Report No. RRTAC 87-6

ASSESSING DESIGN FLOWS AND SEDIMENT DISCHARGE ON THE EASTERN SLOPES

by

HYDROCON ENGINEERING (Continental) LTD.

and

MONENCO CONSULTANTS LTD.

Prepared for

The Mountain Foothills Reclamation Research Program (MFRRP)

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

(Reclamation Research Technical Advisory Committee)

and

THE COAL ASSOCIATION OF CANADA

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 the Environment and two Deputy Chairmen from the Department of Forestry, Lands & 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 Technical Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & 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:

Dr. G.A. Singleton, Chairman
Reclamation Research Technical Advisory Committee
Alberta Environment
14th Floor, Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta T5J 3N4

(403) 427-5815

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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.

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Queen's Printer
11510 Kingsway Avenue
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 handing 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.

EXECUTIVE SUMMARY

This document provides an evaluation of currently available rainfall runoff sediment production methodologies, identifies key parameters, and outlines field programs to gather data for model calibration.

1. RAINFALL RUNOFF

There are two distinct requirements related to rainfall runoff. Firstly, the entire runoff hydrograph must be determined to provide the hydraulic component for sedimentation pond design. Secondly, only the peak flood flow may be required for the design of ditches and culverts. For either case two separate components of the rainfall process must be described, namely the rainfall and runoff components.

The rainfall component refers to the temporal distribution, duration, and frequency of the rainfall which produces the surface runoff. Models used to describe the rainfall component include:

1. The Intensity-Duration-Frequency (IDF) Method.
2. The Soil Conservation Type I and II Curves, and
3. Huff's Method.

The runoff component refers to the transformation of the rainfall to surface runoff, as calculated or measured for a particular location. Thus this includes computation of the losses or abstractions from the rainfall to produce surface runoff and the routing of the flow along stream channels to the point of interest. Losses are usually estimated by infiltration models such as:

1. Philips Two Term Equation.
2. Horton Equation.
3. Holtan Equation.
4. Soil Conservation Service (SCS) Curve Number Method.
5. The Hydrologic Centre (HEC) Model.

After the abstractions estimated by the infiltration models have been subtracted from the gross rainfall, the resultant net or excess rainfall is routed to the stream channel. This is often accomplished by synthetic unit hydrograph models, including:

1. Snyder's Method.
2. Clark's Method.
3. The SCS Method.
4. The Overton and Crosby Method.

Finally, the runoff may be routed down the stream channel to the point of interest. Often a hydrologic channel routing method such as the Muskingum Method is used.

Where peak flow estimates are required the following methods may be used:

1. Rational Formula.
2. Discharge-Area and Regression Formulas
3. Index Flood Method.

Peak flow estimates may also be provided by the synthetic unit hydrograph models.

2. SEDIMENT PRODUCTION

There are two distinct data requirements related to sediment production. Firstly, there may be a need to develop the sedimentgraph (i.e., plot the time variation in runoff sediment concentration) associated with a design strom event at the pond inlet. This is required to determine the sediment removal efficiency of a given pond configuration during the specified design storm event. Secondly, the total amount of sediment delivered to the reservoir over the expected life of the reservoir may be estimated. This is required to size the sediment storage volume of an impoundment.

To determine the sedimentgraph, watershed sedimentologic characteristics are input into a sediment yield model to produce a single storm event yield from the watershed . Sediment yield models include:

1. Modified Universal Soil Loss Equation (MUSLE).
2. Onstad and Foster's Model.
3. Kuh, Reddell, and Hiler's Model.
4. SLOSS.

This sediment yield may then be routed to the control structure inlet by a sediment routing model, such as:

1. Willams Model I.
2. Willams Model II.

Here sediment yield data needs to be combined with information on particle sizes. This information is obtained a similar way to the sediment yield, in that a model computes the eroded sediment particle size distribution for a single storm event based on the parent material size distribution. No generally applicable predictive models exist for the estimation of eroded sediment particle size distributions. Monitoring is required to gather this data. However, models such as the Barfield et al. model do exist for routing the eroded sediment particle size distribuion to the control structure inlet.

Sedimentgraph models, such as Willams (1978) Model, or the Ward, Williams, and Haan Model, use the routed sediment yield and routed sediment size information to produce a sedimentgraph at the inlet to a sediment control structure.

Where sediment pond storage requirements need to be sized, gross erosion models such as the Universal Soil Loss Equation (USLE) may be used to compute gross soil loss. This may then be modified by a delivery ratio model, such as the Haan and Barfield Model, to provide the sediment yield at the basin outlet for a single storm or average annual basis.

3. RECOMMENDED HYDROLOGIC/SEDIMENTOLOGIC MODEL

It is recommended that an existing model be used, rather than designing a new one, because:

1. The development of a new watershed model would be time consuming and therefore, costly.
2. The resulting model would be an untried and untested technique.
3. There is no indication that a new watershed model would be better suited to Alberta conditions than some existing models.

The existing watershed model recommended for evaluating water and sediment discharge in conjunction with the field program is SEDIMOT II (SEdimentology by DIstributed MOdeling Techniques) (Wilson, Barfield, and Moore 1982; Warner et al. 1982b, Monenco Consultants Limited 1986). SEDIMOT II is a single storm model intended for use in designing sediment control structures for surface mined watersheds and analyzing the hydrologic consequences of mining. It is recommended for use in conjunction with the field program because:

1. It was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining.
2. It incorporates all the models necessary to predict inlet hydrologic and sedimentgraphs in one easily useable and well documented format.
3. It includes two options for calculating sediment yields; one of which is relatively well suited for predicting the impact of steep slopes (SLOSS, see Table 31).
4. It has been accepted by a number of jurisidictions in United States for use during the permitting process.

The specific predictive models used in SEDIMOT II are outlined in Table E1.

Table E1 Summary of predictive models used in the hydrologic component of the SEDIMOT II watershed model

PREDICTIVE MODEL TYPE	MODEL(S) INCORPORATED INTO SEDIMOT II
RAINFALL PATTERN	- SCS TYPE 1 or TYPE 2 - - user input rainfall distribution
INFILTRATION MODEL	- SCS curve number model
OVERLAND FLOW (UNIT HYDROGRAPHS)	- Overton and Crosby (1979) for forested and agricultural - SCS for disturbed
CHANNEL FLOW	- Muskingum
SEDIMENT YIELD MODEL	- Modified Universal Soil Loss Equation (MUSLE)
SEDIMENT ROUTING MODEL	- Williams Model I
ERODED SIZE DISTRIBUTION ROUTING MODEL	- Barfield et al.
SEDIMENTGRAPH	- Ward et al. Model

4. <u>MONITORING PROGRAM</u>

On the basis of the literature investigation, the following key data should be measured to permit an accurate calibration of the SEDIMOT II model, and assessment of the variability of model parameters.

1. Rainfall; rainfall intensities as determined by a tipping bucket or similar gauge. Rainfall data may also be used as an index of guide to antecedent moisture conditions (AMC) for the determination of curve numbers (CN). Accurate timing of rainfall is required in order to establish watershed time of concentration, time lag, and rainfall duration values.
2. Streamflow discharge; based upon monitoring stream water levels, and establishing a discharge - water level relationship. Water levels should be logged so that the time of streamflow response to runoff may be identified and related to the timing of rainfall inputs for determination of time of concentration, time lag, etc. From stream discharge data, hydrograph and streamflow routing characteristics may be determined, and based upon corresponding rainfall data, appropriate CN values may be calculated. Discharges are required at entrances to and exits from sedimentation ponds, and water levels are required at sedimentation ponds.
3. Sediment concentrations are required throughout the duration of the runoff hydrograph to define a sedimentgraph. Suspended sediment samples are required at entrances to and exits from sediment ponds. Samples gathered throughout the event may be analysed for particle size distributions. From this data, a lumped parameter index of soil erosion,

(based on soil erodibility factor, K, and control practice factor, CP), may be determined. (Through a sensitivity analysis and with knowledge of the range of each parameter, a range of K and CP values may be determined based on the lumped parameter data.)

4. Eroded Particle Size Distributions are required at the sediment source for use in the SEDIMOT II model. These sediment samples may also be analysed for specific gravity. Samples are mandatory at the sediment source, but may also be taken "en route" to a sedimentation pond to trace the transport (or deposition) of material.

Monitoring devices envisaged for this project include water level and discharge monitoring flumes, automatic pump samplers, eroded sediment traps, and soil moisture probes.

Based on information received from the mine operators the proposed monitoring program includes:

1. Gregg River Resources Ltd. (GRR) - haul road drainage to pond LM1.
2. Luscar Sterco (1977) Ltd. Coal Valley (CV) - Pit 21 reclaimed area.
3. Cardinal River Coals Ltd. (CRC) - plant site and coal piles.

Table E2 summarizes estimated expenditures for the proposed monitoring program.

5. CONCLUSIONS

1. Methodologies for the determination of rainfall runoff and sediment production vary widely in their sophistication and in the number of parameters used to describe or characterize the detailed physical processes occuring in nature.

2. Existing models combining both the hydrologic and sedimentologic components are preferred for use as they can be used for not only sedimentation pond design but for sizing of culverts and ditches as well.
3. The SEDIMOT II model is preferred for hydrologic/sedimentologic use at coal mine developments on Alberta's Eastern Slopes. The detailed analyses of runoff and sediment processes embodied in the SEDIMOT II model make it best suited for modelling the diverse terrain encountered at coal mining sites.
4. Parameters from the SEDIMOT II model which must have values determined for use under conditions found in Alberta's Eastern Slopes are:
    1. Curve numbers (CN) based upon antecedent moisture conditions (AMC).
    2. Soil erodibility factor (K).
    3. Control practice factor (CP).
    4. Eroded particle size distributions.
5. Monitoring of the following variables is required to determine values or ranges of values for key input parameters to the SEDIMOT II model:
    1. Precipitation intensity and duration.
    2. Runoff timing and magnitude.
    3. Eroded sediment particle size distribution and specific gravity.
    4. Sediment hydrograph.
6. Monitoring programs can be undertaken at existing mine sites to gather data on rainfall runoff and sediment production processes.

7. Analysis of runoff and sediment data from the monitoring program can be used to refine estimates of input parameters for the SEDIMOT II model. Some adjustments to the data will be necessary to account for the effects of flocculants in sedimentation ponds, as the SEDIMOT II model cannot evaluate flocculation.

6. RECOMMENDATIONS

1. The SEDIMOT II model should be used for hydrologic sedimentologic design activities at coal mines on Alberta's Eastern Slopes.
2. The monitoring program outlined in Table 11 should be undertaken to properly evaluate key input parameters to the SEDIMOT II model.

Table E2. Proposed monitoring program, expenditures by minesites

COMPANY	YEAR	CAPITOL COSTS	INSTALLATION	MINESITE COSTS TO BE CREDITED TOWARDS THAT COMPANY'S CONTRIBUTION MANPOWER	ANALYTICAL	TOTAL	GRAND TOTAL
GRR	1987	$17 800	$1 200	$ 2 400	$ -	$ 3 600	$ 21 400
	1988	-	-	2,400	1,360	3,760	$ 3 760
	TOTAL	17 800	1 200	4 800	1 360	7 360	$ 25 160
CV	1987	17 800	1 200	2 400	-	3 600	$ 21 400
	1988	-	-	2 400	1 120	3 520	$ 3 520
	TOTAL	17 800	1 200	4 800	1 120	7 120	$ 24 920
GRC	1987			5 000 Software			
		20 300	1 200	2 400 Monitoring	-	8 600	$ 28 900
	1988	-	-	2 400	1 920	4 320	$ 4 320
	TOTAL	20 300	1 200	9 800	1 920	12 920	$ 33 220
MINES TOTAL		$55 900	$3 600	$19 400	$4 400	$27 400	$ 83 300
CONSULTANT	1987						$ 13 200
	1988						$ 48 000
	TOTAL						$ 61 200
CONTINGENCY							$ 8 900
OVERALL TOTAL							$153 400

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ABSTRACT

Many methods are currently used for assessing precipitation, flood flows, and sediment discharge in the design of settling impoundments or sizing culverts and drainage ditches for coal mining developments. This document provides an evaluation of currently available rainfall runoff and sediment production methodologies, identifies key parameters, and outlines field programs to gather data for model calibration.

Methodologies for the determination of rainfall and sediment production vary in their sophistication and ability to accurately predict water discharges or sediment concentrations. Both sophisticated and simple models have a wide range of variability in predicted outputs depending on the input parameter values used. Models such as SEDIMOT II which are both widely used and accepted and which describe in sufficient detail the complex rainfall runoff or sediment production processes are preferred and recommended for use.

Monitoring of site specific values for key parameters such as rainfall, runoff discharge, sediment hydrographs, and eroded particle sizes is required to properly calibrate hydrologic/sedimentologic models. Programs for gathering this data are described and costed for coal mining developments on Alberta's Eastern Slopes.

