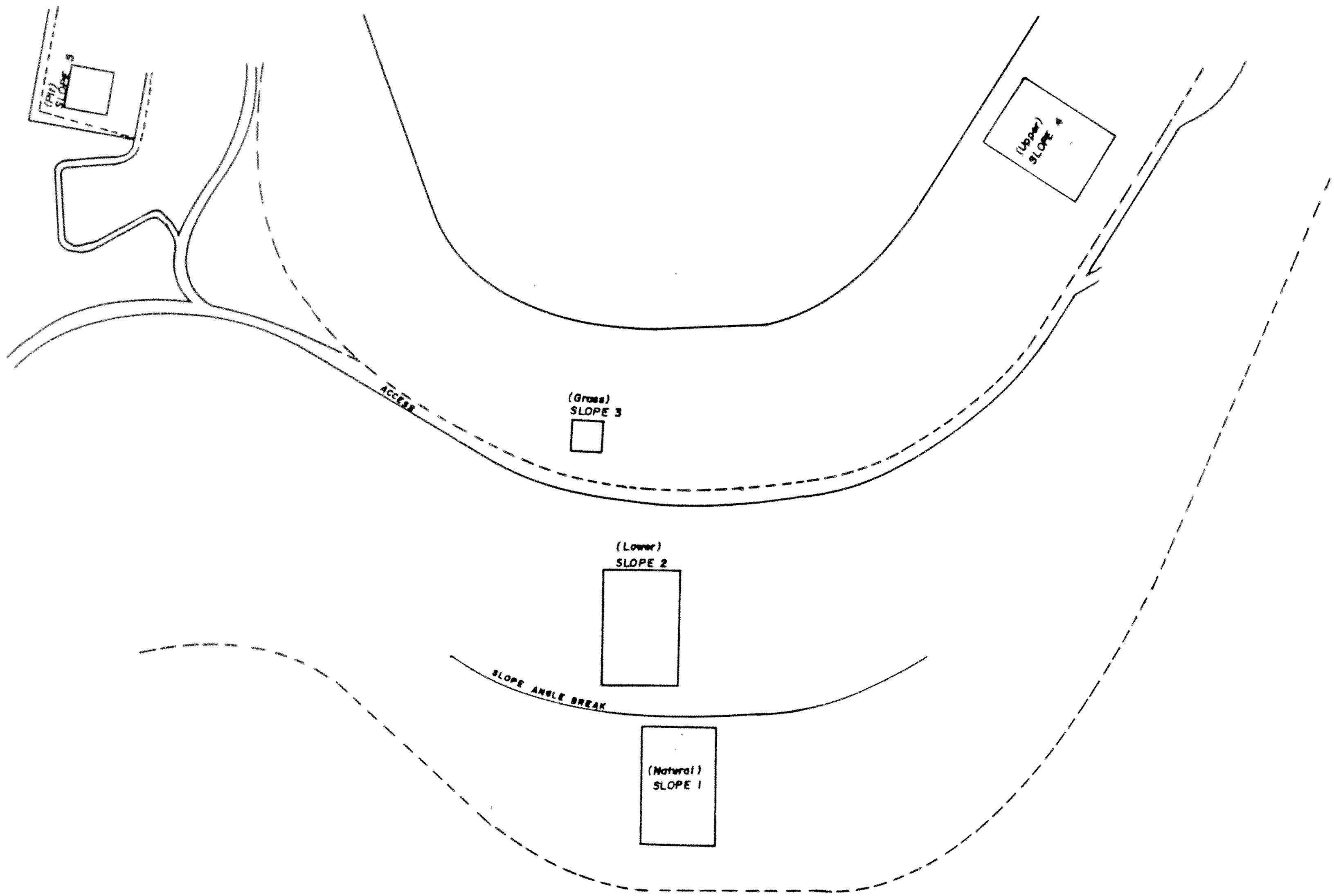
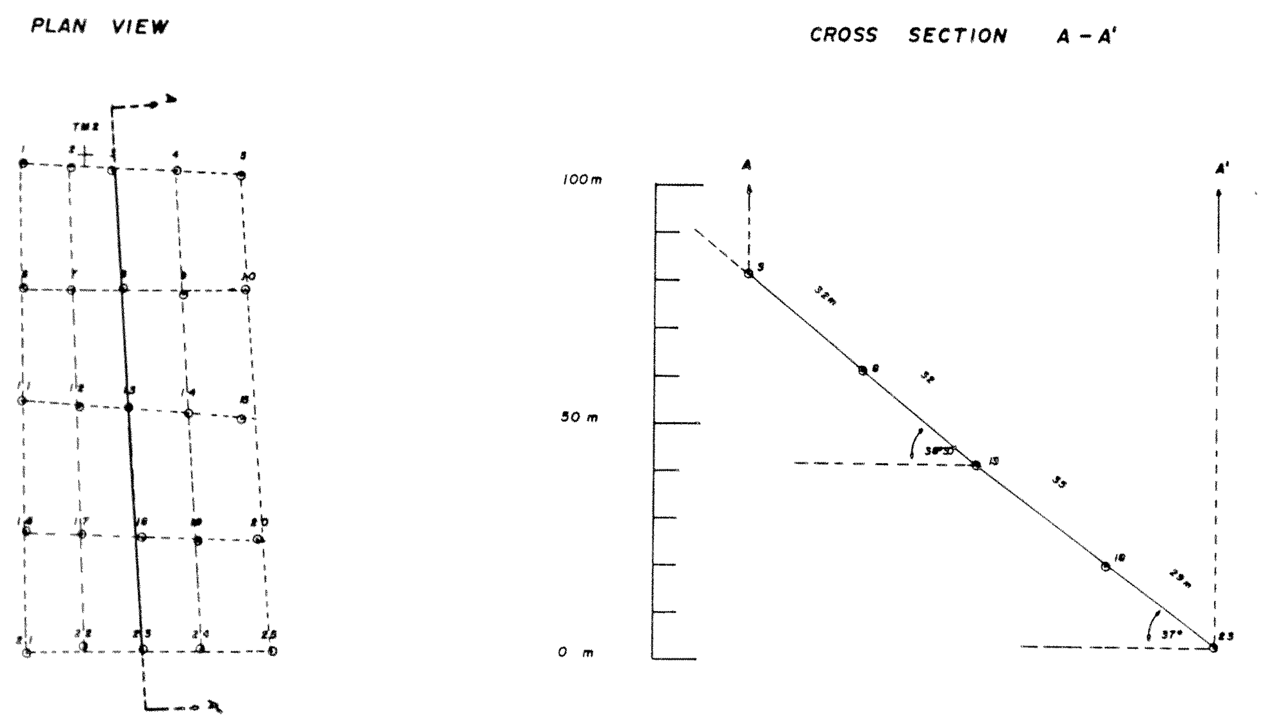


Figure 7. General Location of Research Slopes on Tent Mountain Spoil.



NOTE : Numbered Circles (⊙3) Indicate Plot Numbers

Figure 8. Coleman Collieries Tent Mountain Spoil Slope 1.

- loose, end-dumped material;
- 25 plots were installed in 1984, but large amounts of material sloughing destroyed all plots;

TM2 (Lower slope - Figure 9)

- resloped portion directly above TM1;
- approximately 200 m long;
- resloped to an angle of about 25 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4.

TM3 (Grass slope - Figure 10)

- short, heavily vegetated slope;
- usable length approximately 30 m;
- resloped to an angle of about 26 degrees;
- monitoring consists of 9 plots (3 replicates and 3 transects).

TM4 (Upper slope - Figure 11)

- vegetation becoming established;
- approximately 150 m long;
- resloped to an angle of about 22 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4.

TM5 (Pit slope - Figures 12 and 13)

- minimal amount of vegetation;
- usable length approximately 30 m;
- resloped to an angle of about 16 degrees;
- monitoring consists of 20 plots (5 replicates and 4 transects);
- 5 erosion pins in each plot of replicates 2 and 4;
- sediment deposition stakes at base of slope.