ACKNOWLEDGEMENTS

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- Mr. G. Acott, Cardinal River Coal, Study Co-Manager, Supplied data and information.
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- Mr. D. T. Sneddon, Alberta Energy and Natural Resources, Hydrology Subcommittee Chairman.
- Mr. Th. J. Beukeboom, Alberta Environment, contract management.
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- Mr. C. Brinker, Luscar Sterco (1977) Ltd., supplied data and information.
- Mr. V. G. Betts, Smoky River Coal, supplied data and information.
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1. INTRODUCTION

1.1 NATURE OF THE STUDY

The Hydrology Subcommittee of the Mountain Foothills Reclamation Research Program (MFRRP) is conducting research into the water and sediment runoff control at coal mines located on the Eastern slopes of the Rocky Mountains in Alberta.

MFRRP is a program administered jointly by government and industry representatives. Alberta Government departments participating in the program include; Energy and Natural Resources, Environment, and Forestry, Lands, and Wildlife. Industry representatives fall under the umbrella of The Coal Association of Canada, and include personnel from the following mines; Smoky River Coal Limited, Luscar Sterco (1977) Ltd., Gregg River Resources Ltd., Cardinal River Coals Ltd., and Esso Resources Canada Limited.

As a part of this continuing research, Hydrocon Engineering (Continental) Ltd. was contracted to examine water and sediment runoff processes, modelling and data collection, and was assisted by Monenco Consultants Ltd.

The overall objectives of this study are to evaluate and provide a methodology to assess precipitation, flood flows, and sediment discharge in the mountain and foothills regions of Alberta with respect to their implications for setting impoundment design and culvert and drainage ditch sizing in coal mining developments, and to design a field program to measure critical parameters. The study was separated into two phases: Phase I - the evaluation of methodologies, and Phase II - the design of the field program.

1.2 TERMS OF REFERENCE

The scope of work for this report is based on a request for proposals issued by Dr. Paul F. Ziemkiewicz, Co-Chairman, MFRRP Steering Committee on 1986 March 13. The scope is divided into two phases with several components:

1. Literature Investigation
   - i) a brief review of existing methodologies (development of new methodologies will be entertained);
   - ii) a selection and justification of the most appropriate methodology for each project area;
   - iii) a definition of parameters for each method and an assessment of the relative sensitivity of the parameters within each method and between methods;
   - iv) an outline of data constraints and limitations; and
   - v) an evaluation of feasibility of data collection in terms of cost and ability to collect.

2. Field Program Design
   - i) design a program to monitor a minimum of three areas including a foothills environment, a mountainous environment and the Tri Creeks Watershed Study area;
   - ii) evaluate a minimum of two watersheds within each area for precipitation, streamflow and sediment discharge, intensity and duration;
   - iii) select watersheds to provide an evaluation of pre-mining, active mining, and post-mining hydrological conditions;
   - iv) contact coal companies within the appropriate areas for consultation in the development of the field program.

2. HYDROLOGIC MODELS

Storm runoff information is required on active mining sites for the design of ditches, culverts and sedimentation ponds and other control structures. For ditches and culverts, the peak discharge is most often sufficient for sizing these structures, whereas for sedimentation ponds, the temporal distribution of the surface runoff is required for design.

The determination of either the peak or time distribution of surface runoff requires that the following two components be quantified:

1. Rainfall component.
2. Runoff component.

The rainfall component refers to the temporal distribution, duration and frequency of the rainfall which produces the surface runoff. The runoff component refers to the transformation of the rainfall to surface runoff, as calculated or measured for a particular location.

The following chapters describe some of the basic phenomena involved in the rainfall runoff process, and summarizes the generic types of predictive models that have been developed to simulate them.

2.1 RAINFALL COMPONENT

2.1.1 General Background

The design of hydraulic structures at mine sites is often based on a rainfall depth that occurs for a specified storm duration and frequency. For example, sedimentation ponds in Alberta are designed for the runoff hydrograph resulting from a 1:10 year return period, 24 hour duration storm. Often the intensity of the rainfall may also be specified, as the rate of rainfall can vary significantly throughout a particular storm event.

The selection of a temporal rainfall pattern has a major influence on the predicted hydraulic response from a watershed. For a given rainfall abstraction rate (the losses subtracted from the rainfall to produce surface runoff, which include: vegetative interception, infiltration, and surface storage losses), runoff volume either increases or decreases depending on the rainfall intensity. Therefore a storm pattern that produces high rainfall intensities can generally be associated with a large peak discharge. Likewise, storm patterns that predict earlier peak rainfall intensities will produce runoff hydrographs that have a relatively short time to peak.

The temporal distribution of the rainfall will also have an effect on the rainfall abstraction rate and on the hydraulic response of a watershed. The initial infiltration abstraction (i.e., the volume infiltrated before runoff begins) is inversely proportional to rainfall intensity. Hence, as the rainfall intensity increases for a given volume of rainfall, one would expect an increase in runoff volume.

The hydraulic response of a watershed is also inversely proportional to rainfall intensity. In general, a higher rainfall intensity will produce more runoff, which will result in a greater flow depth over the land surface. Consequently, the overland flow velocity will increase and cause a reduction in the watershed response time.

With regard to the sedimentologic design of water control structures, (see Chapter 3), the selection of temporal rainfall patterns will also affect the amount of soil detached by raindrop impact. As high intensity rainfall events are often characterized by larger size raindrops, the kinetic energy and erosive force of the rain drop impact also increases as intensity increases.

2.1.2 Modelling

The high variability of temporal patterns between individual storms has made the study of temporal distribution difficult. To date, there is no known assessment of the temporal distribution of rainfall for the Eastern Slopes region of Alberta. Three different techniques for predicting the temporal patterns of storms are commonly being used in event-based watershed models. They are intensity-duration-frequency (or depth-duration-frequency) method, the Soil Conservation Services type curves, and Huff's method.

2.1.2.1 Intensity-Duration-Frequency (IDF) Method

The IDF method uses rainfall intensities or depths taken from Environment Canada's Atmospheric Environment Service (AES).

Alternatively, synthetic IDF curves can be simulated by either of the following procedures:

1. Transposition of existing IDF curves for a station with similar weather patterns and topographic setting by relating known values for a specific duration, (eg. shifting curves based on a frequency analysis of daily or 24 hour duration values).
2. Derivation of rainfall amounts for varying frequencies and recurrence intervals based on a rainfall frequency atlas (Environment Canada 1985).

IDF curves are only prepared for selected stations in Alberta, such as Calgary, Edmonton, and Lethbridge. The values given in the IDF curves are determined by evaluating the maximum annual rainfall depths for a particular duration. As such the IDF curves do not provide any information about the actual storm temporal pattern except for the total rainfall depth.

It should be noted that the AES uses the Gumbel frequency distribution to analyse rainfall intensity and duration data. Other distributions such as the Pearson III distribution may be used at the discretion of the hydrologist undertaking the rainfall analysis.

IDF curves may be used to develop a temporal storm pattern by dividing a storm of a particular recurrence interval into time increments. This, however, has two disadvantages. Firstly, the temporal arrangement of the individual rainfall increments must be organized by the hydrologist to determine which time portion (e.g. early, middle, late) of the storm receives the heaviest portion of total rainfall. Secondly, the IDF method assumes that the storm is composed of rainfall depths of the same frequency or return period. These factors may also be viewed positively, as the user can select the storm pattern, and as the constant return period for all durations provides a consistent basis for design.

2.1.2.2 Soil Conservation Service Type I and II Curves The Soil Conservation Service (1973) originally developed two temporal 24 hour storm patterns for different sections of the United States. The Type II curve is normally applied to rainfall events in Canada, excluding the west coast (Barfield, Warner, and Haan 1981).

The Type II curves are based on the IDF method previously described, where the largest 30 minute rainfall depth is located near the middle of the 24 hours (or length of rainfall duration) span, and the smallest 30 minute rainfall depths are located at the beginning and the end of the 24 hour period. The arrangement of the 30 minute depths within the 24 hours period was based on design considerations and not meteorological factors.

The disadvantages of the SCS curves are similar to those of the IDF curves. In addition, the temporal patterns depicted by the curves may not be representative of observed patterns. The advantages of the SCS curve technique are that it is easy to use, it is familiar to hydrologists, and that it is consistent with other SCS techniques and procedures.

2.1.2.3 Huff's Method Huff (1967) evaluated 261 storms that occurred in Illinois between 1955 and 1966 with rainfall varying from 3 to 48 hours. Rainstorms were divided into four quartiles depending on which quarter of the total storm duration received the heaviest duration. The probability of a particular storm receiving a cumulative precipitation amount equal to or greater than a specified value was then determined for each quartile.

The major advantage of Huff's method over the IDF and SCS methods is that it attaches a probability to a storm pattern. Problems arise in selecting the appropriate quartile, unless considerable local data is available to characterize temporal patterns. The applicability of Huff's data outside Illinois may also be questioned.

2.1.2.4 Summary The peak discharge , runoff volume, sediment yield, and the hydraulic responses of a watershed are all influenced by the temporal storm pattern. However, because of high variability between individual storms, the prediction of temporal distribution is very difficult. With the IDF method or SCS's curves, the return period for rainfall depths up to an including the total rainfall depth is known, however, the return period of the storm pattern is not known. Whereas with Huff's method the return pattern of the storm pattern and total rainfall depth is known, the return periods for previous duration rainfall depths are unknown.

Where possible, the design rainfall pattern should be based upon recorded meteorologic data. Otherwise, a pattern may be selected which produces the highest resultant peak runoff.

For design purposes on Alberta's Eastern Slopes, the following procedure is recommended:

1. If no storm rainfall pattern information is available, the following steps should be followed:
   i) determine a synthetic rainfall intensity-duration-frequency values from a rainfall frequency atlas such as Environment Canada (1985).
   ii) for the duration and frequency of interest, use the intensity from the IDF curves in conjunction with the S.C.S. Type II curve to develop the design rainfall pattern.
2. Where storm rainfall pattern data is available, sufficient information will also exist to produce IDF curves. Therefore the recommended procedure would be:
   i) produce IDF curves for the site.
   ii) plot storm rainfall pattern data and select the pattern that best represents design storm conditions, (i.e. that which produces greatest runoff rates).
   iii) use IDF curves and storm pattern information to produce design storm rainfall pattern.

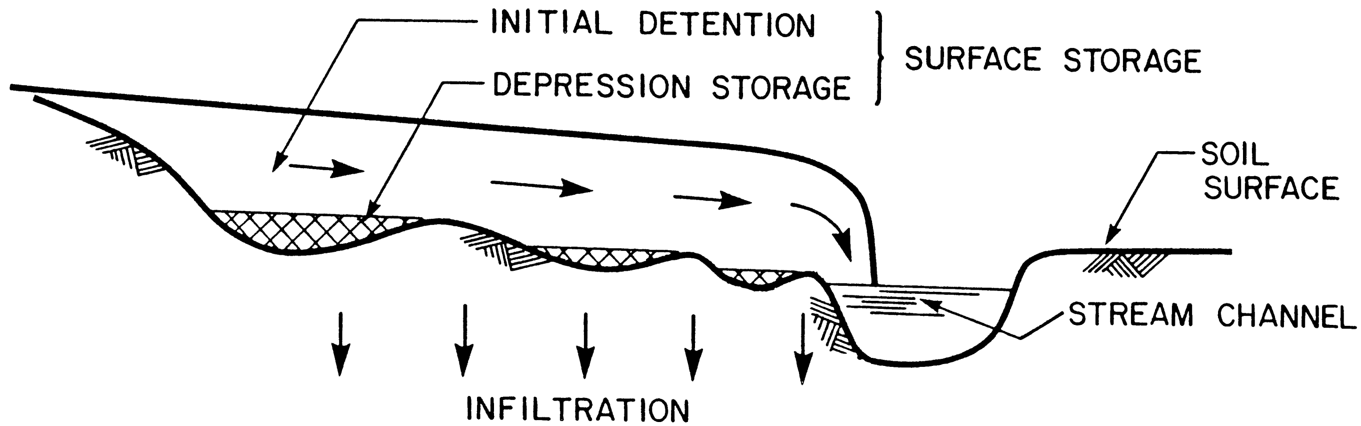
Where meteorological data is being gathered, it is recommended that storm rainfall pattern information be gathered for at least five years (i.e. five summer seasons) to produce sufficient data for anlaysis. This will also provide enough data to construct IDF curves.

2.2 THE RUNOFF PROCESS

The runoff process is described in most hydrology texts, such as Chow (1964), and Gray (1973). Following is an excerpt from Viessman et al. (1977).

"During a given rainfall, water is continually being abstracted to saturate the upper levels of the soil surface; however, this saturation or infiltration is only one of many continuous abstractions. Rainfall is also intercepted by trees, plants, and roof surfaces, and at the same time is evaporated. Once rain falls and fulfills initial requirements of infiltration, natural depressions collect falling rain to form small puddles, creating depression storage. In addition, minute depths of water forming detention storage build up on permeable and impermeable surfaces within the watershed. This stored water gathers in small rivulets which carry the water originating as overland flow into small channels, then into larger channels, and finally as channel flow to the watershed outlet." [Figure 1 illustrates this process. process.]

"In general, the channel of a watershed possesses a certain amount of base flow during most of the year. This flow comes from groundwater or spring contributions and may be considered as the normal day-to-day flow. Discharge from precipitation excess - that is, after abstractions deducted from the original rainfall - constitutes the direct runoff hydrograph (DRH). Arrival of direct runoff at the outlet accounts for an initial rise in the DRH. As precipitation excess continues, enough time elapses for progressively distant areas to add to the outlet flow. Consequently, the duration of rainfall dictates the proportionate area of the watershed amplifying the peak, and the intensity of rainfall during this period of time determines the resulting highest discharge."



SURFACE RUNOFF PHENOMENA

(AFTER GRAY 1973)

Figure 1

Linsley et al. (1975) elaborate on these basic concepts.

"Figure [2] shows schematically the time variations of the hydrologic factors during an extenstive storm on a relatively dry basin. The dotted area of the figure represents the portion of total precipitation which eventually becomes streamflow measured at the basin outlet. Channel precipitation is the only increment of streamflow during the initial period of rainfall. As streams rise, surface area and consequently the volume rate of channel precipitation increase.

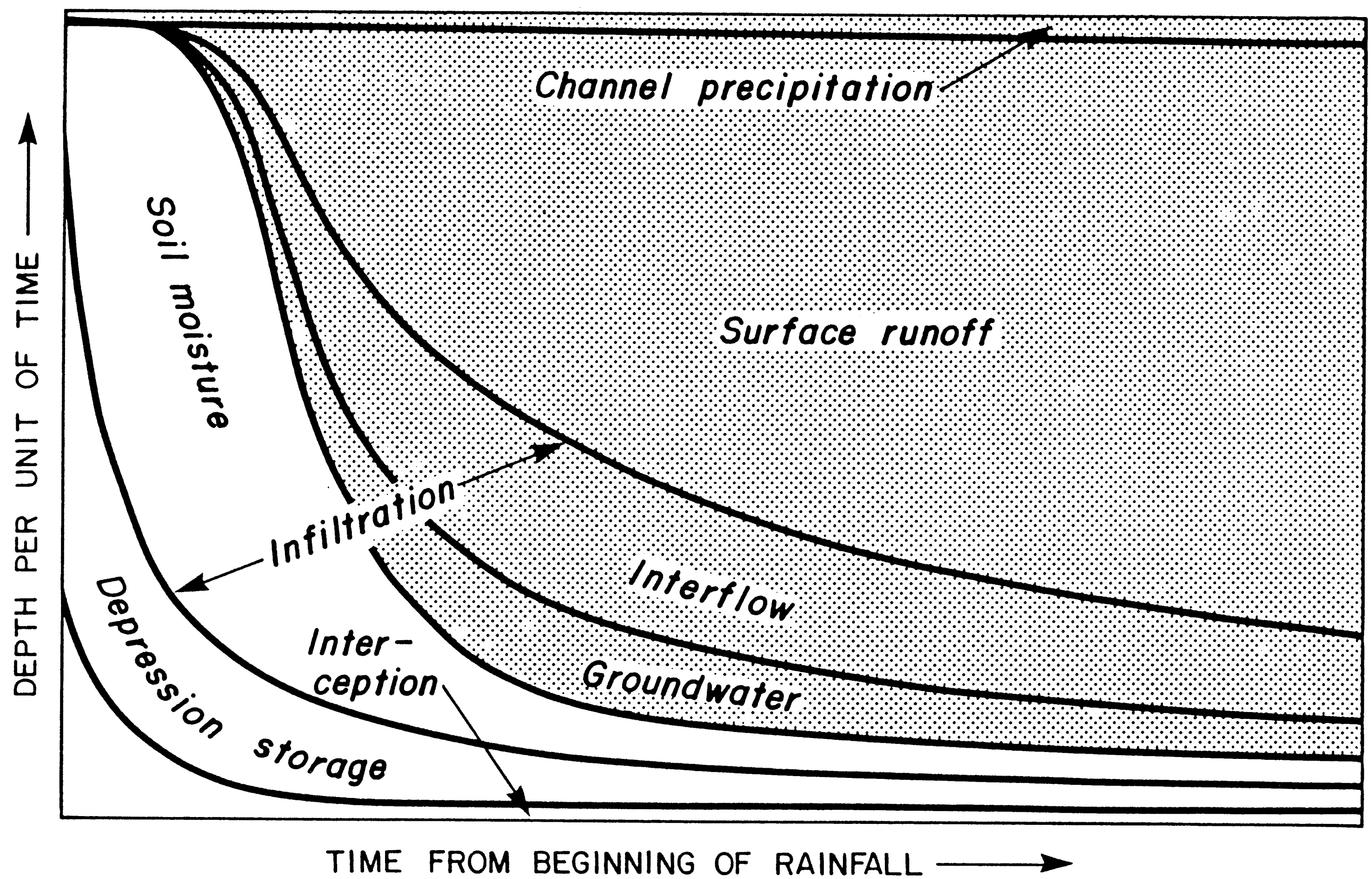
"The rate of interception is high at the begining of rain, especially during summer and with dense vegetal cover. However, the available storage capacity is depleted rather quickly, so that the interception rate decreases to that required to replace water evaporated from the vegetation.

"The rate at which depression storage is filled also decreases rapidly from a high initial value as the smaller depressions become filled and approaches zero at a relatively high value of total-storm rainfall. Depression storage is water retained in depressions until returned to the atmosphere through evaporation.

"Except in very intense storms, the greater portion of the soil-moisture deficiency is satisfied before appreciable surface runoff takes place. However, some of the rain occurring late in the storm undoubtedly becomes soil moisture, since the downward movement of this water is relatively slow.

"Water infiltrating the soil surface and not retained as soil moisture either moves to the stream as interflow or penetrates to the water table and eventually reaches the stream as groundwater. The rate of surface runoff starts at zero, increases slowly at first and then more rapidly, eventually aproaching a relatively constant percentage of the rainfall rate. Both the percentage and the rate of runoff depend upon rainfall intensity.

"Figure [2] illustrates only one of an infinite number of possible cases. A change in rainfall intensity would change the relative magnitude of all the factors. Further complications are introduced by varying rainfall intensity during the storm or by occurence of snow or frozen ground. To appreciate further the complexity of the process in a natural basin, remember that all the factors of Figure [2] vary from point to point within the basin during a storm."



SCHEMATIC DIAGRAM OF THE DISPOSITION OF STORM RAINFALL

(After LINDSEY et al. 1975)

Figure 2

2.3 MODEL TYPES

The runoff component is used to compute a storm hydrograph, based upon a particular rainfall pattern, for sites where sediment or water control structures are located.

Either physically-based or empirical relationships describing the various components of the hydrologic cycle may be used to model the runoff process. The key components of the runoff process which are often considered are: rainfall, vegetative interception, evapotranspiration, depressional storage, infiltration, overland flow, subsurface flow, groundwater flow, and channel flow. For an event model, such as is of interest in designing water or sediment control structures at mine sites, the evapotranspiration and groundwater components may be safely neglected. Also, in most event hydrologic models, vegetative interception, subsurface flow, and depressional storage are commonly ignored or lumped with other components of the runoff process.

The remaining components of the runoff process and models for calculating these components are discussed in Appendices 8.1 to 8.2.

2.4 RECOMMENDED MODELS

The following sections identify the predictive models recommended for use in conjunction with the field program described in Chapter 4. Models are proposed for each of the two basic objectives of the hydrologic component, namely:

1. Runoff hydrographs.
2. Peak runoff discharges.

2.4.1 Objective 1: Runoff Hydrographs

Predictive models suitable for evaluating the runoff response of disturbed areas during a single storm event may be most effectively applied by using a computer, especially if the drainage basin is comprised of many diverse sub-basins. Use of a computer watershed model which incorporates a group of compatible predictive models is often necessary when developing inflow hydrographs to size sedimentation ponds. If these models are already in place, they can be used to provide supplementary estimates of peak flows for designs of ditches and culverts (see Section 2.4.2).

Several options are available for the computer modelling of runoff, namely:

1. Develop a new computer model.
2. Use existing models, which are solely developed for analysing runoff responses.
3. Use an existing model which is capable of handling both the hydrologic and sedimentologic response of a watershed in the mining environment.

The option of developing a new model is not recommended for the following reasons:

1. The development of a new single event runoff model would be very costly.
2. The new model would require extensive testing and calibration to verify its performance.
3. the new model would not necessarily be any better than existing models in simulating runoff on Alberta's Eastern Slopes.

The option of using a solely hydrologic models is also not recommended as combined hydrologic/sedimentologic models are available which can serve either purpose. Therefore a single hydrologic model would not be cost-effective if a separate sedimentologic model was required for other uses.

The existing combined hydrologic/sedimentologic model recommended for evaluating the runoff response of mined areas in conjunction with the proposed field program is SEDIMOT II (SEdimentology by DIstributed MOdelling Techniques), (Wilson et al. 1982, Warner et al. 1982b, Monenco Consultants Limited 1986). SEDIMOT II is a single storm model developed for analysing the hydrologic consequences of mining as well as for designing sediment control structures for surface mined watersheds. It is recommended for use in conjunction with the proposed field program for the following reasons:

1. Because of its specific development for the design of sediment control structures in watersheds disturbed by surface mining, it contains a set of compatible predictive models which satisfactorily simulate rainfall runoff processes.
2. The detailed representation of rainfall runoff processes embodied in the SEDIMOT II model enable it to reproduce widely varied conditions by modifying input parameters.
3. It is relatively widely used and accepted for modelling surface mined basins.

The specific predictive models used in SEDIMOT II are outlined in Table 1. Table 2 summarizes the input parameters for the hydrologic component of SEDIMOT II describes the sensitivity of model outputs to some of these parameters, and provides recommended input values to be verified with data from the field program.

2.4.2 Objective 2: Peak Runoff

Peak runoff estimates for the design of ditches and culverts should be determined from detailed computer-based runoff models such as SEDIMOT II described in Section 2.4.1 above,

Table 1. Summary of predictive models used in the hydrologic component of the SEDIMOT II watershed model

PREDICTIVE MODEL TYPE	MODEL(S) INCORPORATED INTO SEDIMOT II
RAINFALL PATTERN	- S.C.S. TYPE 1 or TYPE 2 - (Section 2.1.2.2) - user input rainfall distribution
INFILTRATION MODEL	- S.C.S. curve number model (Table 20)
OVERLAND FLOW (UNIT HYDROGRAPHS)	- Overton and Crosby (1979) for forested and agricultural (Table 21) - S.C.S. (Table 20) for disturbed.
CHANNEL FLOW	- Muskingum (Table 22).

Table 2. Description of input parameters for the hydrologic component of the SEDIMOTT I watershed model

INPUT[1] PARAMETER	SENSITIVITY	RECOMMENDED VALUES VALUE	AREA	COMMENTS
STORM DURATION (SDUR)	N/A[2]	SITE SPECIFIC (hours)	ALL	Dependent on time concentration of watershed; use with all distributions
TOTAL RAINFALL DEPTH (P)	a +10% change in rainfall depth will result in a +10% change in watershed outflow.	SITE SPECIFIC (inches)	ALL	for use with all distributions
ACCUMULATED RAINFALL DEPTH (RTAB1) AND TIME (RTAB2)	N/A	SITE SPECIFIC (inches, hours)	ALL	for user input rainfall pattern
PEAK 30 MINUTE (P30INT) RAINFALL INTENSITY	affects soil erosion, no effect on runoff.	SITE SPECIFIC (inches, hour)	ALL	for user input rainfall pattern
MUSKINGUM K	N/A	SITE SPECIFIC	ALL	for routing outflow hydrographs
MUSKINGUM X	N/A	0.2	ALL	for routing outflow hydrographs
DRAINAGE AREA	+10% change in area will result in approximately +10% change in watershed outflow.	SITE SPECIFIC	ALL	for each subwatershed
CURVE NUMBER[3]	a +5% change results in a +5% to +104% change in peak discharge;	89 93 86	FOREST CLEARED DUMPS	value to be provided for each subwatershed value to be provided for each subwatershed AMC III advised for design purposes.
	a -5% change results in a -11% to -52% change in peak discharge.	99	HAUL ROADS	values are dependent on soil type.
TIME OF CONCENTRATION	a +25% change results in a -5% to -24% change in peak discharge; a -25% change results in a +4% to +29% change in peak discharge.	SITE SPECIFIC	ALL	for each subwatershed
UNIT HYDROGRAPH TYPE	change in type can affect peak discharge from -63% to +62%.	1 2 3	DISTURBED AGRICULTURAL FORESTED	for each subwatershed

NOTES:

1. inputs for the number of structures, branches, and junctions characterizing the watershed or the number of subwatersheds above each structure are not considered in this table.
2. N/A - indicates estimates of input parameter sensitivity are not available.
3. recommended CN values are maximum values for antecedent moisture condition III.

provided these models have already been compiled for other purposes. This will allow for efficient use of information and avoid extra work.

Where computer models have not been compiled it is recommended that the S.C.S. synthetic unit hydrograph method (Table 20) be used to provide peak flow estimates. The reasons for this recommendation are:

1. It provides continuity with the recommended model for runoff hydrographs, thereby avoiding confusion between procedures and varying values of calibration parameters.
2. A well-documented rationale exists for determination of curve numbers.

The commonly-used Rational Method (Table 23) is not recommended, because of its historical mis-application and the need to use an additional method (or methods) as checks on the calculated flow. Other regional methods are also not advisable because of questionable accuracy in extrapolating to small drainage areas and different basin hydrologic conditions.