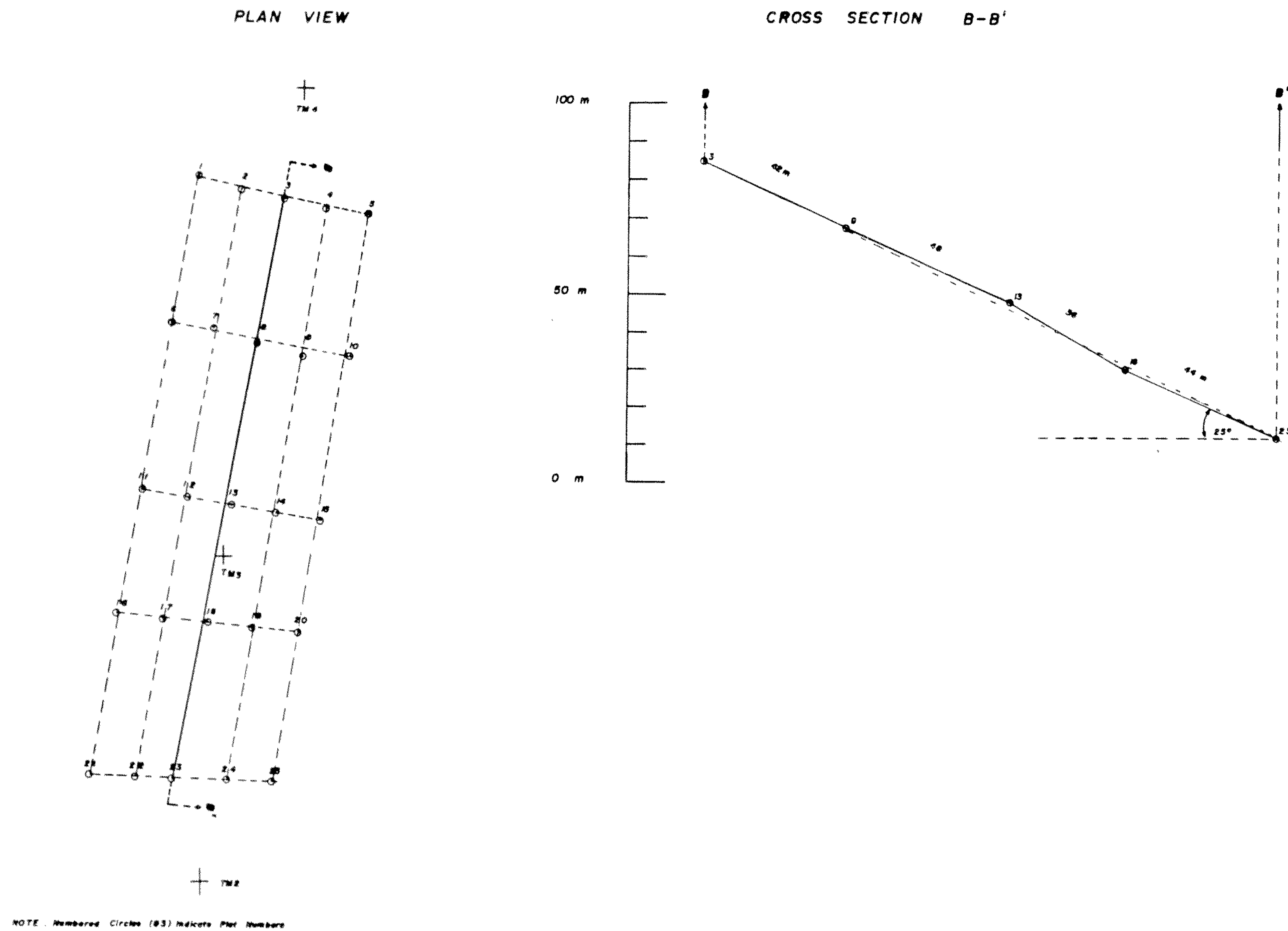
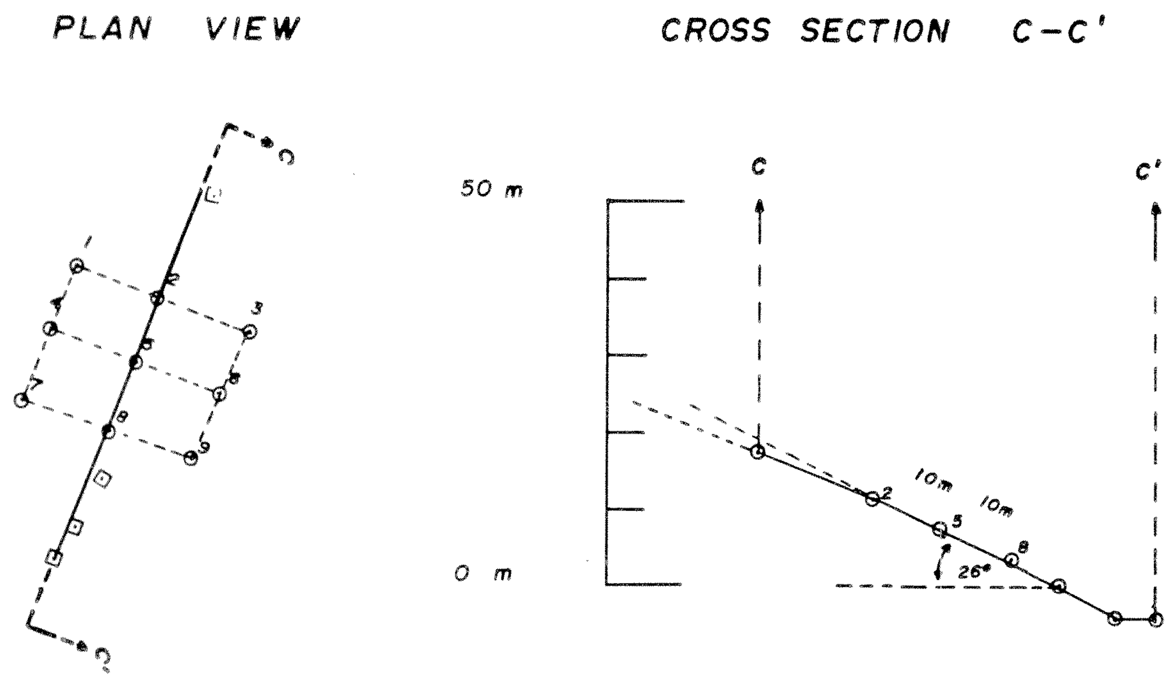
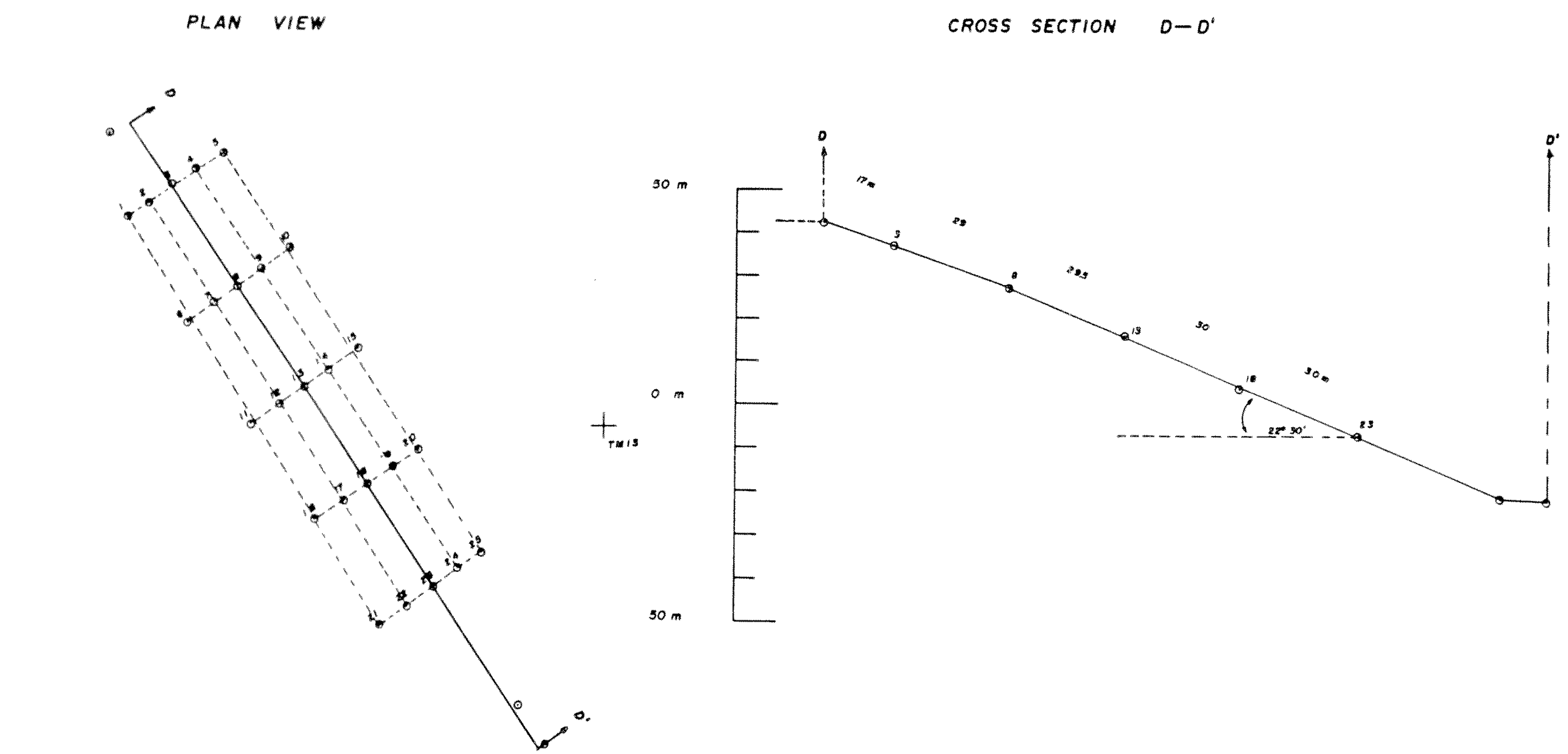


Figure 9. Coleman Collieries Tent Mountain Spoil Slope 2.



NOTE : Numbered Circles (83) Indicate Plot Numbers

Figure 10. Coleman Collieries Tent Mountain Spoil Slope 3.



NOTE: Numbered Circles (05) Indicate Plot Numbers

Figure 11. Coleman Collieries Tent Mountain Spoil Slope 4.

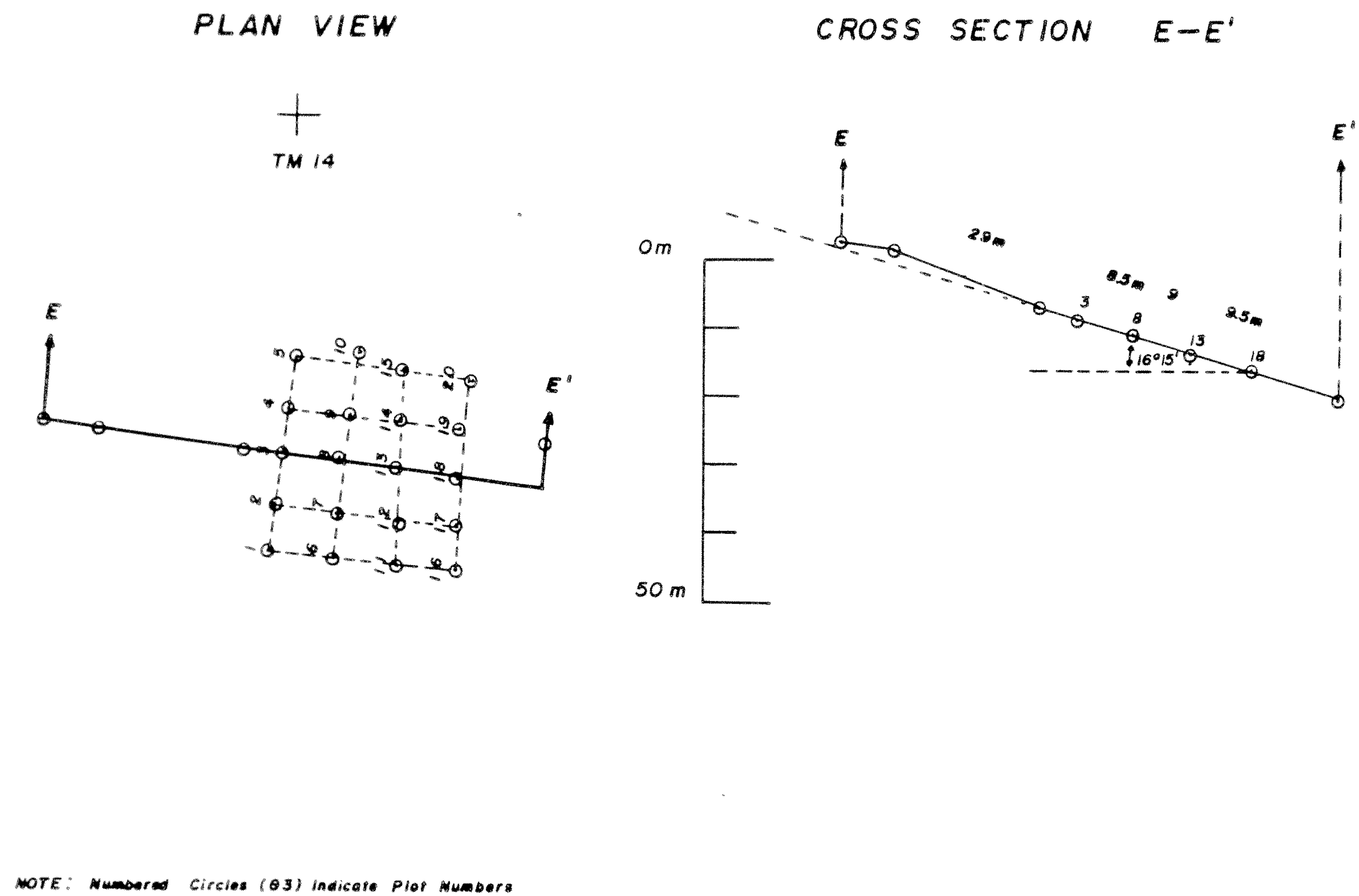


Figure 12. Coleman Collieries Tent Mountain Spoil Slope 5.

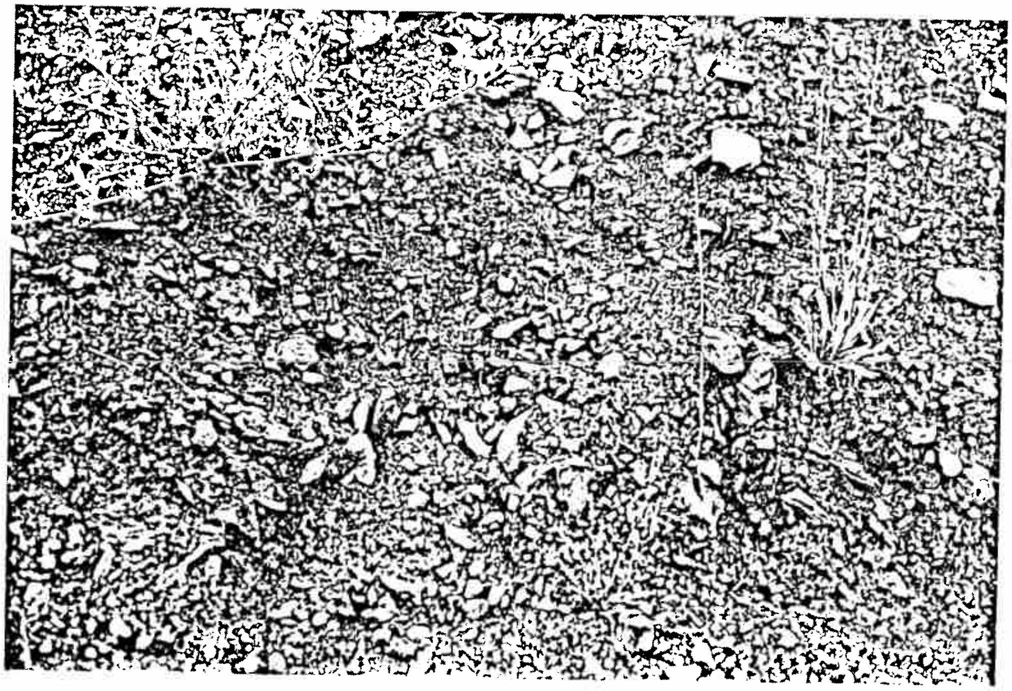


Figure 13. Photograph of Plot 18 on Tent Mountain Slope 5.

2.3 CARDINAL RIVER

A site map of the research slopes appears in **Figure 14.** Slope cross-sections are shown in **Figure 15 to 18.** The plots at Cardinal River were monitored only once in 1984. RRTAC and CMRC decided to discontinue monitoring at this site because of extensive damage done to the plots when hydro-seeder access roads were cut through the study area the previous fall.

CR1 (C-1 dump - Figure 15)

- approximately 180 m long;
- resloped to an angle of about 23 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4.

CR2 (C-1 dump - Figure 16)

- located directly below CR1;
- approximately 100 m long;
- resloped to an angle of about 26 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4.

CR3 (C-1 dump - Figure 17)

- located at the side of CR2;
- approximately 100 m long;
- resloped to an angle of about 18 degrees;
- monitoring consists of 25 plots (5 replicates and 5 transects);
- 5 erosion pins in each plot of replicates 2 and 4.

CR4 (Gregg Dump - Figure 18)

- older, weathered and vegetated surface;
- approximately 75 m long;
- resloped to an angle of 23 to 30 degrees;
- monitoring consists of 5 plots (each consisting of 5 erosion pins).

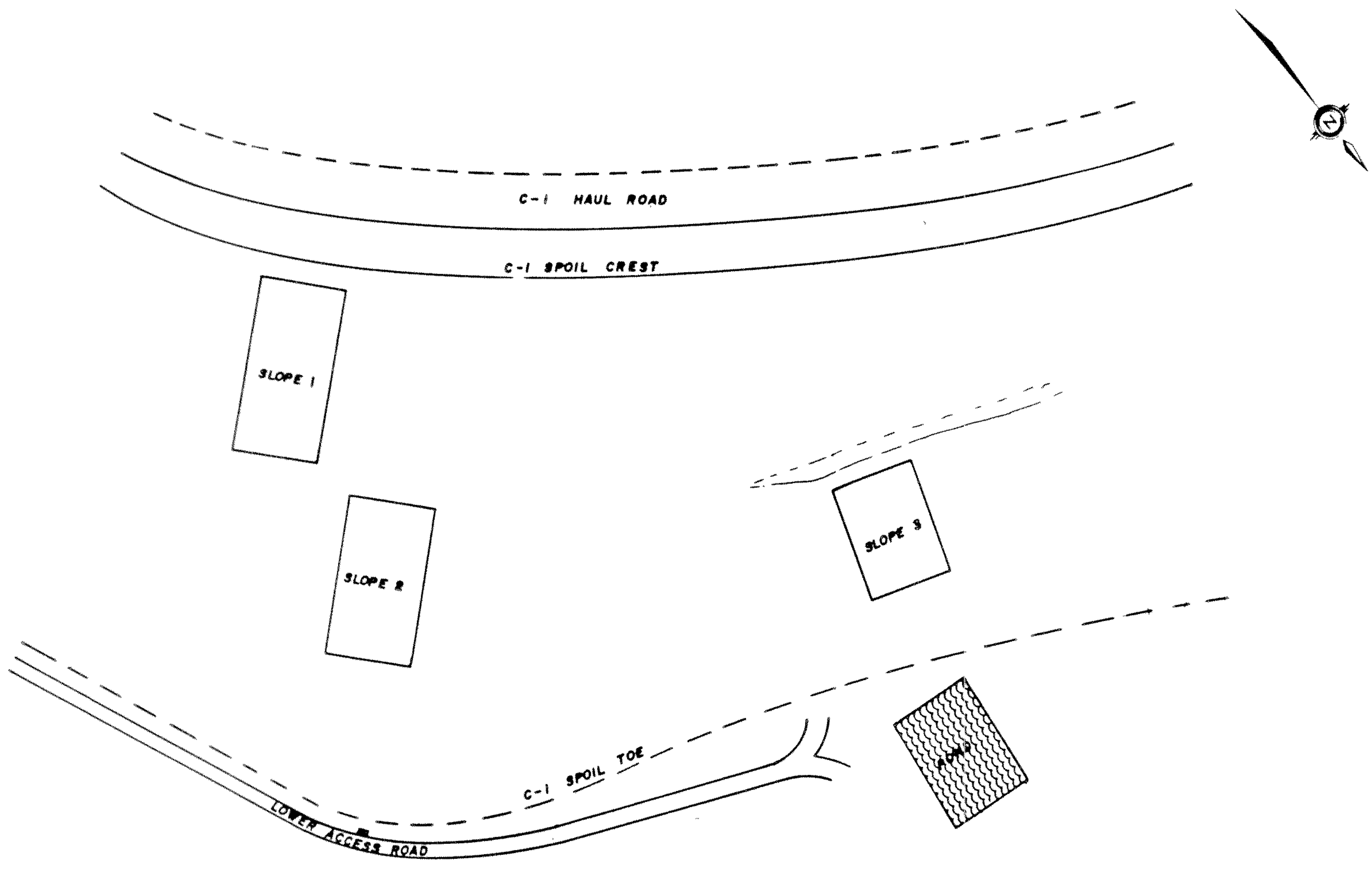


Figure 14. General Location of Research Slopes on C-1 Spoil, Cardinal River.

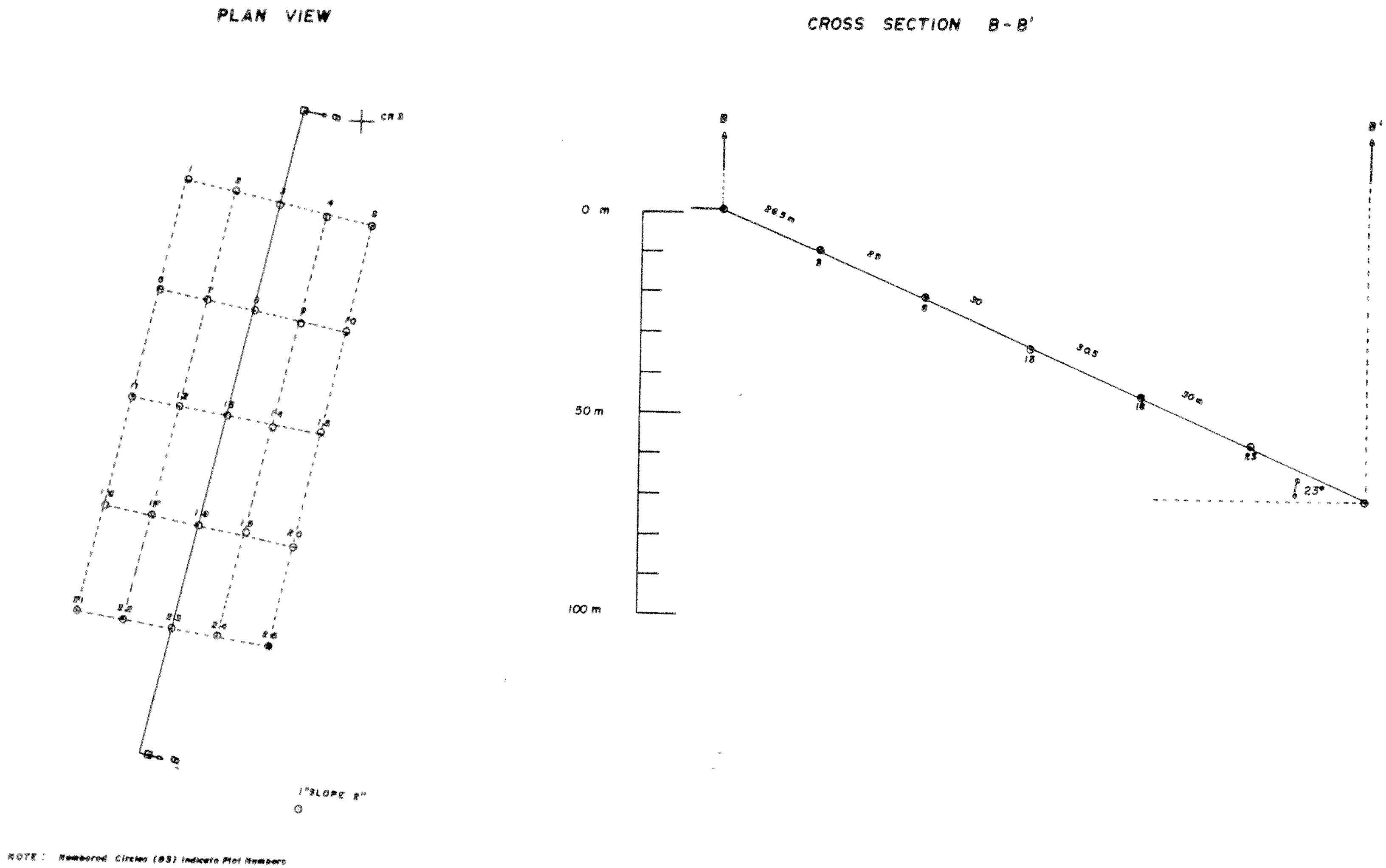
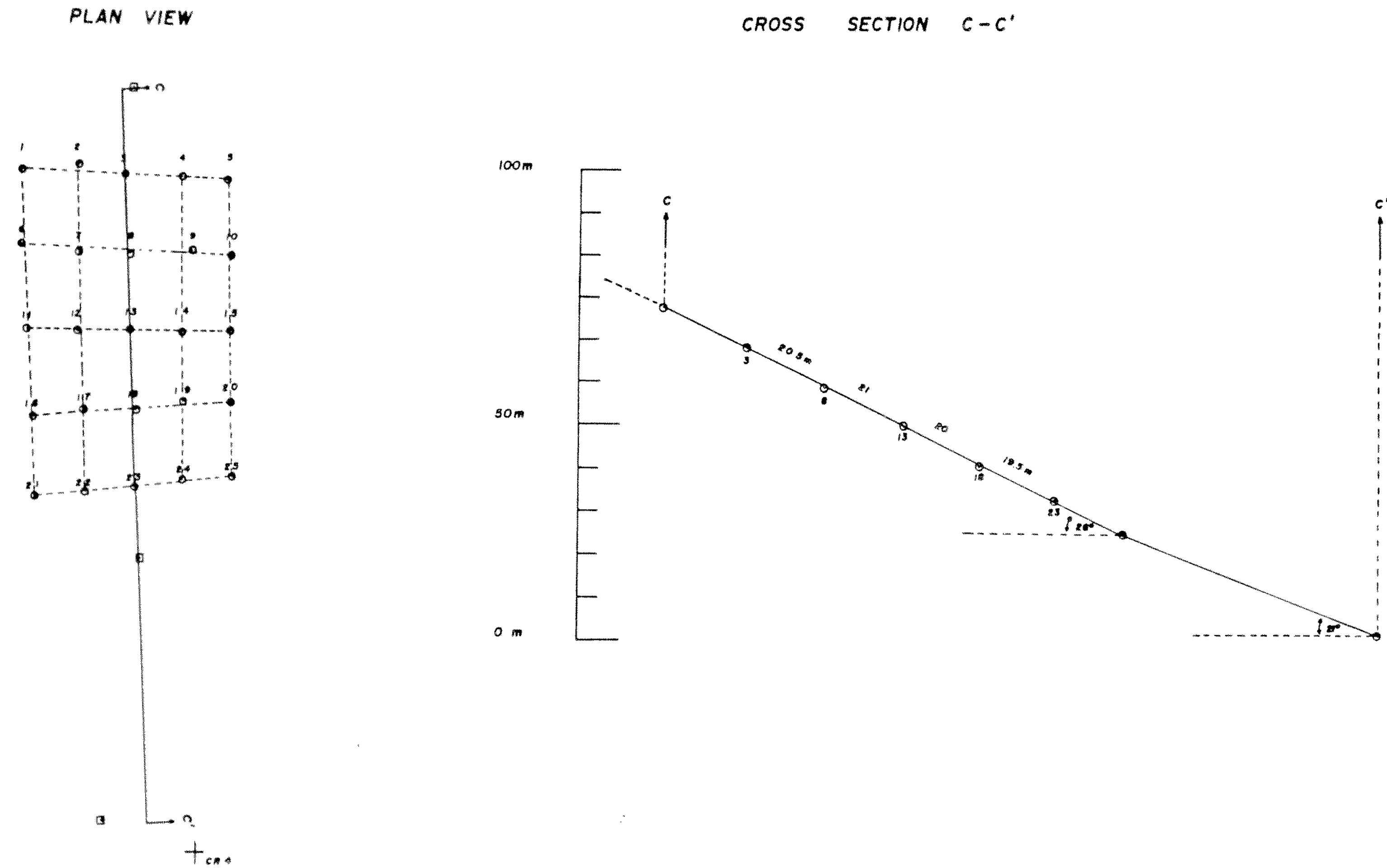
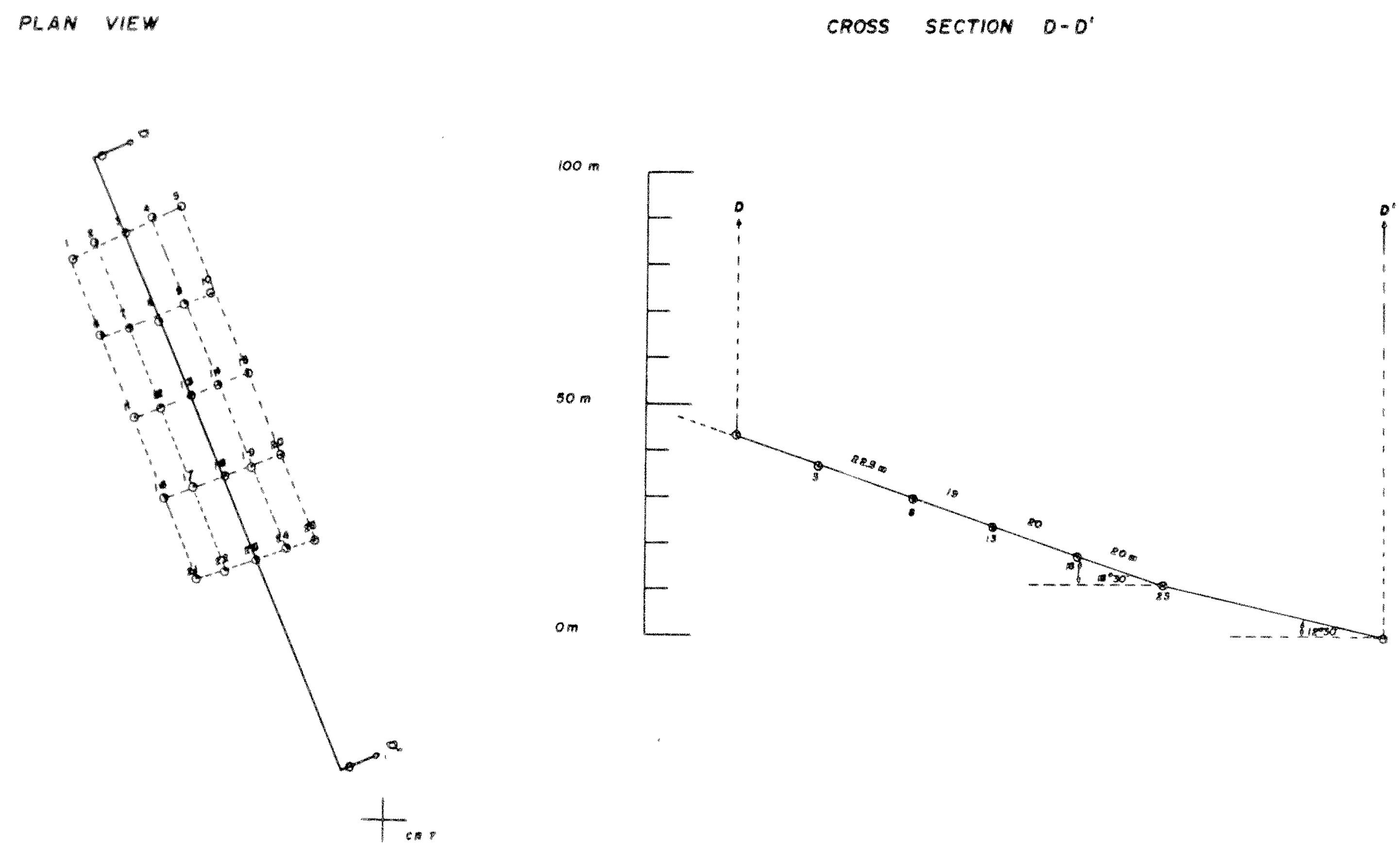