3. SEDIMENTOLOGIC MODELS

The sediment component of any settling pond design methodology should be capable of satisfying two basic objectives:

1. Development of the sedimentgraph (i.e., plot of the time variation in runoff sediment concentration) associated with a design storm event at the pond inlet.
2. Estimation of the total amount of sediment delivered to the reservoir over the expected life of the structure.

The pond inlet sedimentgraph is required to determine the sediment removal efficiency of a given pond configuration during the specified design storm event (Geddes, 1986). An estimate of the total sediment discharged from a watershed over the life of an impounment is required to size its sediment storage volume.

There is no single design model which is capable of satisfying either of the above objectives. A number of compatible models must be used within the framework of an overall watershed model to generate the desired outputs .

The following sections describe some of the basic phenomena involved in the erosion process and summarize the generic types of predictive models that have been developed to simulate them.

3.1 THE EROSION PROCESS

Erosion can be defined as the loosening or dissolving and removal of earthy or rock materials from any part of the Earth's surface by an eroding agent (ASCE, 1975). Precipitation and the flowing water it generates are the equivalent eroding agents for settling impoundment design. The erosion they cause can be grouped into the following general catagories:

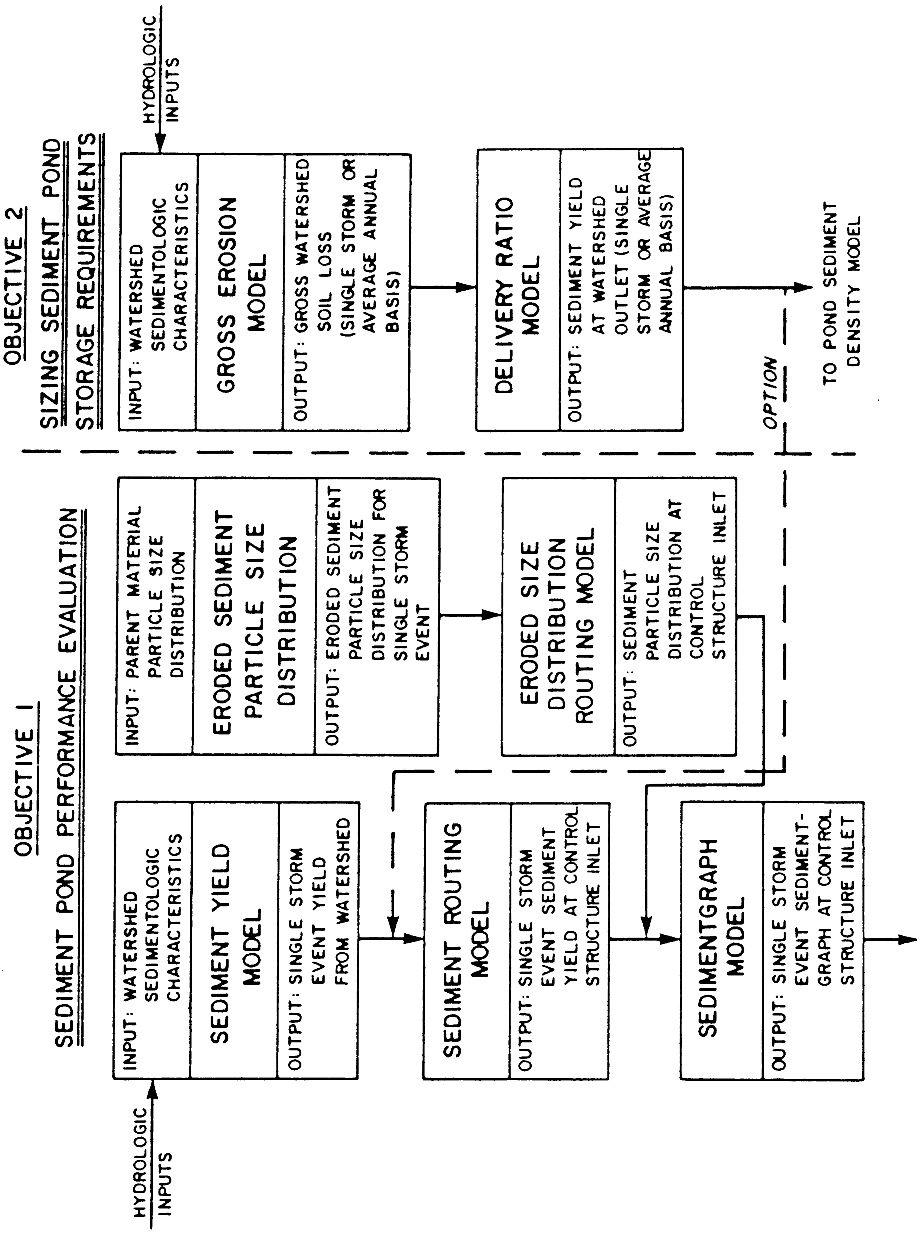
1. Interrill or sheet erosion; the erosion which occurs where water travels as sheet or overland flow.
2. Rill erosion; the soil removed by water flowing in small surface channels or rills.
3. Gully erosion; the removal of soil by water flowing in channels too large to be removed by normal cultivation methods.

The extent of erosion in any particular watershed is influenced by watershed area, slope, shape, soil type, vegetation and by the charactertistics of the storm event generating the erosion. The number of these relevant factors and their wide variation from site to site increase the difficulty of developing models which realistically evaluate the erosion process.

3.2 MODEL TYPES

Various types of predictive models are required to simulate the erosion process. Figure 3 summarizes the kinds of models that can be used to satisfy the basic objectives described previously and illustrates the interaction of these models in the generation of the desired output. Figure 3 also distinguishes between models that predict the effects of single storm events and those that describe average annual effects. The former are used to evaluate impoundment performance during the design storm event while the latter are necessary to estimate pond sediment storage requirements.

It should be noted that the model types in Figure 3 estimate the impacts of uncontrolled storm flows only; they cannot be used to evaluate the effects of sediment in any controlled or pumped flows discharged to a settling pond. Techniques for characterizing the sediment load in pumped flows have not been



SUMMARY OF SEDIMENT DISCHARGE PREDICTIVE MODELS

Figure 3

widely researched. Section 3.5 describes the significance of these pumped flows in more detail.

Model types included in Figure 3 are described in Section 8.3. Specific predictive techniques that fall into one of the model categories are discussed in Section 8.4.

3.3 RECOMMENDED MODELS

The following sections identify the predictive models recommended for use in the field program described in Section 4. Models are proposed for each of the two basic objectives of the sediment component described in Section 3.0.

3.3.1 Objective 1: Sediment Pond Performance Evaluations

Most of the predictive models suitable for evaluating sediment pond performance during a single storm event are most effectively applied using a computer. The most common approach to the development of a pond inlet sedimentgraph is to use a computer watershed model which incorporates a group of compatible predictive models.

An approach for estimating sediment discharges in Alberta can be developed by designing a new sedimentology watershed model or by using an existing one. The latter option is recommended because:

1. The development of a new watershed model would be time consuming and therefore, costly.
2. The resulting model would be an untried and untested technique.
3. There is no indication that a new watershed model would be better suited to Alberta conditions than some existing models.

The existing watershed model recommended for evaluating sediment discharge in conjunction with the field program is SEDIMOT II (SEdimentology by DIstributed MOdeling Techniques) (Wilson, Barfield, and Moore 1982; Warner et al 1982b, Monenco Consultants Limited 1986). SEDIMOT II is a single storm model intended for use in designing sediment control structures for surface mined watersheds and analyzing the hydrologic consequences of mining. It is recommended for use in conjunction with the field program because:

1. It was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining.
2. It incorporates all the models necessary to predict inlet sedimentgraphs in one easily useable and well documented format.
3. The detailed representation of sediment production processes embodied in the SEDIMOT II model enable it to reproduce widely varied conditions by modifying input parameters.
4. It includes two options for calculating sediment yields; one of which is relatively well suited for predicting the impact of steep slopes (SLOSS, see Table 31).
5. It has been accepted by a number of jurisdictions in United States for use during the permitting process.

The specific predictive models used in SEDIMOT II are outlined in Table 3. Table 4 summarizes the input parameters for the sedimentology component of SEDIMOT II, describes the sensitivity of model outputs to some of these parameters, and provides recommended input values that will be verified with data from the field program.

TABLE 3. Summary of predicitive models used in sedimentology component of the SEDIMOT II watershed model

PREDICTIVE MODEL	MODEL(S) INCORPORATED INTO SEDIMOT II
. SEDIMENT YIELD MODEL	- Modified Universal Soil Loss Equation (MUSLE) (Table 27)
	- SLOSS (Table 31)
. SEDIMENT ROUTING MODEL	- Williams Model I (Table 32)
. ERODED SIZE DISTRIBUTION ROUTING MODEL	- Barfield et al. Model (Table 35)
. SEDIMENTGRAPH	- Ward et al. Model (Table 37)

Table 4. Description of input parameters for the sedimentology component of the SEDIMOT II watershed model

INPUT PARAMETER	SENSITIVITY	RECOMMENDED VALUES VALUE	AREA	COMMENTS
For Entire Watershed:				
1. SPECIFIC GRAVITY OF ERODED SEDIMENT	- +10% change in parameter value results in - 25% change in model output[bc]. - -10% change in parameter value results in +36% change in model output [b,c].	2.00	All	- Specific gravity (SG) of eroded sediment depends on degree of aggregation of primary soil particles. S.G. of primary particles is typically around 2.60; recommended value is for a 'small aggregate.
2. SEDIMENT LOAD DISTRIBUTION COEFFICIENT	- N/A [d]	1.5	All	- The sediment load distribution coefficient varies beween 1.0 and 2.0 and is used to distribute sediment mass within the runoff hydrograph. A value of 1.0 provides a constant sediment concentration that does not vary appreciably with flow rate. A value of 2.0 provides a concentration that varies linearly with flow rate.
3. SUBMERGED BULK SPECIFIC GRAVITY	- N/A	1.25	All	- Submerged bulk specific gravity is used to estimate settleable solids concentrations in runoff and its value depends on the sediment size distribution. This parameter typically varies between 1.0 and 1.75.
For Each Sub-Watershed:[a]				
4. ERODED SEDIMENT PARTICLE SIZE DISTRIBUTION	- a 90% reduction in D_{50} and D_{90} particle diameters in conjunction with a 60% reduction in D_{10} particle diameter can produce a 45% increase in model output[b,c].	Site Specifc	All	- Data on particle size distributions for surface mined watersheds is scarce. Best estimated using procedures described in Section 8.4.2.
5. SOIL ERODIBILITY FACTOR (K)	- +10% change in parameter value results in +13% change in model output[b,c]. - -10% change in parameter value reuslts in -5% change in model output[b,c].	Site Specific	All	- K-factors for field program must be selected after detailed evaluation of proposed test sites. - Literature data on K Factors for disturbed areas is very limited. - Best estimates can be prepared from Chapter 5 of Barfield, Warner, and Haan (1981) and p.76 of Warner et al. (1982).
6. SLOPE LENGTH (L)	- +10% change in parameter value results in +5% change in model output,[b,c]. - -10% change in parameter value results in -5% change in model output[b,c].	Site Specific	All	- For the MUSLE option, slope length is defined as the distance from the point of origin of overland flow to the point at which slope decreases such that deposition occurs or until the flow enters defined channel. - For the SLOSS option, slope length is defined as the actual length of the flow path for each slope segment.

Table 4. (Concluded)

INPUT PARAMETER	SENSITIVITY	RECOMMENDED VALUES		COMMENTS
		VALUE	AREA	
7. AVERAGE SLOPE (S)	- +10% change in parameter value results in a +13% change in model output[b,c]. - -10% change in parameter value results in -13% change in model output[b,c].	Site Specific	All	- For the MUSLE option, average slope is the typical or representative slope for each sub-watershed - For the SLOSS option, average slope is the slope of each individual slope segment.
8. CONTROL PRACTICE FACTOR (CP)	- +10% change in parameter value results in +10% change in model output[b,c]. - -10% change in parameter value results in -10% change in model output[b,c].	Site Specific	All	- The CP factor is defined as the ratio of sediment loss from a field with a given cover and conservation practice to that of a field in continuous fallow. - Best estimates of CP values for surface mined watersheds can be prepared from Appendix 5A of Barfield, Warner, and Haan (1981).
For the SLOSS option, the Following Additional Parameters are Required:				
9. NUMBER OF SLOPE SEGMENTS	N/A	Site Specific	All	- Anywhere from 1 to 6 slope segments may be used to characterize a representative flow path for a given sub-watershed.
10. SURFACE CONDITION FACTOR	N/A	1 2 3	Disturbed Agricul. Forest	- The surface condition factor is entered for each slope segment.
11. SLOPE SEGMENT AREA	N/A	Site	All	- The sum of the slope segment areas must equal the total area of the sub-watershed.
12. SLOPE STEEPNESS	N/A	50 10	Slopes greater than 20% Slopes less than 20%	- The slope steepness factor is defined for each slope segment. - Recommended values are based on very limited data base.