Figure 15. Cardinal River C-1 Spoil Erosion Plots Slope 1.



NOTE: Numbered Circles (03) Indicate Plot Numbers

Figure 16. Cardinal River C-1 Spoil Erosion Plots Slope 2.



NOTE: Numbered Circles (83) Indicate Plot Numbers

Figure 17. Cardinal River C-1 Spoil Erosion Plots Slope 3.

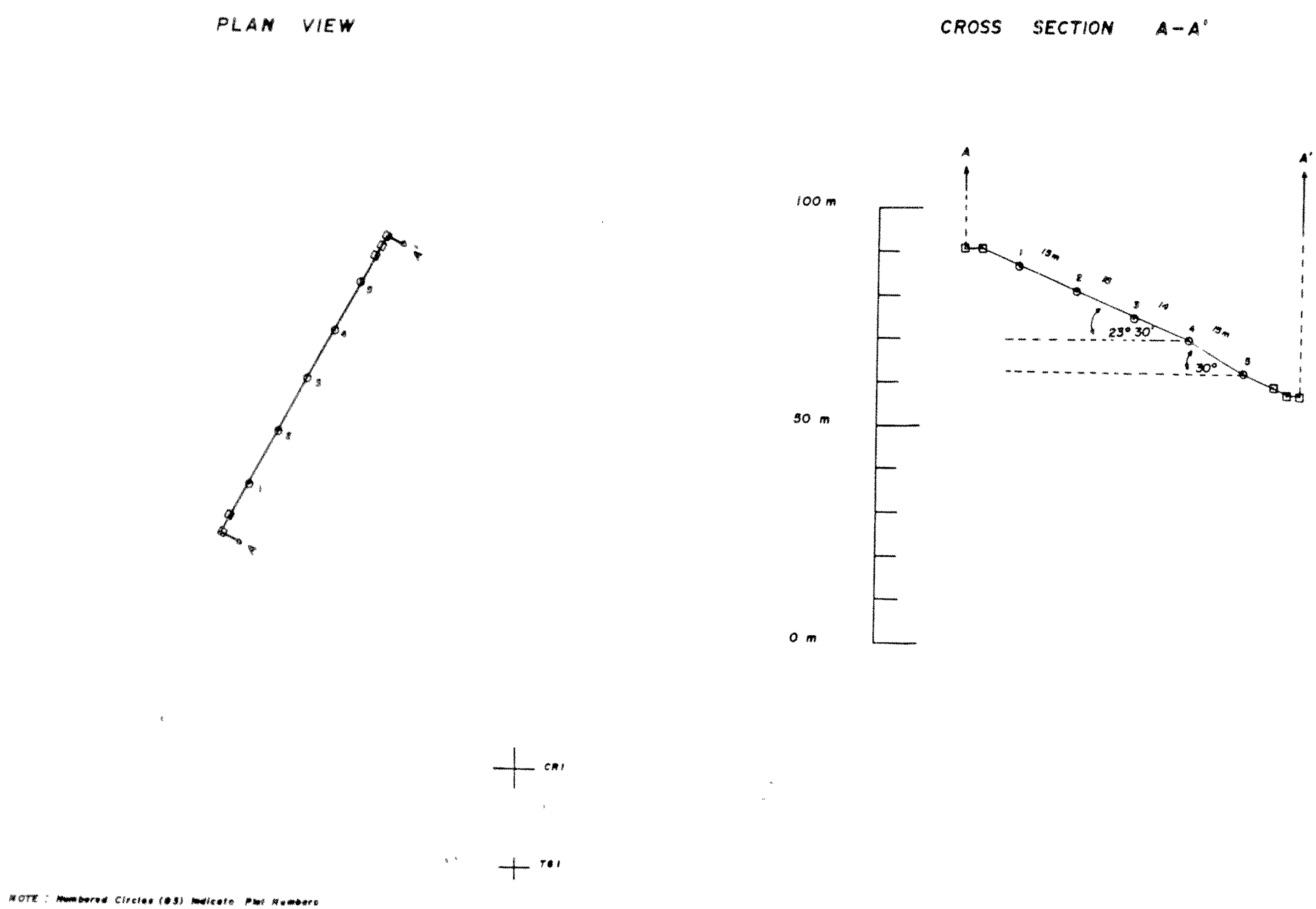


Figure 18. Cardinal River Gregg Dump Erosion Plots.

3. METHODOLOGY

3.1 PLOT DESIGN

Since the primary objective of the study was to examine the effect of waste dump configuration, several slopes with a variety of slope angles were chosen at each site. Transects were laid out parallel to the slope contours; five on long slopes (100 m or more) and four on shorter slopes (Figure 19). Five plots were set out along each transect. The choice of the number of plots was based on an 80% chance of detecting a difference as small as 10% of the experimental mean at the 5% level of significance.

For the purposes of statistical analysis, the transects were considered to be treatments (distance from the crest of the slope or slope length) and each set of four or five plots down the slope was considered to be a replicate (Figure 19).

3.2 LEVEL SURVEY

A detailed profile of each slope was obtained when the plots were first constructed. Control points were located on the slopes, adjacent to each transect, to verify the plot datum. This ensured that subsequent measurements were related to those of the previous year. In addition, control stations were located off the dumps on undisturbed ground to allow for any movement of the entire slope itself.

3.3 EROSION MEASUREMENT

Because erosion occurs sporadically, it is difficult to observe directly, and, therefore, the consequences of erosion must be examined. Each erosion measurement plot was 2 m long, defined by stakes at each end. An "erosion board" was positioned over the plot to obtain a detailed profile of the ground surface within the plot. The "board" consists of 21 rods mounted every 100 mm across a 0.75 m high by 2.2 m long plywood sheet (Figure 20). The board was fastened to the plot stakes each time a reading was taken, guided by a notch and pin at one end to ensure consistent placement. When a plot was measured, the rods were allowed to contact the ground surface, and the vertical positions of the rods were noted.

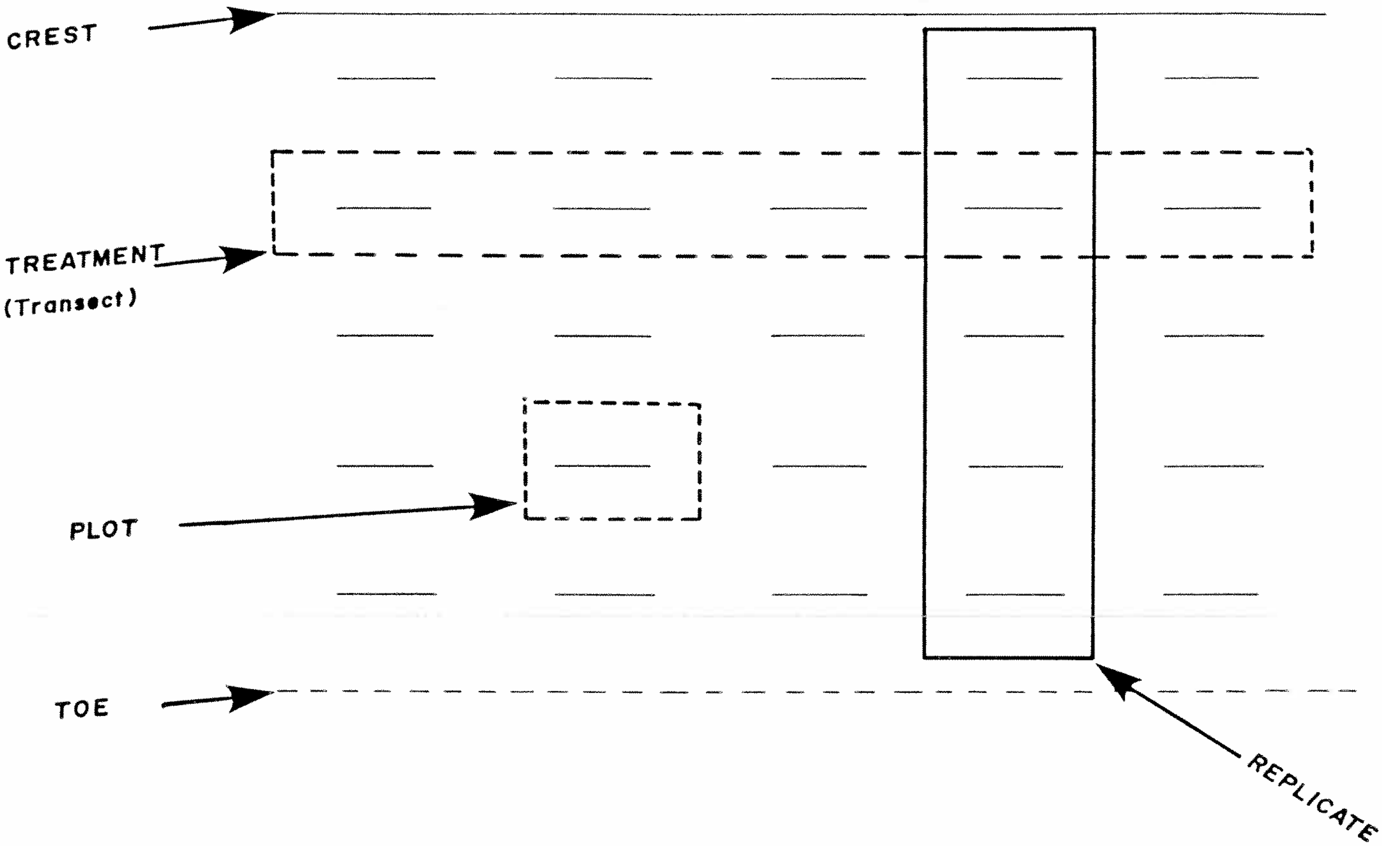


Figure 19. Plot Design.

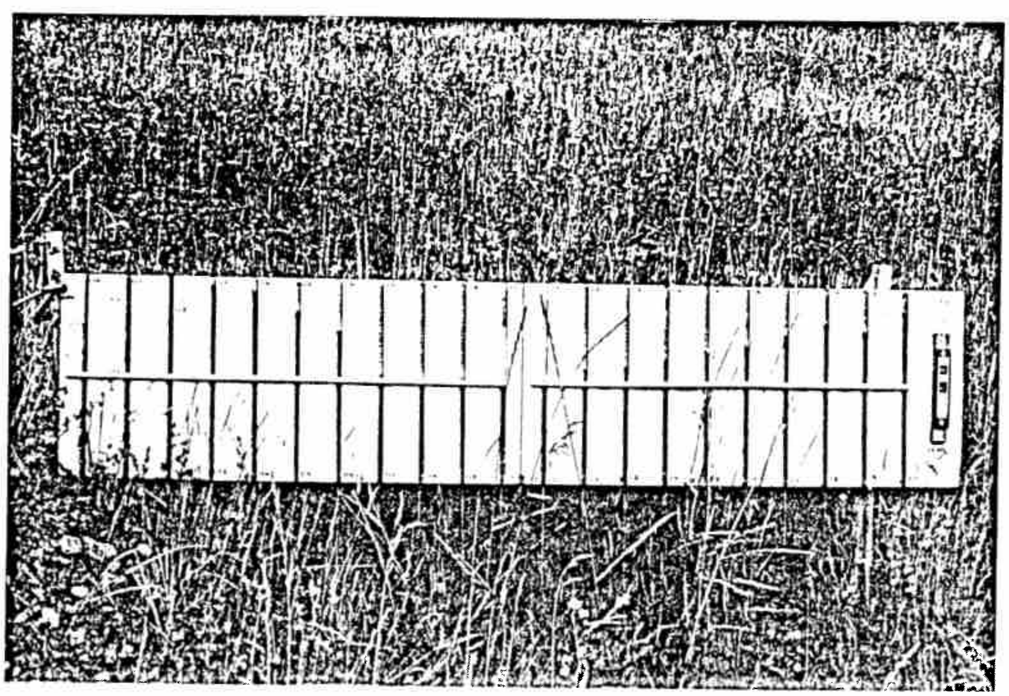


Figure 20. Photograph of the Erosion Board.

The elevations of the stakes were surveyed every spring to ensure no stake movement had occurred and to provide a grid to which erosion board readings could be related. In addition, plots within replicates 2 and 4 usually contained erosion pins (300 mm long steel spikes with washers). The pins were spaced 400 mm apart between the two plot stakes. Using a steel rule or tape, the distance was measured between the head of the spike and the washer which lies on the ground surface. The values of surface erosion obtained from pin readings were compared with those from the erosion board to evaluate both methods, and to serve as a check on accuracy.

Erosion board and erosion pin readings were conducted at the sites as follows: August 1983; September/October 1983; June 1984; August 1984; October 1984; June 1985; August 1985; and October 1985. In October 1984, only the plots at Smoky River were measured. Unexpectedly heavy snowfalls which occurred the day after the site visit to Smoky River prevented the readings from being taken at Tent Mountain.

3.4 DEPOSITION MEASUREMENT

An additional effort to try and explain the occurrence of large amounts of apparent deposition was undertaken in 1985. This involved the painting of narrow lines on the ground surface between the plot stakes when the first set of measurements was taken in the year. During subsequent visits, these lines were examined for evidence of the movement of lumps of material, for actual deposition, as well as for erosion. Close-up photos of each plot were used to aid in the visual comparison of the plots from event to event.

A survey grid at the base of Slope 5 at Tent Mountain (TM5) was established to assist in measuring the amount of material that was being deposited there. This was accomplished using steel pins spaced at approximately 1 m intervals over the deposition area. The pins were measured again in August 1985. It should be noted that slopes other than Slope 5 contribute to the deposition which accumulates in the basin. The pins were installed to observe what was happening to the area in general, as opposed to attempting to measure deposition resulting from erosion of Slope 5 in particular.

3.5 PRECIPITATION MEASUREMENTS

Non-recording rain gauges were situated at two locations on the Smoky River site and the Tent Mountain site. The gauges were read intermittently between site visits to Smoky River, and at the time of each visit to Tent Mountain. Precipitation during the time between the last reading in fall and the first in spring was estimated from the closest monitoring station maintained by Environment Canada (**Table 1**). Two instances of wildlife entering the rain gauge enclosure and upsetting the gauge occurred at Tent Mountain.

3.6 SOIL SAMPLING AND ANALYSIS

A composite soil sample was collected from each slope at the time the plots were first installed. Material was gathered randomly from five points on each test site and then subjected to the following analyses:

1. grain size analysis (size distribution);
2. liquid limit;
3. plastic limit;
4. specific gravity;
5. dry bulk field density; and
6. moisture content.

Results of the analyses on the composite samples were provided in an unpublished 1983 CMRC Report #84-08C, entitled "2nd Quarterly Report, Waste Dump Design for Erosion Control".

Because of the variability of the material among the various plots on each slope, it was later determined that the results of the analysis of the composite samples could not be used. In 1985, therefore, a limited plot-by-plot soil sampling and testing program was conducted. In total, 39 samples were collected from Smoky River slopes 2, 3, and 4 in June 1985.

The following analyses were conducted on the samples:

1. material classification (visual);
2. grain size analysis;
3. specific gravity; and
4. field bulk density.

Results of the laboratory and field tests are presented in Appendix J.

Table 1. Estimated precipitation amounts for Tent Mountain and Smoky River[1]

Site	Precipitation (mm)
Tent Mountain	
August to September 1983	70
September 1983 to June 1984	316
June to August 1984	73
August 1984 to June 1985	288
June to August 1985	79 to 87
August to October 1985	156 to 165
Smoky River	
August to October 1983	65 to 69
October 1983 to June 1984	300
June to August 1984	82 to 106
August to October 1984	127 to 135
October 1984 to June 1985	159
June to August 1985	41 to 60
August to October 1985	133 to 146

[1] Estimated from nearest Environment Canada meteorological station.

3.7 SURFACE FEATURES

Surface features such as cracks, depressions and trenches were another factor thought to affect the amount of erosion at any particular location on a slope. For example, large cracks between transects on a slope can act as runoff intercepts. Diversion trenches cut diagonally across a slope face can redirect runoff and alter the lengths of uninterrupted surface. These and other significant surface features were identified and mapped by walking over each slope and noting the position and nature of the items, keeping in mind their effects of erosion and runoff patterns. Graphical representations are shown in Appendix K.

3.8 STATISTICAL ANALYSIS

Analysis of the data obtained from the erosion board readings consisted of several steps:

1. Calculation of the amount of surface movement from event to event;
2. Calculation of the seasonal amount of surface movement;
3. Calculation of the cumulative amount of surface movement;
4. Check on the distribution of the data (e.g., normal);
5. Rejection of outliers (extremely large values) based on Chauvenet's criterion;
6. Calculation of the plot mean and standard deviation values;
7. "t" test analysis to determine significance (at the 5% level) of the plot values; and
8. Single and multiple regression analyses.

4. RESULTS

4.1 EROSION MEASUREMENTS

Tables of raw data are provided in Appendix A. **Table 2** is provided as an example of the actual readings as they were recorded from the erosion board. Similar data were obtained for each slope every time a set of readings was taken. Data on the changes in the elevations of the 21 points in each plot from visit to visit are also presented in Appendix A.

Erosion pin readings, which measure erosion directly without the need for calculation from event to event, are presented in Appendix B.

4.2 DEPOSITION MEASUREMENTS

When the plots containing the painted lines were sampled, the results showed that material was moving down the slope in a few cases. Material with paint on it could be found as far as one metre from its original position. From the paint it was also possible to see those areas where material was breaking down. In those areas where no paint was visible, it was not possible to determine whether the paint had been covered over or simply washed away without destroying the plot site.

Results of the deposition measurements from Tent Mountain are presented in Appendix B. The average depth of deposition was found to be 17 mm over an area of about 60 square metres. When the deposition volume of 1 m^3 is considered in light of the large contributing area, the conclusion is that surface erosion of the slopes is minimal.

4.3 FREQUENCY DISTRIBUTION OF DATA

The first statistical analysis performed on the plot elevation differences was a check on how the data were distributed. The distribution of the data in part determines the kinds of subsequent analyses which may be performed.

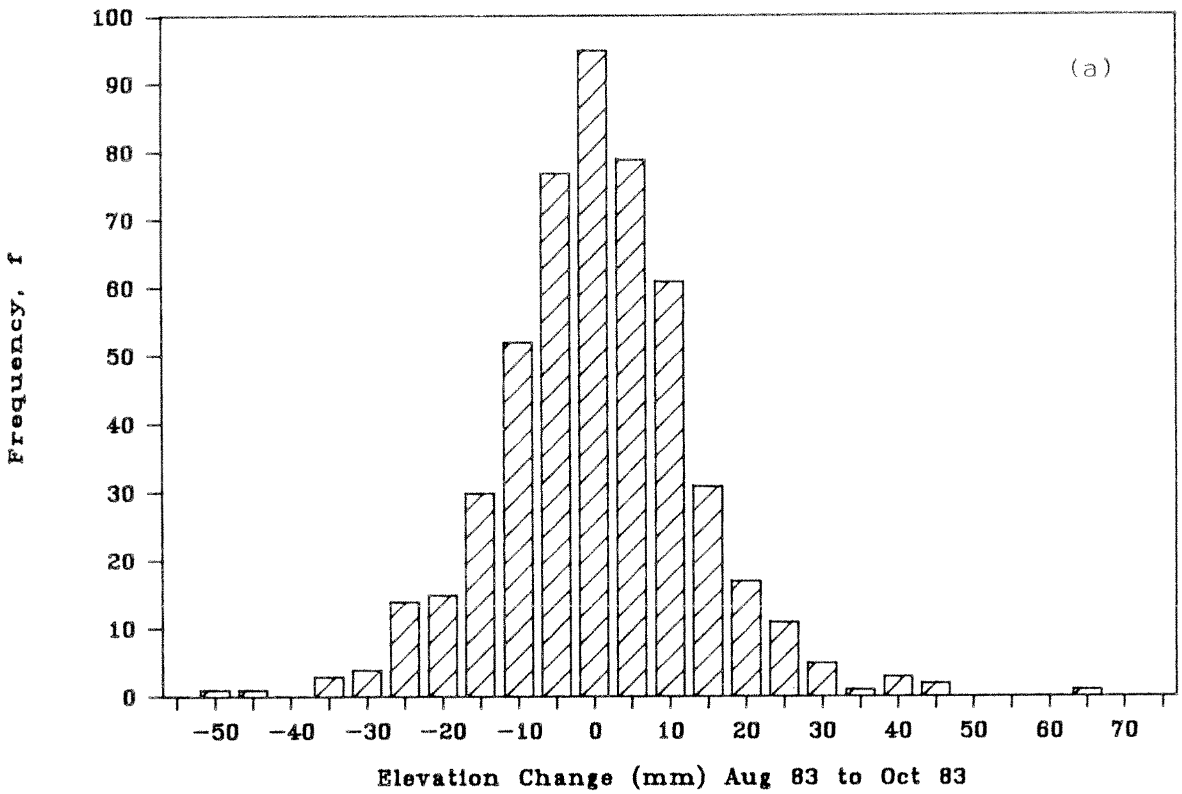
Several checks were done on the results obtained from individual slopes. The data were found to be normally distributed, as shown by the two examples of frequency histograms in **Figure 21**. This then permitted analyses such as the calculation of plot means and standard deviations, the application of Chauvenet's criterion, t-tests, and regression analyses to be conducted.

Table 2. Erosion Board Measurement (millimetres)* Smoky River, 20 degree slope (Slope 2).