NOTE: SEDIMOT II has two options for calculating sediment yield; the MUSLE algorithm and the SLOSS algorithm. In the SLOSS option, each sub-watershed is divided into as many as six slope segments.

a - When using the SLOSS option, these input parameters are identified for each sub-watershed slope segment.
b - from Monenco Consultants Limited (1986).
c - 'Model output' is the peak settling pond effluent suspended solids concentration predicted by the DEPOSITS subroutine of SEDIMOT II using an inlet sedimentgraph based on the input parameter noted.
d - N/A indicates estimates of input parameter sensitivity are not available.

3.3.2 Objective 2: Pond Sediment Storage Requirements

Models for estimating settling pond sediment storage requirements need not be as rigorous or complex as those for evaluating single storm pond performance. A poor estimate of long term sediment volumes will not compromise a settling reservoir's performance capabilities during a design storm event. Such an estimate will result in an oversized sediment storage volume or an increase in the required frequency of pond sludge removal operations.

For the field program it is recommended that the USLE (Table 26) be used in conjunction with Haan and Barfield's delivery ratio model (Table 34) to predict long term sediment yield. These equations share a number of parameters with some of the SEDIMOT II algorithms. This will reduce the number of independent variables requiring evaluation during the field program. The input requirements for the USLE and delivery ratio models are described in Tables 5 and 6 respectively.

3.4 PIT FLOWS

Most surface mining operations in Alberta have open pits which are not self draining. Intercepted groundwater and storm flows entering the pit are normally collected in sumps and pumped to a settling reservoir.

Sediment loads in storm runoff discharged to the pit sumps can be estimated using the predictive models described previously. There are no predictive techniques identified in the literature which are capable of estimating sediment loads in pit groundwater flows. The best approach for characterizing the expected pit groundwater quality at a new operation is to sample pit flows at a similar land disturbing activity over a wide range of conditions.

Table 5. Description of input parameters for the universal soil loss equation (USLE)

INPUT PARAMETER	SENSITIVITY	RECOMMENDED VALUES		COMMENTS
		VALUE	AREA	
1. RAINFALL EROSION FACTOR (R)	- Model ouput varies linearly with input parameter.	Site Specific	All	- Appropriate R values for various Alberta locations shown in Figure 2 of Monenco Consultants Limited (1986). - R values and predictive relationships based on agricultural field studies are directly transferable to surface mining applications.
2. SOIL ERODIBILITY FACTOR (K)	- Model output varies linearly with input parameter.			- See input parameter #5 in Table 4.
3. SLOPE LENGHT (L)	- +10% change in parameter value results in +4% change in computed gross erosion. - -10% change in parameter value results in -4% change in computed gross erosion.	Site Specific	All	- Slope length is defined as distance from the point of origin of overland flow to the point at which slope decreases such that deposition occurs or until the flow enters a defined channel.
4. SLOPE (S)	- +10% change in parameter value results in +11% change in computed gross erosion. - -10% Change in parameter value results in -11% change in computed gross erosion.	Site Specific	All	- Slope is to be typical and representative average slope for entire watershed.
5. CONTROL PRACTICE FACTOR (CP)	- Model ouput varies linearly with input parameter.	Site Specific	All	- The CP factor accounts for the combined effect of cropping management factor (C) and and the erosion control practice factor (P). - Best estimates of CP can be derived from Section 2.5.1.2.1 of Monenco Consultants Limited (1986).

Table 6. Description of input parameters for the Haan and Barfield Delivery ration model

INPUT PARAMETER	SENSITIVITY	RECOMMENDED VALUES		COMMENTS
		VALUE	AREA	
1. WATERSHED AREA	- +10% change in parameter value results in +10% change in delivery ratio. - -10% change in parameter value results in -10% change in delivery ratio.	Site Specific	All	- Watershed area is used to estimate the Da factor described in Table 24, see Figure 4 of Monenco Consultants Limited (1986).
2. VEGETATED AREA FLOW PATH LENGTH	- +10% change in parameter value results in -2% change in delivery ratio. - -10% change in parameter value results in +2% change in delivery ratio.	Site Specific	All	- Vegetated area flow path length is used to estimate the Dv factor described in Table 34.
3. WATERSHED REIIEF TO LENGTH RATIO	- +10% change in parameter value results in +6% change in delivery ratio. - -10% change in parameter value results in -6% to -12% change in delivery ratio.	Site Specific	All	- Watershed relief to length ratio is used to estimate the Dc factor described in Table 34; see Figure 5 of Monenco Consultants Limited (1986)
4. PIT DESPOSTION FACTOR (Dp)	- Model ouput varies linearly with input parameter.	Site Specific	All	- Dp factor accounts for reduction in delivery ratio resulting from pit storage. See Section 2.5.1.2.2 of Monenco Consultants Limited (1986) for Dp estimation procedure.

Procedures for estimating the sediment load in pumped discharges from the pit sumps are not well established. Sediment deposition in the sumps can be predicted by analyzing the structure as a small settling pond. However, a considerable amount of resuspension can be caused by pump induced turbulence if the pump is not drawing supernatant from the top of the sump and/or if the pump capacity is very high. At present, the only practical way of predicting pumped water quality is by sampling similar discharges

at other locations. The current lack of techniques for predicting sump water quality may not be of critical importance for the design of many settling ponds. Sump flows are limited by pump capabilities and can often be desynchronized with peak storm flows. In many cases, the hydraulic and sediment loading associated with storm flows will be more critical than those generated by sump discharge.

4. MONITORING PROGRAM

4.1 OBJECTIVE

As stated in the terms of reference, the objective of this study component is:

> "To design a field program to measure rainfall, flood flows, and sediment discharge in mountain [and] foothills regions of Alberta with regard to the implications on settling pond design, culvert, and drainage ditch sizing in coal mining developments."

On the basis of the literature investigation, (Chapters 2 and 3), the following key data should be measured to permit an accurate calibration of the SEDIMOT II model, and assessment of the variability of model parameters.

1. Rainfall; rainfall intensities as determined by a tipping bucket or similar gauge. Rainfall data may also be used as an index of guide to antecedent moisture conditions (AMC) for the determination of curve numbers (CN). Accurate timing of rainfall is required in order to establish watershed time of concentration, time lag, and rainfall duration values.
2. Streamflow discharge; based upon monitoring stream water levels, and establishing a discharge - water level relationship. Water levels should be logged so that the time of streamflow response to runoff may be identified and related to the timing of rainfall inputs for determination of time of concentration, time lag, etc. From stream discharge data,

hydrograph and streamflow routing characteristics may be determined, and based upon corresponding rainfall data, appropriate CN values may be calculated. Discharges are required at entrances to and exits from sedimentation ponds, and water levels are required at sedimentation ponds.

3. Sediment concentrations are required throughout the duration of the runoff hydrograph to define a sedimentgraph. Suspended sediment samples are required at entrances to and exits from sediment ponds. Samples gathered throughout the event may be analysed for particle size distributions. From this data, a lumped parameter index of soil erosion, (based on soil erodibility factor, K, and control practice factor, CP), may be determined. (Through a sensitivity analysis and with knowledge of the range of each parameter, a range of K and CP values may be determined based on the lumped parameter data.)
4. Eroded Particle Size Distributions are required at the sediment source for use in the SEDIMOT II model. These sediment samples may also be analysed for specific gravity. Samples are mandatory at the sediment source, but may also be taken "en route" to a sedimentation pond to trace the transport (or deposition) of material.

Monitoring devices to measure these parameters directly or to obtain data allowing calculation of these parameters, are discussed in Section 4.3.1.

4.2 SCOPE

The scope of the monitoring program exercise will include:

1. A desciption of the layout of the field monitoring equipment for each of the mine sites.
2. A listing of the equipment required (while some gathering and assessment of equipment data and cost have been conducted, it should not be considered to be exhaustive or complete. It is considered sufficient to define capabilities and order-of-magnitude costs.).
3. A cost estimate for the purchase, installation, and operation for one complete summer season, (assuming two runoff events), and reduction and analyses of raw data provide recommended parameter values for use in the SEDIMOT II model.

The cost estimate does not include extended operation of the field program beyond the time period assumed herein.

4.3 LAYOUT

The layout of monitoring programs for individual sites will be presented in the following sections. The location of monitoring equipment is shown on Figures 4 to 7, while equipment listings and prices, are included in Tables 7 to 37. These sites represent all feasible areas for monitoring during 1987 and 1988 as discussed with mine personnel.

4.3.1 Monitoring Devices

Briefly, the monitoring devices envisaged for this project include:

1. PRECIPITATION - a rain gauge giving instantaneous rainfall intensities. Output data is logged electronically, with perhaps a chart backup. Estimated unit cost is $4,000 for a Belfort rain gauge and $1,800 for a Lakewood 8K datalogger, LE8110. Optional small plastic tipping bucket rain gauge from Lakewood (LE8411) is $130.00. In most instances, however, existing mine site rain gauges can be used to provide the required data.
2. WATER LEVEL/DISCHARGE - water level measuring device, and rate of change in stage detection device (event detection) to turn on other gauges such as sediment samplers. Discharge determined by rating curves, etc. Estimated unit cost is $4000 for Parshall flume and sonic sensor/logger. (Mine personnel should be used for installation and dismantling of facilities, under consultant direction. The cost of manpower and equipment are included in the budget, but may be credited back to the mine.)
3. SEDIMENT CONCENTRATION - automated pump sampler. Sampler to operate only on event basis. Estimated unit cost is $4,500 for Manning 4401 automatic sampler.
4. SEDIMENT SAMPLING - manually operated samplers, such as plastic pails excavated into the ground to trap sediment runoff at or near the point of production. Trapped materials to be retained for particle size

particle size gradation analysis and specific gravity determination. The negligible cost of these items is included in the contingency allowance.

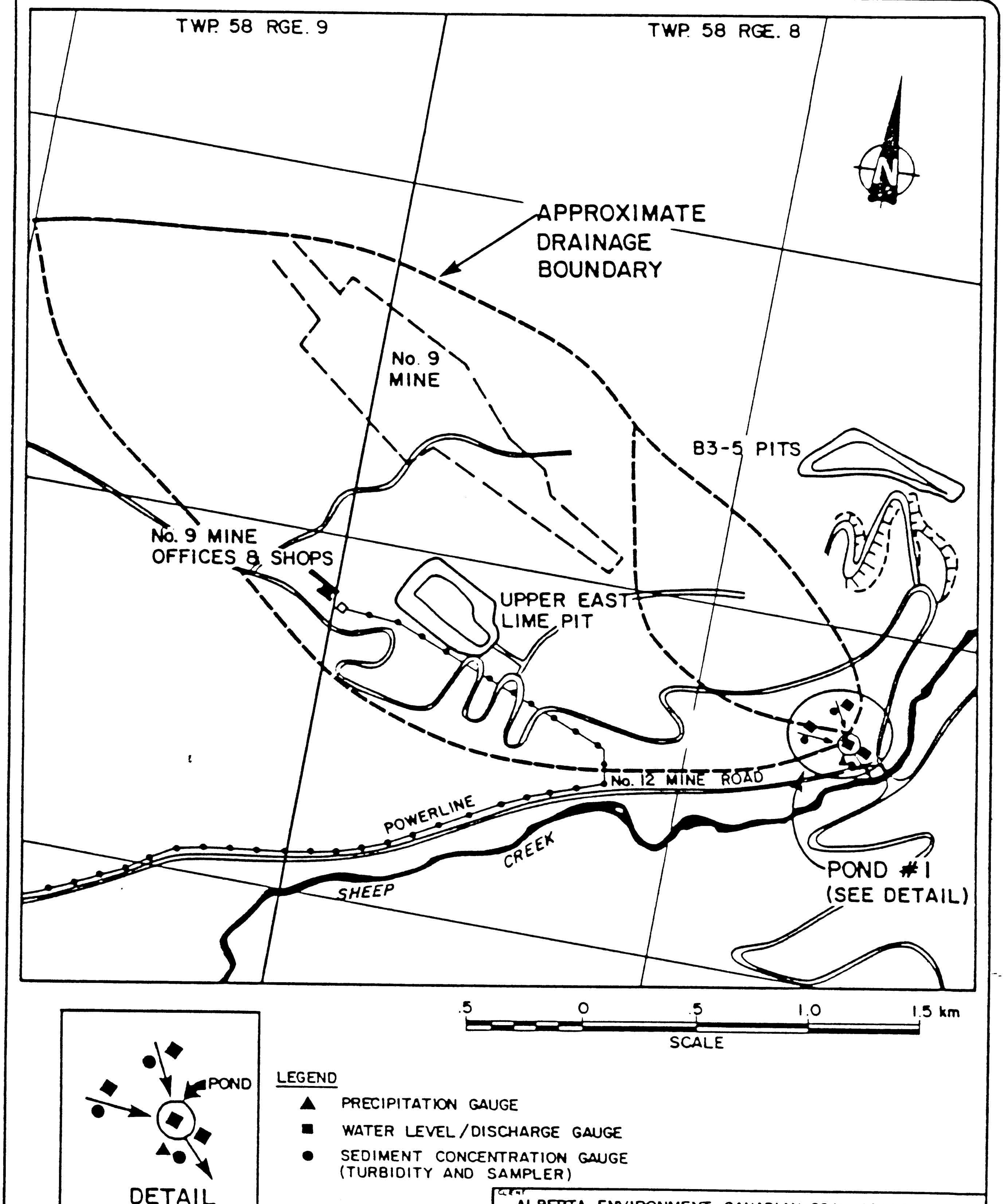
5. SOIL MOISTURE - while antecedent rainfall conditions may provide a general idea of soil moisture at the onset of a precipitation runoff event, it may be useful to take supplementary measurements of soil moisture with a gypsum block probe, and have the data logged for comparison. Estimated cost of LE8316 gypsum block probe from Lakewood is $200.