Date Read: 1983 August 04

PLOT #	PLOT POSITION 0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1	25	65	100	95	85	115	120	110	115	120	135	145	150	170	140	135	120	145	140	165	160
2	120	140	190	200	175	155	160	155	135	125	105	85	65	80	95	110	115	135	110	110	95
3	100	100	120	125	120	80	60	95	120	195	110	105	50	20	100	70	65	65	55	50	60
4	220	245	220	195	135	95	100	60	40	35	55	70	50	75	65	95	120	160	220	275	260
5	20	55	50	80	120	160	245	290	290	310	325	325	310	350	350	320	300	300	305	345	370
6	530	480	470	470	460	435	360	340	280	210	160	175	105	30	50	50	80	85	130	210	260
7	30	25	50	130	125	140	115	100	85	80	115	125	125	105	90	85	100	85	80	125	190
8	140	140	145	105	120	100	105	100	130	140	85	80	85	65	50	75	60	100	110	130	155
9	70	100	130	125	90	105	100	95	135	130	75	95	90	110	95	75	70	45	115	125	125
10	70	80	85	100	100	100	115	120	115	115	125	140	155	170	185	165	150	135	100	125	100
11	75	30	40	80	140	195	210	235	230	250	250	250	240	240	230	210	210	190	195	190	185
12	30	60	65	125	140	155	130	135	165	180	175	160	150	155	150	115	150	200	215	225	215
13	85	90	95	80	80	45	5	30	60	75	80	100	85	80	145	190	210	195	185	185	210
14	400	400	370	335	310	260	155	95	60	20	90	150	220	310	380	445	515	585	610	660	680
15	85	100	110	105	130	145	145	145	160	185	190	200	180	185	220	165	175	210	235	285	285
16	110	70	100	120	125	155	120	145	120	110	105	100	100	80	40	20	10	20	30	40	0
17	145	155	145	155	175	180	185	170	140	125	130	130	115	130	115	90	85	100	120	110	135
18	110	120	110	115	100	100	80	95	80	95	115	115	100	125	135	120	105	125	120	135	130
19	50	120	175	215	220	320	330	340	470	515	520	490	415	410	390	370	370	330	290	295	305
20	115	105	120	130	60	95	120	120	105	130	120	110	80	55	35	40	40	35	30	25	20
21	320	220	165	145	95	70	35	25	80	40	70	140	140	110	110	115	95	100	160	140	150
22	110	120	185	240	265	275	260	270	305	315	355	325	320	385	370	305	255	270	255	305	315
23	70	50	10	0	0	0	15	30	40	45	60	65	80	75	30	60	30	55	70	90	120
24	75	100	95	95	70	80	45	30	105	95	100	110	85	105	100	85	100	100	80	90	105
25	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888	888

*888 denotes no reading



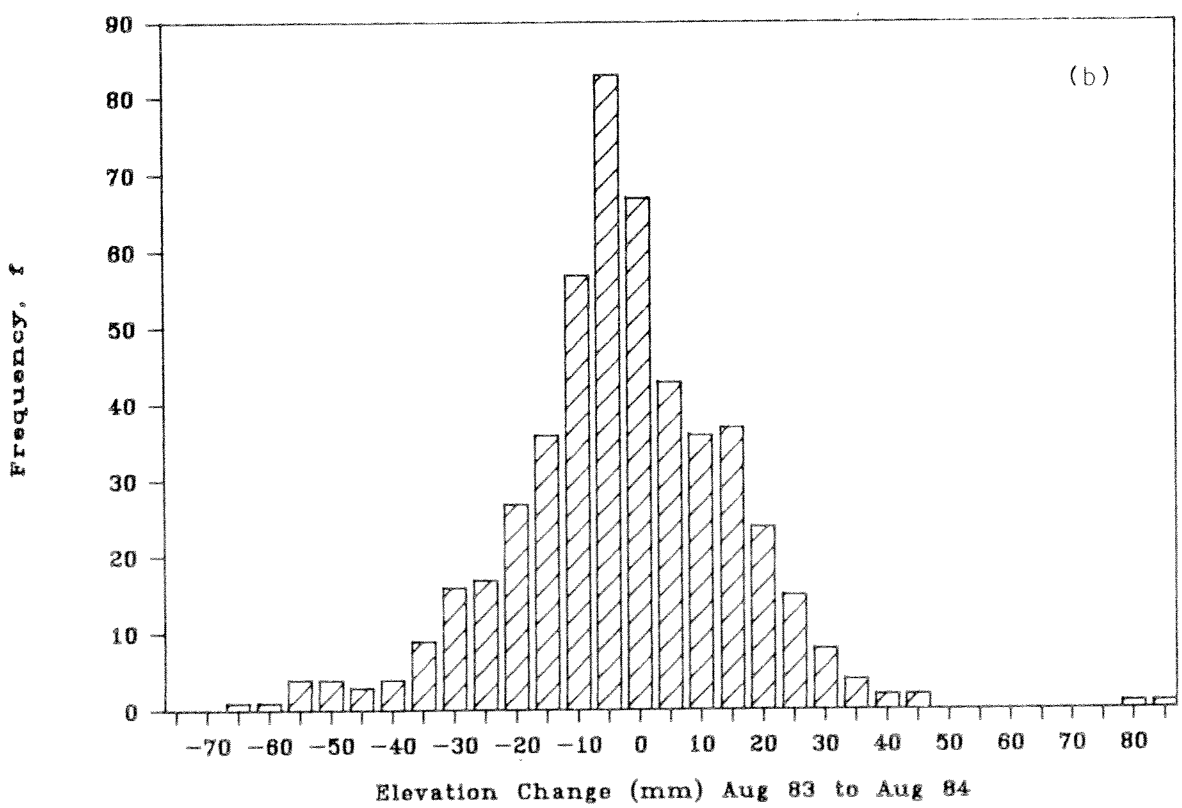


Figure 21. Frequency Histograms, (a) Cardinal River Slope 1, (b) Smoky River Slope 2.

4.4 EVENT-TO-EVENT CHANGES IN PLOT READINGS

The data for each plot in the tables appearing in Appendix A show that a number of particularly high and low values are present. In arriving at an average value and a standard deviation for the material movement for the 21 points in each plot, these values were rejected. The majority of the values for any plot were considered to be measures of sheet or inter-rill erosion, while the large positive values were attributed to rill or gully erosion. This phenomenon was also evident from a visual inspection of the plots, and can be considered valid.

Large negative values, indicating a rise in ground elevation, were considered to be either depressions which had filled in, or large lumps of material which had rolled into place from farther up the slope. Evidence of this was also present.

Rejection of these "outliers" was based on Chauvenet's criterion, which states an observation in a sample of size "n" is rejected if it has a deviation from the mean greater than that corresponding to a 1/(2n) probability, based on the normal distribution.

The tables in Appendix C are similar to those of Appendix A only this time the outliers which were rejected have been replaced with "999"s, simply as position occupiers. The plot mean and standard deviation were calculated after the outliers were rejected. "888"s appear where no plot readings were possible.

4.5 CUMULATIVE CHANGES IN PLOT READINGS

The overall results for each slope, determined by comparing the initial plot measurements with the last readings, e.g., August 1983 to October 1985, are presented in Appendix D.

4.6 TREND SURFACE MAPS

The spatial distributions of the plot means for each slope from the tables in Appendix D are shown on the surface maps in Appendix E. Negative values represent material deposition. Values are millimetres of material movement.

The values which appear on the sheet correspond to the locations of the plots for which the means are shown.

4.7 T-TESTS FOR PAIRED VARIABLES

The plot means between events were compared in order to determine whether there was a significant difference between them. The mean difference between the two events (plot means) was considered as the variate and compared with its standard deviation, i.e., the t-test was applied to paired data. In this manner, the effect of the event-to-event variation was eliminated.

The results of this analysis are presented in Appendix F. Graphical representations of the significance tables are included in Appendix G.

4.8 OUTLIER TREND CONSISTENCE

The outliers which were rejected using Chauvenet's criterion were analyzed for trends to determine whether or not rills or gullies were developing, or if deposition was consistent. If an outlier reversed itself (from positive to negative or vice-versa), it was not considered to be following a trend. The results of this determination are presented in Appendix H.

4.9 REGRESSION ANALYSES

Erosion depends on more than one independent variable. Therefore, multiple regression was used since it establishes the correlation of erosion with one independent variable, with the other independent variables kept constant. Single-factor regression does not control the other variables. However, several single factor linear regression analyses were performed to determine trends caused by independent variables.

The independent variables considered were:

1. Time in months since initial plot reading;
2. Precipitation amount in millimetres;
3. The season the reading was taken (spring, summer, fall);
4. Distance of the plot from the crest of the slope (length); and
5. Steepness of the slope (angle).

Linear regression of the form

$$y = b + b_1x_1 + b_2x_2 + b_nx_n$$

was used. The results of various regression analyses using all available data are presented in Appendix I.

Graphical representation of simple linear regression for erosion against precipitation, age and slope length of Slope 4 at Smoky River are shown in Figures 22, 23, and 24.

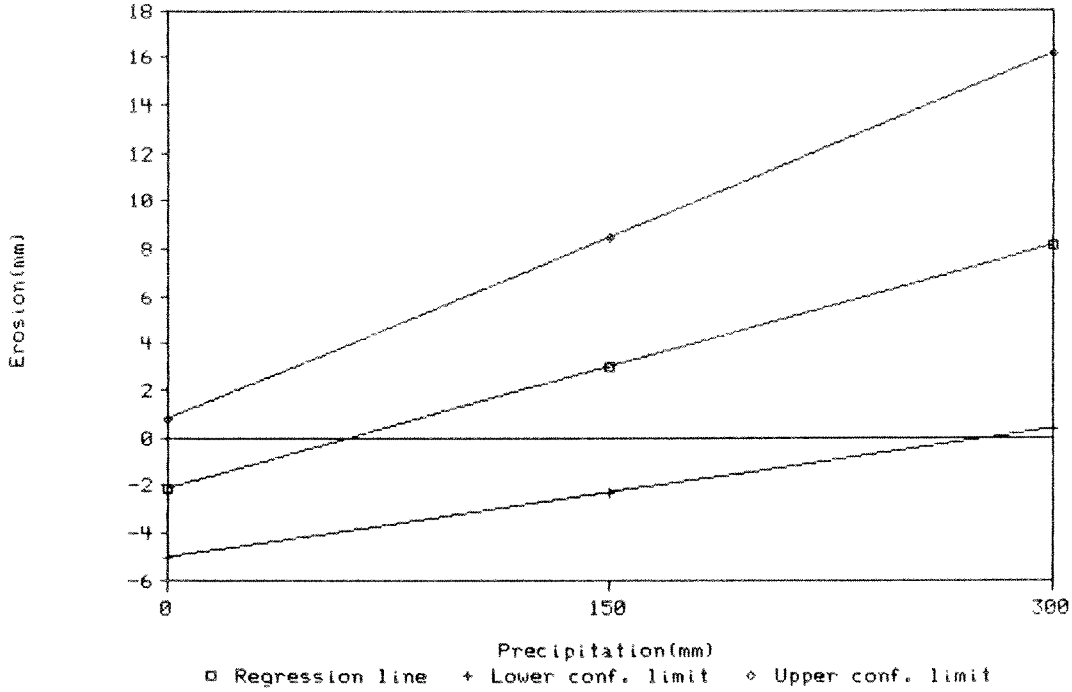


Figure 22. Linear Regression Analysis of Precipitation against Erosion on Smoky River, Slope 4.

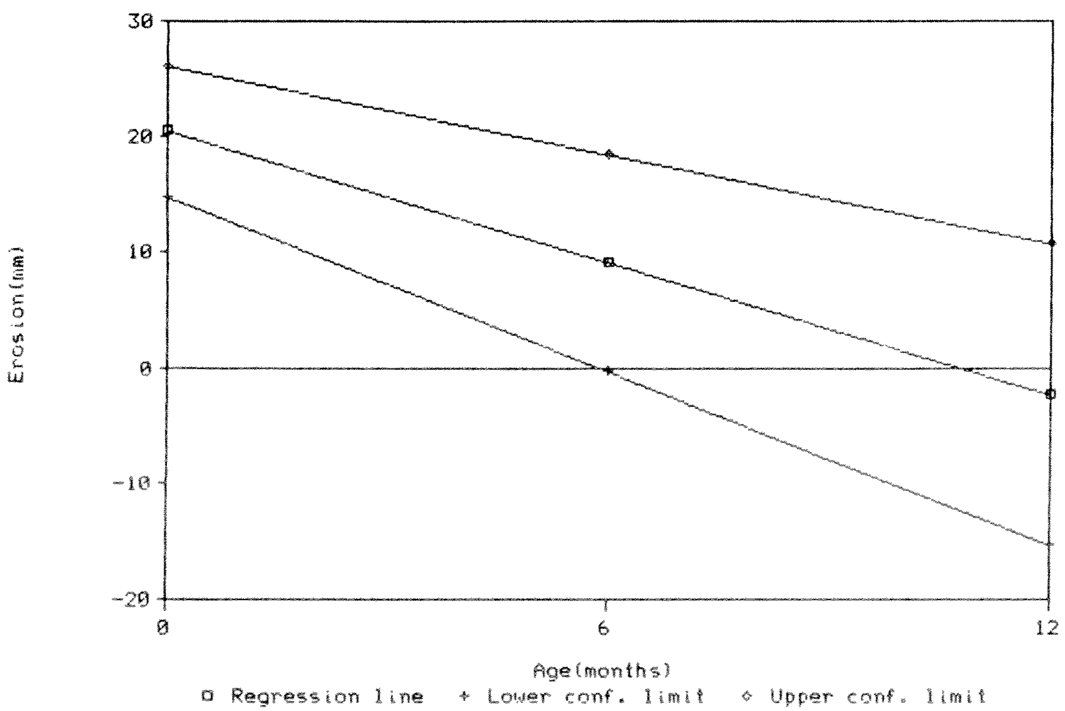


Figure 23. Linear Regression Analysis of Age against Erosion on Smoky River, Slope 4.

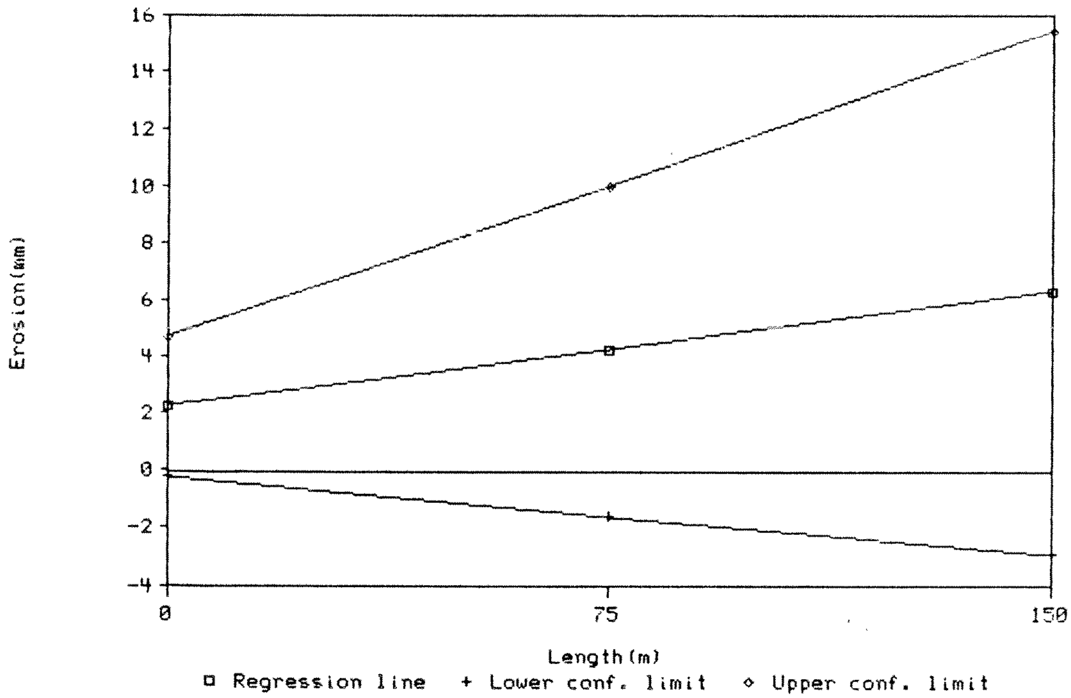


Figure 24. Linear Regression Analysis of Slope Length against Erosion on Smoky River, Slope 4.

5. DISCUSSION AND CONCLUSIONS

In general, the most reliable and dramatic results were obtained from the one slope which was monitored as soon as reclamation was completed. The effects of specific variables on the amount of erosion are presented individually in the next subsections. Reference can also be made to the regression analyses in Appendix I for mathematical representations of the influence of each factor, either alone or with all other factors, for each slope individually or as a group.

5.1 SIGNIFICANCE OF RESULTS

The t-tests demonstrated that a large number of the plots exhibited no significant change in ground surface elevation from event to event. Considering the amount of precipitation recorded during these times, this occurrence is understandable. Generally speaking, only about half of the plot means were significantly different between events. Of those which were significant, less than half indicated erosion. The exception to this was Slope 4 at Smoky River. The monitoring of this slope began immediately after the topsoil was spread. On all other slopes monitoring began several months after regrading was completed.

Analysis of the erosion outliers showed than an average of 10 to 15 rills or gullies were developing in the plots on each slope at Smoky River and Tent Mountain. These gullies were determined to be as deep as 100 mm in several instances. The outliers indicating deposition are attributed to material moving into depressions or lumps rolling onto the plot profile.

5.2 EFFECT OF COVER

As expected, the slopes which were covered with dense grasses (Slope 1 at Smoky River and Slope 3 at Tent Mountain) showed no signs of erosion. The other slopes were developing strong vegetation stands, to the point of making erosion board readings difficult. It is expected that thick mats of vegetation will soon prevent any sheet erosion from occuring at all.

5.3 EFFECT OF AGE

The influence of time since regrading was found to be as expected: that the amount of erosion decreases with time, due to initial loss of fine particles and to the formation of a weathered surface as well as increased vegetative cover.

Also as expected, the greatest amounts of erosion were found on slopes which were newly regraded. Results obtained from Slope 4 at Smoky River were much more significant compared with other slopes which were older by at least one winter. Monitoring of Smoky River Slope 4 began immediately after reclamation was completed.

The older slopes at Smoky River and Tent Mountain also exhibited similar results, i.e., erosion decreasing with age, although not as dramatically as with new slopes. The average annual amounts of erosion which were measured on slope are shown in **Figures 25 to 30.** In most instances, however, the average surface erosion is minimal, e.g., 0 to 5 mm.

5.4 EFFECT OF PRECIPITATION

The amount of erosion was found to be directly proportional to precipitation for newly-graded surfaces. On older slopes the correlation between precipitation and erosion was relatively poor.

5.5 EFFECT OF SLOPE LENGTH

The results of correlations for erosion with slope length were not significant except for Slope 4 at Smoky River. The linear regression analysis predicts an increase of 4 mm of erosion with every 100 m of slope length for this location.

5.6 EFFECT OF SLOPE ANGLE

Steepness of the slope was found to be poorly correlated with erosion. Results showed positive and negative effects of slope angle on the amount of erosion, with questionable reliability.

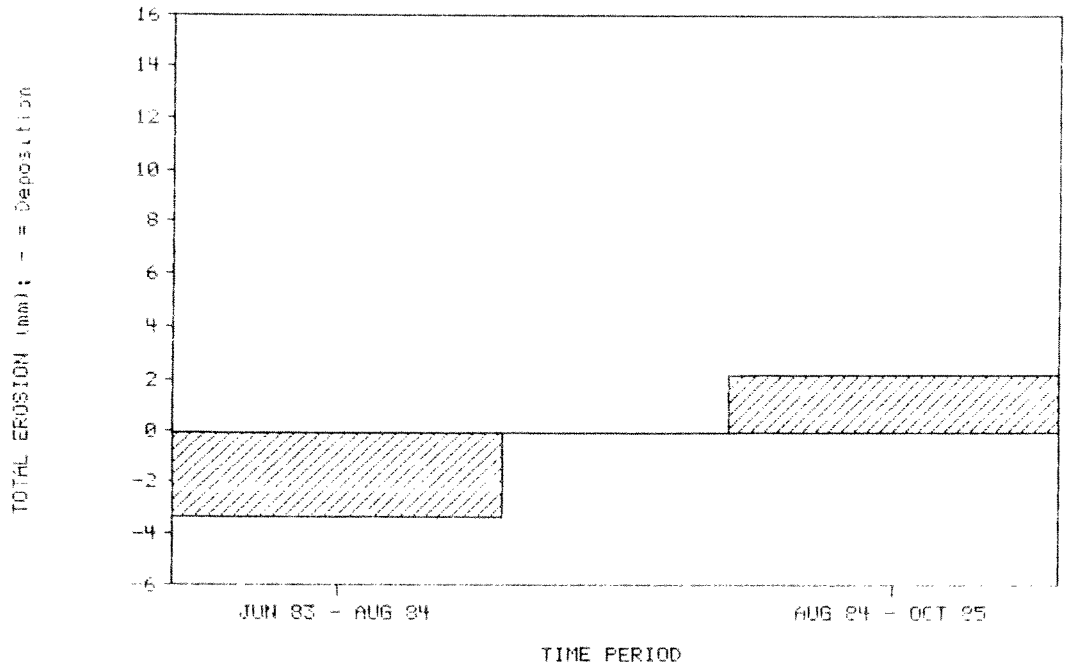


Figure 25. Average Annual Slope Erosion on Tent Mountain, Slope 2.

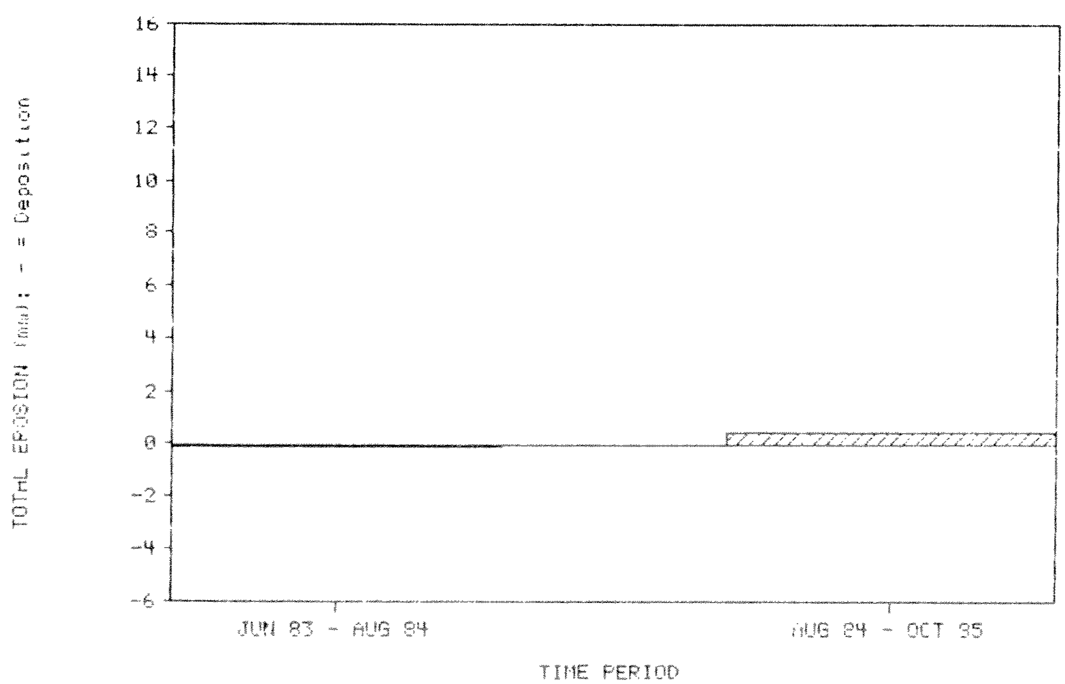


Figure 26. Average Annual Slope Erosion on Tent Mountain, Slope 4.

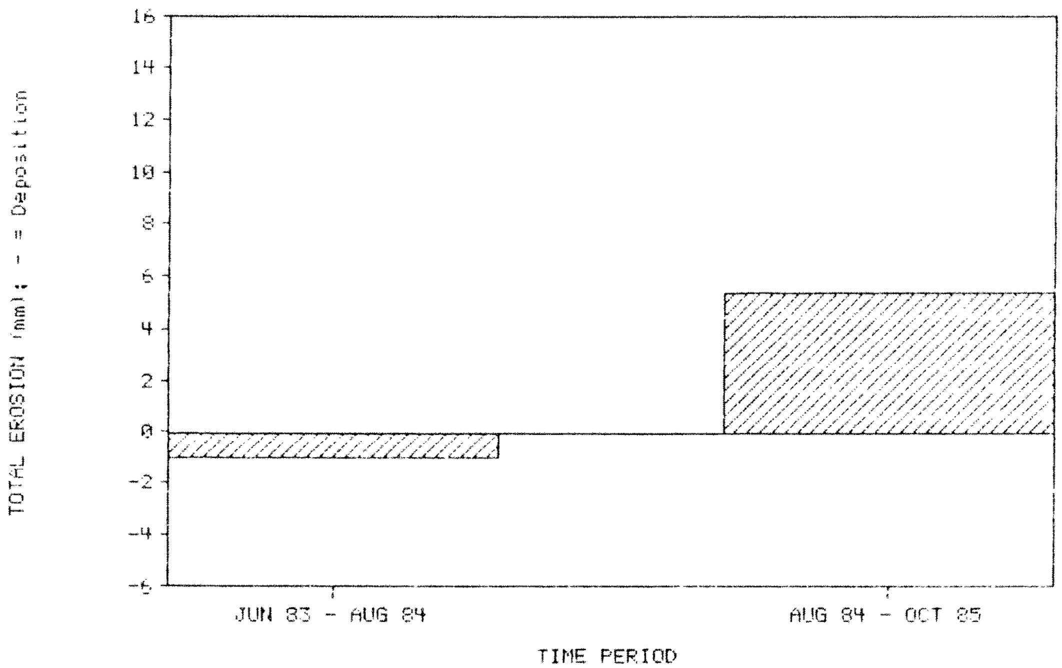


Figure 27. Average Annual Slope Erosion on Tent Mountain, Slope 5.