4.3.2 Smoky River Coal (SRC)

Most of the existing impoundments at the Smoky River Coal (SRC) discharge all or a significant proportion of their effluent through percolation, (V. Betts, personal communication). Pond No.1, however, exhibits the least percolation, and is therefore, best suited to monitoring. Other areas which are scheduled to be developed in the near future may be suitable for monitoring (new No. 12 mine area) but facilities will not be operational in 1987.

As shown in Figure 4, Pond No. 1 has two inlet channels. The west channel which drains the lower East Limb pit, also carries runoff which passes through rock fill in the haul road, as well as some groundwater flow. It is the cleaner of the two inflow channels, and has an ill-defined drainage area.

The east channel, has a better-defined drainage area encompassing drainage from two open pits, the portal area of an underground mine, the shop area, the haul road and an undisturbed area.



CLIENT: ALBERTA ENVIRONMENT CANADIAN COAL ASSOCIATION

PROJECT: DESIGN FLOWS AND SEDIMENT DISCHARGES

SUBJECT: LAYOUT OF MONITORING PROGRAM
SMOKY RIVER COAL

HE HYDROCON ENGINEERING (CONTINENTAL) LTD

DRAWN BY	DESIGNED	APPROVED	DATE		JOB No	FIGURE	REV
KK	GREB	WMV	12/86		279	4	1

REV	BY	DESCRIPTION	DATE	APPR'D
1	KK	ISSUED FOR FINAL REPORT	87/03	WMV
0	KK	FIRST ISSUE FOR DRAFT REPORT	86/12	WMV

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At this time it is suggested that the inflows to Pond No. 1 be considered as lumped inflows. The equipment requirements are as presented in Table 7, below.

Table 7. Instrumentation listing - Smoky River Coal

SITE	PRECIPITATION	WATER LEVEL/ DISCHARGE	SEDIMENT CONCENTRATIONS
POND 1	1 (1+)	4, 3+	3 (+)

NOTE: + indicates data logging device(s) required
(+) indicates data logging device useable from other installation or gauge.

As this site is remote from the main rain gauge at the office site located in the Smoky River valley, it is recommended that a rain gauge be established at this site (i.e. in the Sheep Creek valley).

4.3.3 Gregg River Resources (GRR)

Monitoring devices may be established in the following two areas:

1. Pond LM1 (Zone I) - haul road runoff.
2. Pond LM2 (Zone J) - pumped pit outflows.

The instrumentation requirements are presented in Table 8 and Figure 5.

Table 8. Instrumentation listing - Gregg River Resources

SITE	PRECIPITATION	WATER LEVEL DISCHARGE	SEDIMENT CONCENTRATIONS	SEDIMENT SAMPLING	SOIL MOISTURE
POND LM1	1+	3,2+	2(+)	4	-
POND LM2	-	2,1+	1(+)	2	-
TOTAL	1+	5,3+	3(+)	6	-

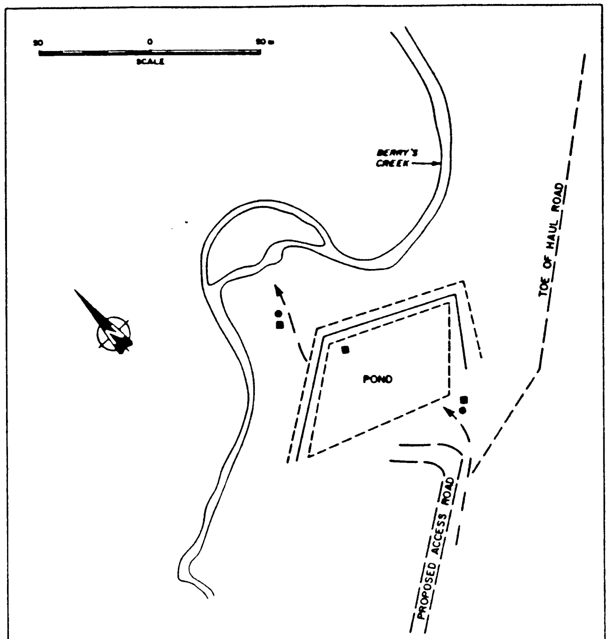
NOTE: + indicates data logging device(s) required
(+) Indicates data logging device useable from other installation or gauge.

The outflows from Pond LM2 will be via seepage, so gauging is not possible. However, monitoring of pumped inflows from the pits is possible.

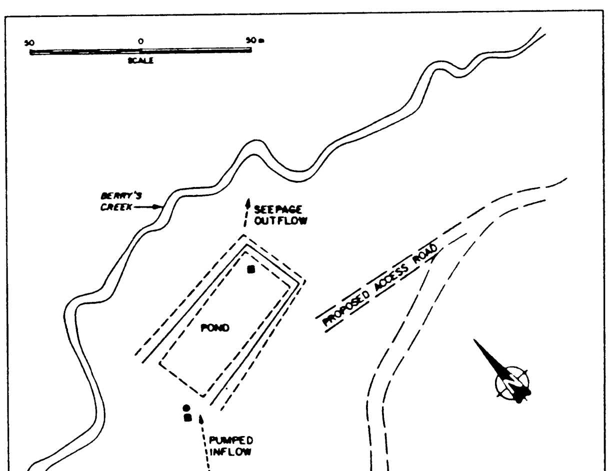
4.3.4 Cardinal River Coal (CRC)

Here the proposed monitoring setup is located in the line 50-B-5 portion of the mine site, where CRC has established an extensive monitoring setup. Because of the complicated nature of the mine development at this location, a possible monitoring program has been developed which is divided into 3 components, gradually increasing in complexity, as follows:

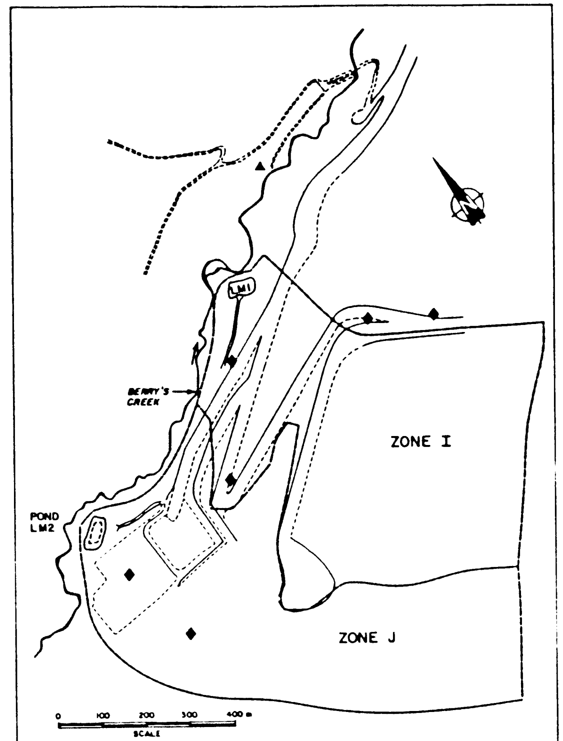
1. Monitors inflows to the pre-settling ponds from the plant site, prior to entry into the long 600mm culvert.



LM POND NO. 1
Location: Twp. 47 Rge. 24 W5M



LM POND NO. 2
Location: Twp. 47 Rge. 24 W5M



GENERAL PLAN

LEGEND

- ▲ PRECIPITATION GAUGE
- ■ WATER LEVEL / DISCHARGE GAUGE
- ● SEDIMENT CONCENTRATION GAUGE (TURBIDITY AND SAMPLER)
- ◆ SEDIMENT TRAP (SIZE DISTRIBUTION)

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LAYOUT OF MONITORING PROGRAM
GREGG RIVER RESOURCES

HYDROCON ENGINEERING (CONTINENTAL) LTD.

DRAWN BY	DESIGNED	APPROVED	DATE	JOB No.	FIG. No.
KK	GREB	WMV	12/86	279	5

B. Monitors inflows into the 50-B-5 sedimentation pond on Luscar Creek, (as well as pond levels and outflows), and treats intermediate inflows downstream of component A as lumped input.

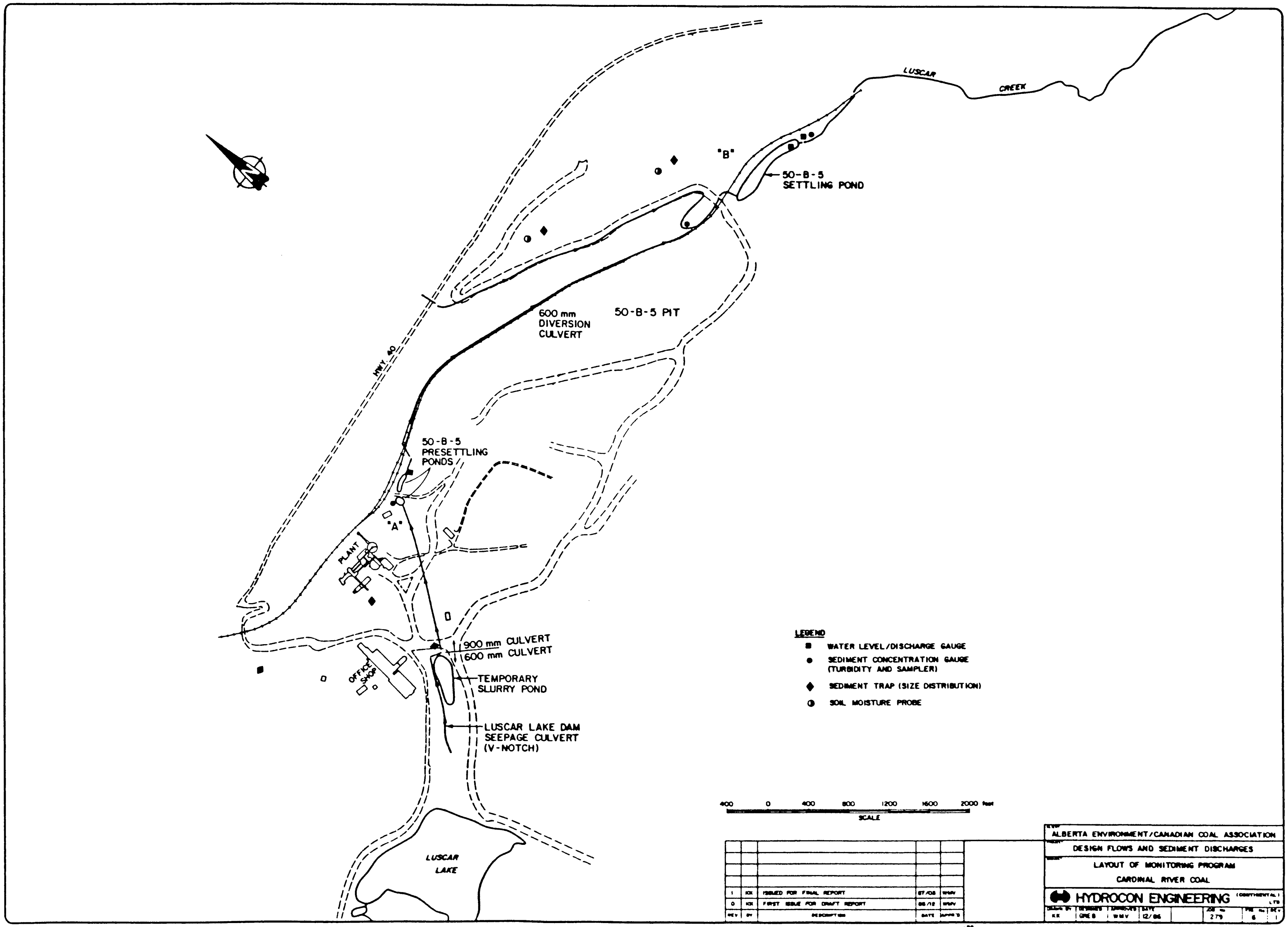
C. Monitors individual parts of the intermediate inflows from Component B.

These components are presented in Table 3.4 and Figure 10.

Table 9. Instrumentation listing - Cardinal River Coal

COMPONENT	WATER LEVEL/ DISCHARGE	SEDIMENT CONCENTRATION	SEDIMENT SAMPLING	SOIL MOISTURE
A	1,1+	1(+)	3	-
B	3,2+	2(+)	2	2
C	2,2+	2(+)	-	-
TOTAL	6,5+	5(+)	5	2

It should be noted that due to the proximity of the existing CRC rain gauge to the study area, it is not considered necessary to take an independent measurement of precipitation. However, in terms of data and analysis it may be useful to have CRC's data logged in a compatible format or have it logged independently from a separate instrument if CRC's instrument is not accessible.