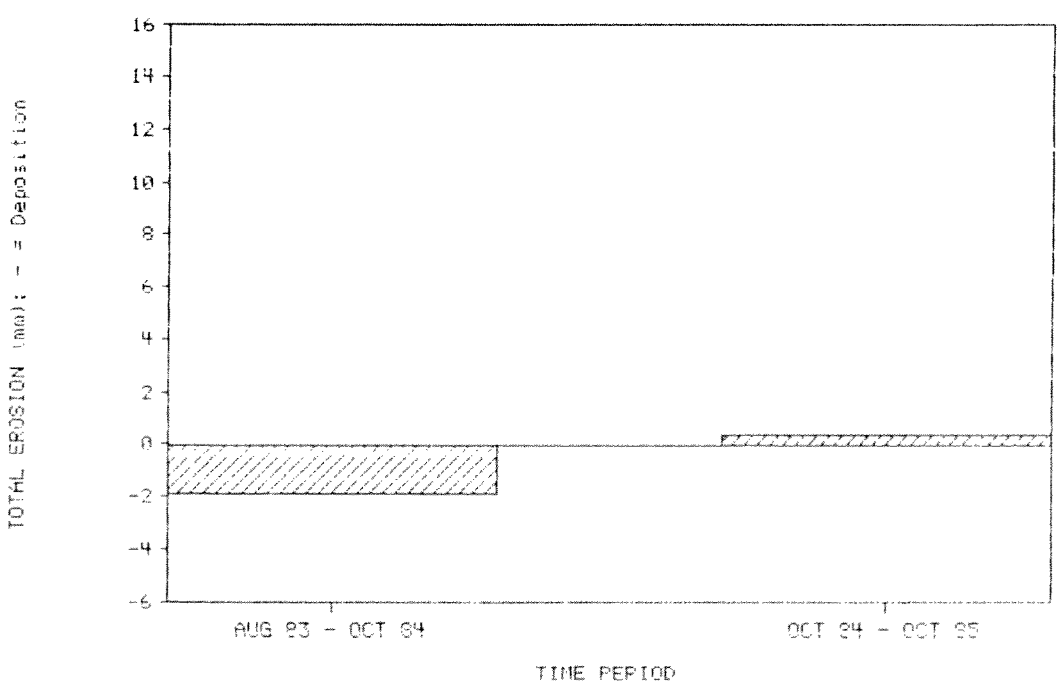


Figure 28. Average Annual Slope Erosion on Smoky River, Slope 2.

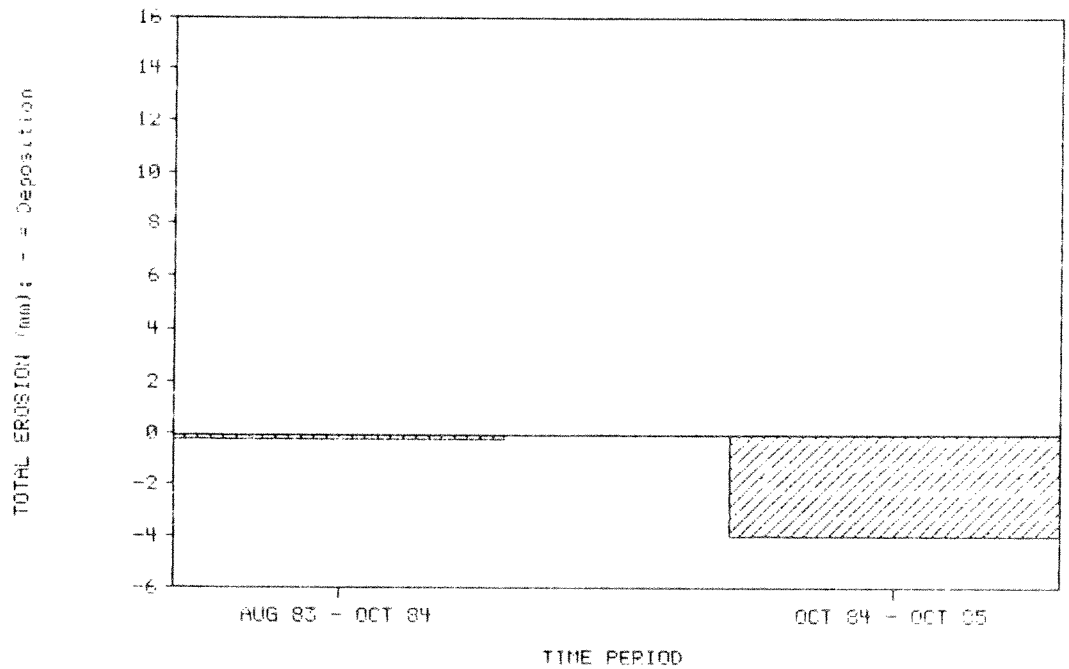


Figure 29. Average Annual Slope Erosion on Smoky River, Slope 3.

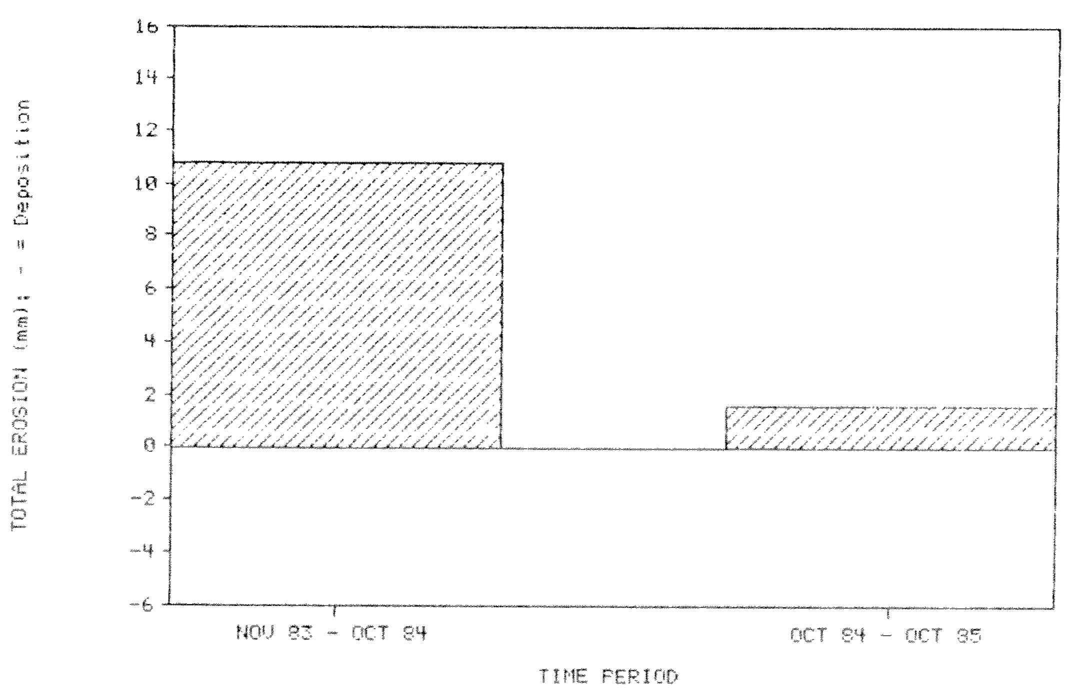


Figure 30. Average Annual Slope Erosion on Smoky River, Slope 4.

5.7 EFFECT OF MATERIAL CHARACTERISTICS

Laboratory analyses of the samples collected from the slopes at Smoky River were not as helpful as initially expected. There appears to be some relationship between density and erosion for Slope 4 as shown in Figure 31, where erosion decreases with an increase in density of the soil. When the analysis from Slopes 2 and 3 are included, no well-defined relationship is apparent, as portrayed in Figure 32.

The grain size analyses showed no appreciable differences between plot samples. The same was true for the specific gravity tests.

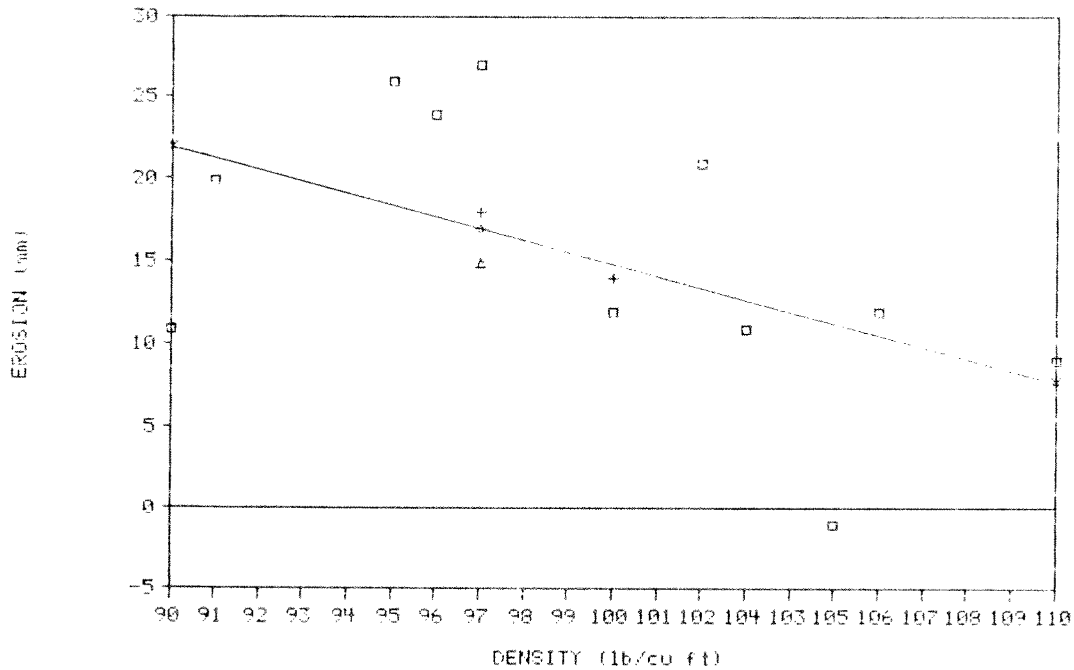


Figure 31. Erosion vs. Density on Smoky River, Slope 4.

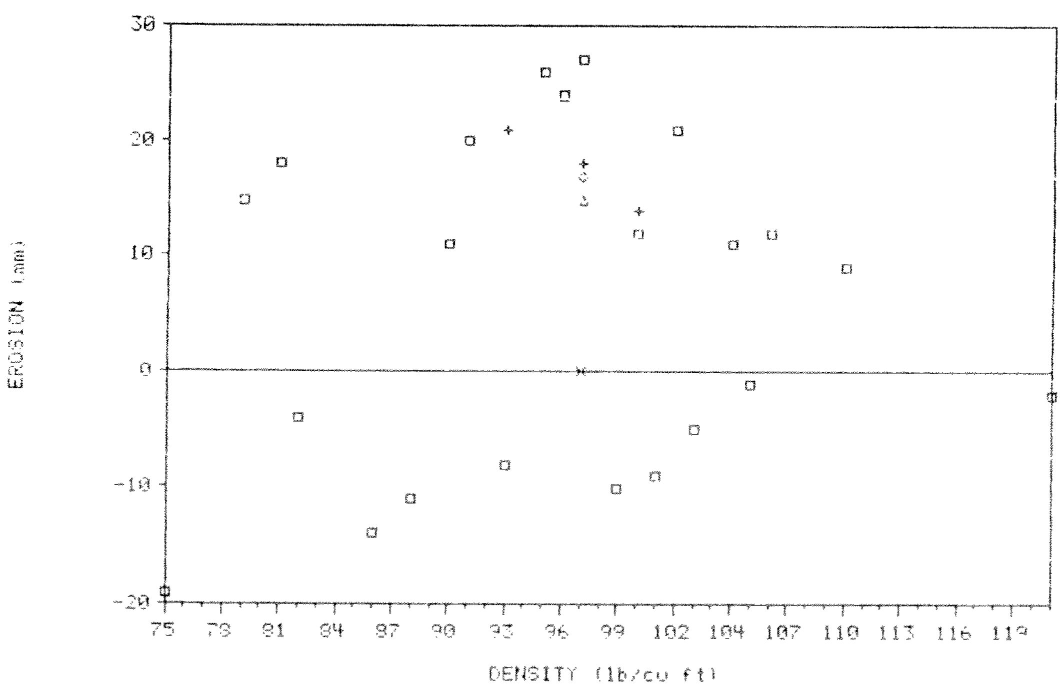


Figure 32. Erosion vs. Density on Smoky River, Slopes 2, 3, and 4.

5.8 CONCLUSIONS

Over the two-year time period that erosion was measured, the total amount of erosion on most slopes was minimal which made it difficult to establish models or trends of the influence of contributing factors on erosion itself. A general observation of all the results, based on two annual periods of erosion measurement on the slopes, is that there appears to be no need for a great deal of concern about waste dump erosion. Other than for a small initial amount of surface deflation immediately after regrading is complete, no significant amount of material seems to leave the slopes. From knowledge of the nature of the materials involved (i.e., extremely coarse-grained "topsoil" overlying blocky, angular waste rock) one concludes that even measurable erosion is mostly likely redistributed over the slope itself (as evidenced by numerous deposition results of plot measurements). One year after resloping, measured erosion becomes almost insignificant as fine particles have been deposited in voids in the waste rock.

Within the limits of the waste dump design parameters studied, there appears to be no reason to establish design criteria from the standpoint of erosion control. There was also no evidence to support the need for erosion intercepts (dozer cuts located diagonally across the slope face), supported by the results from the long, undisturbed Slope 2 at Tent Mountain.