LUSCAR CREEK
"B"
50-B-5
SETTLING POND
HWY 40
600 mm
DIVERSION
CULVERT
50-B-5 PIT
50-B-5
PRESETTLING
PONDS
"A"
PLANT
OFFICE
SHOP
900 mm CULVERT
600 mm CULVERT
TEMPORARY
SLURRY POND
LUSCAR LAKE DAM
SEEPAGE CULVERT
(V-NOTCH)
LUSCAR
LAKE
LEGEND
WATER LEVEL/DISCHARGE GAUGE
SEDIMENT CONCENTRATION GAUGE
(TURBIDITY AND SAMPLER)
SEDIMENT TRAP (SIZE DISTRIBUTION)
SOIL MOISTURE PROBE
400 0 400 800 1200 1600 2000 feet
SCALE
1 KK ISSUED FOR FINAL REPORT 87/03 WMV
0 KK FIRST ISSUE FOR DRAFT REPORT 86/12 WMV
REV BY DESCRIPTION DATE APPR'D
ALBERTA ENVIRONMENT/CANADIAN COAL ASSOCIATION
DESIGN FLOWS AND SEDIMENT DISCHARGES
LAYOUT OF MONITORING PROGRAM
CARDINAL RIVER COAL
HYDROCON ENGINEERING
LTD
KK GREB WMV 12/86 279 6 1

4.3.5 Tri Creeks Watershed Study Area

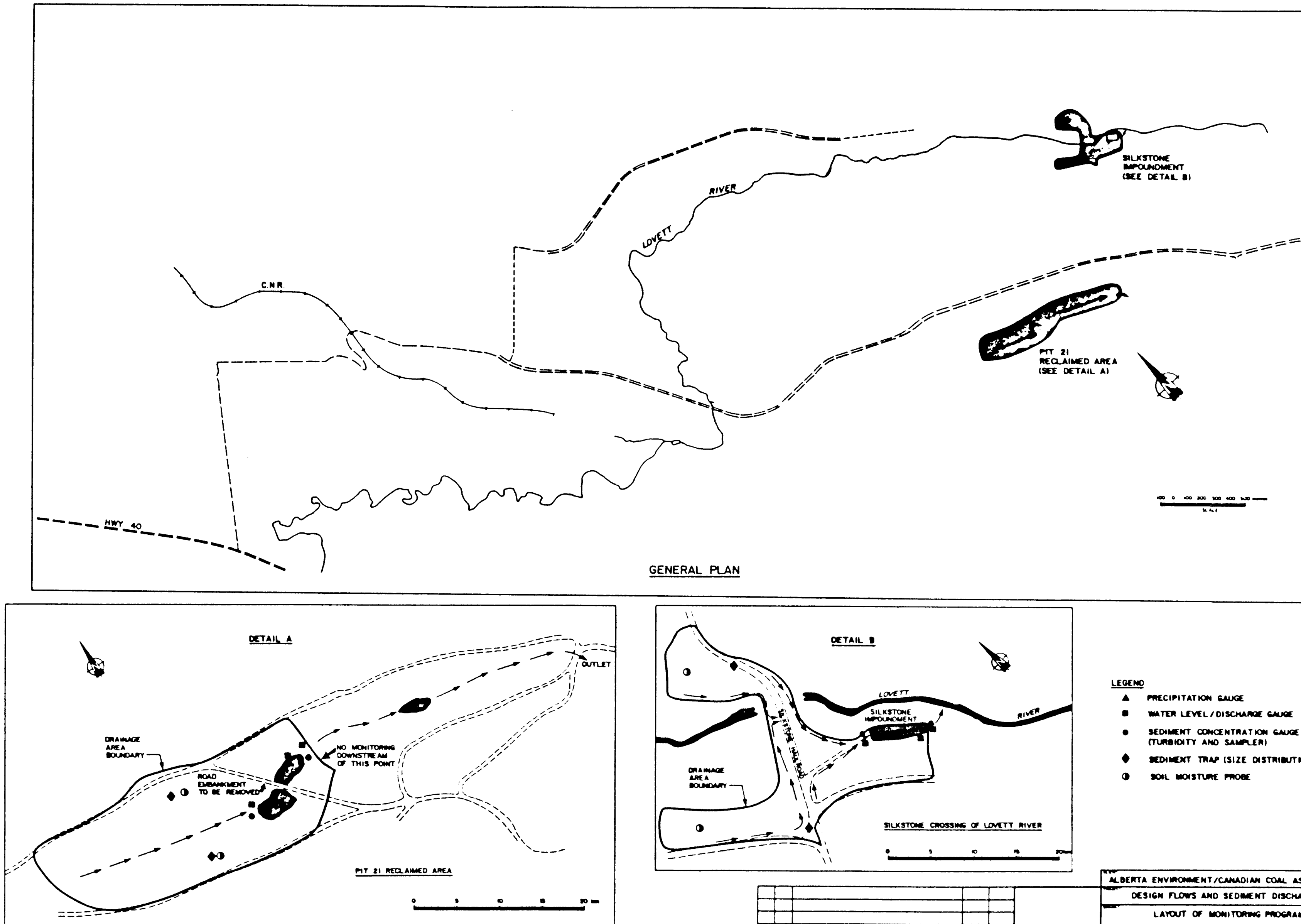
In order to effectively extend the available recorded precipitation data gathered at the Tri Creeks Watershed Study area, two precipitation gauges would need to be installed. Instrument requirements would be a standard rain gauge with data logger at each of the following sites;

1) LOWER BASIN - at the site of either Wampus-A, Deerlick A, or Eunice-A (former meteorologic instrument sites).
2) UPPER BASIN - at either Wampus #8, or Deerlick-J, (former meteorologic sites).

These sites are considered appropriate for measuring rainfall characteristics within the basins, (D.T. Sneddon, Energy and Natural Resources; A. Nip, Alberta Forestry; R. Olsen, Meteorologist; personal communications). Specific sites would be determined at time of installation based on adjacent vegetation growth.

4.3.6 Luscar Sterco, Coal Valley, (CV)

As illustrated on Figure 7 and Table 10, possible monitoring sites would be a reclaimed dump, and at a sedimentation pond collecting haul road runoff.



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ALBERTA ENVIRONMENT/CANADIAN COAL ASSOCIATION

DESIGN FLOWS AND SEDIMENT DISCHARGES

LAYOUT OF MONITORING PROGRAM

LUSCAR STERCO, COAL VALLEY

HYDROCON ENGINEERING (CONTINENTAL) LTD.

KK | GREB | WWV | 2/86 | 279

Table 10. Instrumentation listing - Luscar Sterco, Coal Valley

SITE	WATER LEVEL/ DISCHARGE	SEDIMENT CONCENTRATION	SEDIMENT SAMPLING	SOIL MOISTURE
PIT 21 (RECLAIMED)	3,2+	2(+)	2	2(+)
SILKSTONE HAUL ROAD	3,2+	2(+)	2	2(+)
TOTAL	6,4+	4(+)	4	4(+)

At the Pit 21 site, it has been assumed that monitoring will be conducted downstream of the pond below the present road crossing, (about 81 ha drainage area), thereby excluding the lowest pond and reducing the amount of sampling and equipment. Further, Luscar plans to remove the road separating the upper two ponds, (C. Brinker, personal communication), which would reduce monitoring requirements to that listed in Table 10.

4.4 COST ESTIMATE

A cost estimate has been prepared based upon the following assumptions:

1. Precipitation monitoring at Tri Creeks Watershed Study Area should not be included as data may be available from Alberta Environment. Exclusive of this data availability, correlations may be

determined with Cardinal River Coals Ltd. data and Alberta Forest Service data to extend the historical period of record at Tri Creeks, and aid in determining rainfall frequencies.

2. Monitoring should not be conducted at Smoky River Coal Limited, because of the lumped parameter inputs to Pond 1. In addition, its remoteness from the other sites would add to monitoring costs.
3. The mines are to do the monitoring using internal manpower and equipment. Monitoring time will be charged back to the MFRRP project.
4. Limited seeage at Pond LM1 (GRR) and provision for measureable outflow should make this site suitable for monitoring. If these conditions cannot be met, the Silkstone haul road sie at Coal Valley can be monitored for the same price.
5. Total Suspended Solids (TSS) analyses and monitoring installation costs will be handled by the mines, and charged back to the MFRRP project. 6. Cardinal River Coals Ltd. will provide software for assimitation of water level and flow data on data loggers, which can then be tabulated and plotted with existing software. An amount of $5,000 has been budgeted for this function.
7. No costs are included for the dismantling of monitoring equipment. The mines assume ownership of the monitoring equipment at the end of the MFRRP project.
8. Data analysis and model calibration will be based on the two highest flow events for each site. Where possible, samples will be stored until the two events are selected; particle size and total suspended

solids analyses will ony be conducted on those two sets of samples.

Throughout the monitoring program, the consultant will be responsible for overall direction, quality control, data analysis, and reporting. This work will include:

1. Detailed specification and ordering of monitoring equipment. (Estimated cost $4,000).
2. Supervision of monitoring equipment installation at three mine sites. (Estimated total cost $5,000).
3. Review of monitoring procedures and results following first two runoff events. (Estimated cost $4,200).
4. Assembly and analysis of data for the two selected runoff events. Data to be modelled by SEDIMOT II program and recommended parameter values to be determined. Results of the monitoring program to be presented in a report. (Estimated cost $48,000).

4.4.1 Recommended Monitoring Program

A preferred monitoring program has been determined based upon discussions with industry and government representatives which is recommended for implementation. This program is based upon the following factors and criteria:

1. Ease of access.
2. Control over water and sediment inflows/outflows and ability to measure these flows.
3. Definition of contributing drainage area.
4. Uniqueness of catchment relative to land use.
5. Optimization of potential results at least cost between comparable sites.
6. Ability to utilize historical data.

7. Priority based on the general sediment production rates of particular mine area, (i.e., high production areas such as haul roads, plant sites and recently reclaimed dumps are generally acknowledged to produce more sediment and are therefore of greater concern than active pits or dumps which are not reclaimed.

Table 11 presents the recommended monitoring program.

As allowances must be made for ordering and delivery of equipment, monitoring for the full runoff season in 1987 is not possible. Therefore the monitoring program is planned to proceed for a season and a half, through to the end of 1988. This will spread the costs over two fiscal years as illustrated in Table 12.

Table 11. Recommended monitoring program expendistures by minesite

COMPANY	YEAR	CAPITOL COSTS	INSTALLATION	MINESITE COSTS TO BE CREDITED TOWARDS THAT COMPANY'S CONTRIBUTION MANPOWER	ANALYTICAL	TOTAL	GRAND TOTAL
GRR	1987	$17 800	$1 200	$ 2 400	$ -	$ 3 600	$ 21 400
	1988	-	-	2,400	1,360	3,760	$ 3 760
	TOTAL	17 800	1 200	4 800	1 360	7 360	$ 25 160
CV	1987	17 800	1 200	2 400	-	3 600	$ 21 400
	1988	-	-	2 400	1 120	3 520	$ 3 520
	TOTAL	17 800	1 200	4 800	1 120	7 120	$ 24 920
GRC	1987	20 300	1 200	5 000 Software 2 400 Monitoring	-	8 600	$ 28 900
	1988	-	-	2 400	1 920	4 320	$ 4 320
	TOTAL	20 300	1 200	9 800	1 920	12 920	$ 33 220
MINES TOTAL		$55 900	$3 600	$19 400	$4 400	$27 400	$ 83 300
CONSULTANT	1987						$ 13 200
	1988						$ 48 000
	TOTAL						$ 61 200
CONTINGENCY							$ 8 900
OVERALL TOTAL							$153 400

Table 12. Schedule of budget expenditures

FISCAL YEAR	1987-1988	1988-1989	
MONTH	J F M A M J J A S O N D J F M	A M J J A S O N D J F M	
Activity			
Equipment Purchase and Installation	$75,000 /------/		
Monitoring - 1987	$18,400 /------/	$11,600 /-----------------/	
Final Report		$48,000 /--------/	
TOTAL TO DATE	$93,800	($59,600)	$153,400

5.0 CONCLUSIONS

1. Methodologies for the determination of rainfall runoff and sediment production vary widely in their sophistication and in the number of parameters used to describe or characterize the detailed physical processes occuring in nature.
2. Existing models combining both the hydrologic and sedimentologic components are preferred for use as they can be used for not only sedimentation pond design but for sizing of culverts and ditches as well.
3. The SEDIMOT II model is preferred for hydrologic/sedimentologic use at coal mine developments on Alberta's Eastern Slopes. The detailed analyses of runoff and sediment processes embodied in the SEDIMOT II model make it best suited for modelling the diverse terrain encountered at coal mining sites.
4. Parameters from the SEDIMOT II model which must have values determined for use under conditions found in Alberta's Eastern Slopes are:
    1. Curve numbers (CN) based upon antecedent moisture conditions (AMC).
    2. Soil erodibility factor (K).
    3. Control practice factor (CP).
    4. Eroded particle size distributions.
5. Monitoring of the following variables is required to determine values or ranges of values for key input parameters to the SEDIMOT II model:

   1. Precipitation intensity and duration.
   2. Runoff timing and magnitude.
   3. Eroded sediment particle size distribution and specific gravity.
   4. Sediment hydrograph.

6. Monitoring programs can be undertaken at existing mine sites to gather data on rainfall runoff and sediment production processes.
7. Analysis of runoff and sediment data from the monitoring program can be used to refine estimates of input parameters for the SEDIMOT II model. Some adjustments to the data will be necessary to account for the effects of flocculants in sedimentation ponds, as the SEDIMOT II model cannot evaluate flocculation.

6.0 RECOMMENDATIONS

1. The SEDIMOT II model should be used for hydrologic sedimentologic design activities at coal mines on Alberta's Eastern Slopes.
2. The monitoring program outlined in Table 11 should be undertaken to properly evaluate key input parameters to the SEDIMOT II model.

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8. APPENDICES

8.1 RUNOFF MODEL TYPES

Models used to compute a storm hydrograph based upon a particular rainfall pattern are discussed in this section of the appendices.

8.1.1 Infiltration Models

Infiltration may be defined as the movement of water into the soil surface. It is a key component in the runoff generating process as it separates water flow into either surface or subsurface flow components. Models and equations used to predict infiltration may be either physically-based or developed from empirical relationships. Physically-based equations tend to describe the flow process by utilizing concepts from soil physics, while empirical equations use parameters that must be determined from observed infiltration data.

8.1.2 Overland Flow Models

Overland flow is the movement of rainfall excess (i.e. rainfall minus interception, depressional storage and infiltration) over the watershed surface to a watershed channel. Although the water depth is usually small, it generally contains a significant amount of storage, (small depth multiplied by a large surface area), and thus affects the time response of the runoff hydrograph. Runoff volume may also be reduced in route to the channel by infiltration and evaporation of water as it moves over the surface.

Physically based models are usually used to determine solutions to both the steady and unsteady rainfall excess situations. However, the numerical solution of the governing overland flow equations for these situations generally has the disadvantages of being expensive and requiring large amounts of input data. An alternative to this approach is to use empirical unit hydrograph techniques discussed in Section 8.1.3.

8.1.3 Unit Hydrograph Models

The unit hydrograph method evolved from a method of unit graphs which originally assumed that for a given duration rainfall, the hydrograph time base should remain constant. The unit graph is defined as follows:

> If a given one-day rainfall produces a 1-in. or (1 mm) depth of rainfall over the given drainage area, the hydrograph showing the rates at which the runoff occurred can be considered a unit graph for that watershed.

Application of a unit graph to design rainfall excess amounts other than 1-in. (or 1 mm) is accomplished simply by multiplying the rainfall excess amount by the unit graph ordinates, since the runoff ordinates for a given duration are assumed to be directly proportional to rainfall excess. Time periods other than 1-day are also widely used.

As this study is ultimately concerned with determining calibration parameters for a wide range of basin conditions, standard unit hydrograph derivation will not be addressed. The following discussion will deal solely with methods of constructing synthetic unit hydrographs.

8.1.3.1 Synthetic Methods of Unit Hydrographs In a mining environment, basic streamflow and rainfall data are not available to allow construction of unit hydrographs. In addition, the frequent changes made to the watersheds as a result of mining activities alter the hydrologic response to rainfall inputs, invalidating the use of a (single) unit hydrograph to describe the outflows. Therefore, techniques have evolved that allow generation of "synthetic unit hydrographs", which when applied to discrete basins, can be combined to represent outflows from the whole watershed.

8.1.4 Channel Routing Models

Channel routing is used to convert an inflow hydrograph at the beginning of a channel reach (as either an overland flow hydrograph or as the outflow hydrograph for the previous reach) to an outflow hydrograph at the end of the reach. The peak discharge of the routed hydrograph is translated in time and reduced in magnitude, with a resulting dispersion of the time base, because of the storage capacity of the channel.

Mathematical models to estimate channel routing are classified as either hydraulic or hydrologic. Hydraulic models use a continuity equation that accounts for spatial and temporal variation within a given channel reach, (i.e., partial differential equations are necessary for describing the system). While they have the advantage of containing parameters that are measureable, they often require a large number of inputs and are usually difficult to solve, (closed-form solutions to the complete hydraulic routing equations do not exist). For this reason, hydraulic routing models will not be considered further.

Hydrologic models use a continuity equation that has only temporal variations within a given channel reach, (i.e. ordinary differential equations can be used for describing the system). Their flow rate functions are usually defined conceptually with respect to storage. Hydrologic models are simple to use, but usually require the fitting of parameters to the observed data.

8.1.5 Peak Flows Formulas

Often the entire runoff hydrograph is not required in design. In the cases where a culvert is to be sized or ditch size to be determined, only the peak discharge for a specified recurrence interval may be required. The time and expense to compile a detailed watershed model using the parameters discussed in Appendices 8.1.1 to 8.1.4 may not be warranted, unless it is required for other uses. Therefore, there is a need for models that directly provide peak runoff estimates.

Numerous methods are available for estimating the peak rates of runoff required for design applications in small watersheds. Some incorporate a rational analysis of the rainfall-runoff process, while others are completely empirical or correlative in that they predict peak runoff rates by correlating the flow rates with simple drainage basin characteristics.

Although both categories of peak flow determination are easily adapted and have had wide application, two relatively major difficulties are normally encountered in applying the techniques. First, the rainfall-runoff formulas are difficult to apply unless the return periods for rainfall and runoff are assumed to be equal. Also, estimates of coefficients required by these formulas are subjective and have received considerable criticism (see discussion of the Rational Formula, Table 11). The empirical and correlative methods are limited in application because they are derived from localized data and are not vaild when extrapolated to other regions.

It should be noted that previously-discussed synthetic unit hydrograph methods (see Section 8.1.3.1) such as Snyder's or S.C.S. can also be used to determine peak flow rates.

8.2 PREDICTIVE MODELS

8.2.1 Model Summary Tables

There are a large number of predictive models for each of the runoff components discussed previously. Tables 13 to 25 summarize some of the models that have been proposed by various hydrologists. Much of the information included in these tables has been adapted from standard hydrology texts such as Gray (1973), Viessman et al. (1977), Chow (1964), and a literature review by Wilson et al. (1982).

8.2.2 Model Limitations

Most hydrologic models incorporate coefficients designed to simulate the site specific characteristics of individual drainage basins. Often these coefficients are difficult to apply in specific instances for two reasons. First, coefficients are based upon back-calculating or calibration from known runoff data. Secondly, relationships may be derived for site-specific applications, thereby limiting the transposibility to other areas.

A significant amount of hydrologic research has been concentrated on runoff determination for small agricultural and urban watersheds. Models proposed for use in mine areas often rely on site-specific coefficients that were originally developed for agricultural or urban conditions. Therefore, considerable work remains to be done in investigating and identifying coefficients applicable to basins on the mine site.

Table 13. Phillips two term equation

MODEL TYPE: INFILTRATION (PHYSICALLY BASED)

DESCRIPTION:

Expresses the cumulative infiltrated volume (F) as a function of sorptivity(s), a constant (A) depending on the physical properties of the flow system, and time (t).
Based upon Richard's equation for determining infiltration.

COMPUTED OUTPUT:

Cumulative infiltration volume.

INPUT PARAMETERS:

s, sorptivity.
A, a constant on the physical properties of the flow system.

COMMENTS/APPLICABILITY:

A and s may be difficult to determine.
A for long time periods may equal the saturated conductivity.
Because of the independent variable, time, the model breaks down if the precipitation supply rate drops below the infiltration capacity.

REFERENCES:

Wilson, Barfield, and Moore (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)

Table 14. Horton equation

MODEL TYPE: INFILTRATION (EMPIRICAL)

DESCRIPTION:

Based upon an observation that infiltration rates decrease with time, Horton proposed an equation with parameters which are usually fitted to observed data.

COMPUTED OUTPUT:

Infiltration rate, f.

INPUT PARAMETERS:

fc, the asymptotic infiltration rate.
fo, infiltration rate at time (t) equal to zero.
K_f, a constant for a given curve.

COMMENTS/APPLICABILITY:

Horton's equation has been shown to fit empirical data for many soil types.
Difficulties in determining useful values for fo and K restrict use of this equation.

REFERENCES:

Wilson, Barfield, and Moore (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)

Table 15. Holtan equation

MODEL TYPE: INFILTRATION (EMPIRICAL)

DESCRIPTION:

Predicts infiltration as a function of available water storage contained in a specified depth soil.

COMPUTED OUTPUT:

Infiltration rate, f.

INPUT PARAMETERS:

Sa, available water storage in the surface layer.
fc, the constant rate of infiltration after long wetting.
a, n, constants; (use some publications, n = 1.4).

COMMENTS/APPLICABILITY:

Infiltrating rates with respect to time are determined indirectly from this equation, (as Sa decreases, f decreases as a result). The original equation has been modified to account for the ability of mature plant roots to provide additional infiltration paths.

REFERENCES:

Wilson, Barfield, and Moore (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)

Table 16. S.C.S. method

MODEL TYPE: INFILTRATION (EMPIRICAL)

DESCRIPTION:

Predicts cumulative runoff as a function of cumulative rainfall.
Accounts for initial abstraction of rainfall, such as vegetative interception, surface depression storage and infiltration volume, prior to the start of runoff.
Infiltration is not computed directly but is the difference between excess rainfall and runoff.

COMPUTED OUTPUT:

Actual runoff volume, Q.

INPUT PARAMETERS:

CN, curve number.
P, rainfall depth.

COMMENTS/APPLICABILITY:

Usually assumes that initial abstractions are a function of the curve number.
Method is widely used.
Method is generally accepted.

REFERENCES:

Wilson, Barfield, and Moore (1982)
U.S. Bureau of Reclamation, (1974)

Table 17. Hydrologic centre (HEC) model

MODEL TYPE: INFILTRATION (EMPIRICAL)

DESCRIPTION:

The loss rate is an exponential decay function that depends on the rainfall intensity and the antecedentlosses.

COMPUTED OUTPUT:

Instantaneous loss rate, L_t.

INPUT PARAMETERS:

K', a coefficent, decreasing with time as losses accumulate.
K_0, the loss coefficient at the beginning of the storm (when CUML = 0), an average value of 0.6 - CUML, the accumulated loss from the beginning of the storm to time, t.
C, a coefficient, average value = 3.0
P_t, intensity of the rain.
E, the exponent of recession (range of 0.5 to 0.9).

COMMENTS/APPLICABILITY:

initial loss coefficients, K_0, are difficult to estimate.
standard curves are available to determine initial infiltration rates.
for gauged basins, HEC-1 program allows the users to input rainfall and runoff data from which the loss rate parameters are optimized to give a best fit to the information provided.

REFERENCES:

Viessman, Knapp, Lewis, and Harbaugh (1977)

Table 18. Snyder's method

MODEL TYPE: SYNTHETIC UNIT HYDROGRAPH

DESCRIPTION:

Computes lag time, unit hydrograph duration peak discharge, and hydrograph time width at 50% and 75% of peak flow.

COMPUTED OUTPUT:

Time to peak, t_L.
Duration of the rainfall excess, t_r.
Peak discharge, Q_p.
Time base of hydrograph, T.

INPUT PARAMETERS:

C_t, coefficent representing variations of watershed slopes and storage.
L, length of mean stream channel from the outlet to the divide.
L_{ca}, length along the main channel to a point opposite the watershed centroid.
C_p, coefficient accounting for flood wave and storage conditions.
A, watershed area.

COMMENTS/APPLICABILITY:

Originally derived for watersheds from 25.9 km^2 to 25,900 km^2 located in the Appalachian Highlands.
May predict excessive time base for small watersheds.
Corp of Engineers has developed curves to estimate W_{50} and W_{75}, the widths of the hydrograph at 50% and 75% of the peak flow.
C_p and C_t need to be evaluated for other regions.

REFERENCES:

Viessman, Knapp, Lewis, and Harbaugh (1977)
Gray (1973)

Table 19. Clark's method

MODEL TYPE: SYNTHETIC UNIT HYDROGRAPH

DESCRIPTION:

The unit graph for an area is derived by routing to time-area concentration curve through an appropriate amount of reservoir storage. In the routing procedure, an instantaneous unit graph is formed. The unit graph for any rainfall duration is obtained from the instantaneous graph by averaging the ordinates of the instantaneous graph.

COMPUTED OUTPUT:

Outflow hydrograph.

INPUT PARAMETERS:

Time-area-curve ordinates.
The time of concentration for the Clark unit graph.
The watershed storage coefficient.

COMMENTS/APPLICABILITY:

HEC-1 program contains a synthetic time-area curve for use if one is not available for the watershed of interest.
HEC-1 can determine values for Clark's parameters based on Synder's t_L and C_p.

REFERENCES:

Viessman, Knapp, Lewis, and Harbaugh (1977)
Gray (1973)

Table 20. S.C.S. method

MODEL TYPE: SYNTHETIC UNIT HYDROGRAPH

DESCRIPTION:

Constructs a synthetic unit hdyrograph based on a dimensionless hydrograph represented by a triangle, (Figure 8).
Based on an analysis of a large number of natural unit hydrographs from a wide range in size and geographic locations.

COMPUTED OUTPUT:

Outflow hydrograph, including time to peak and, peak discharge.

INPUT PARAMETERS:

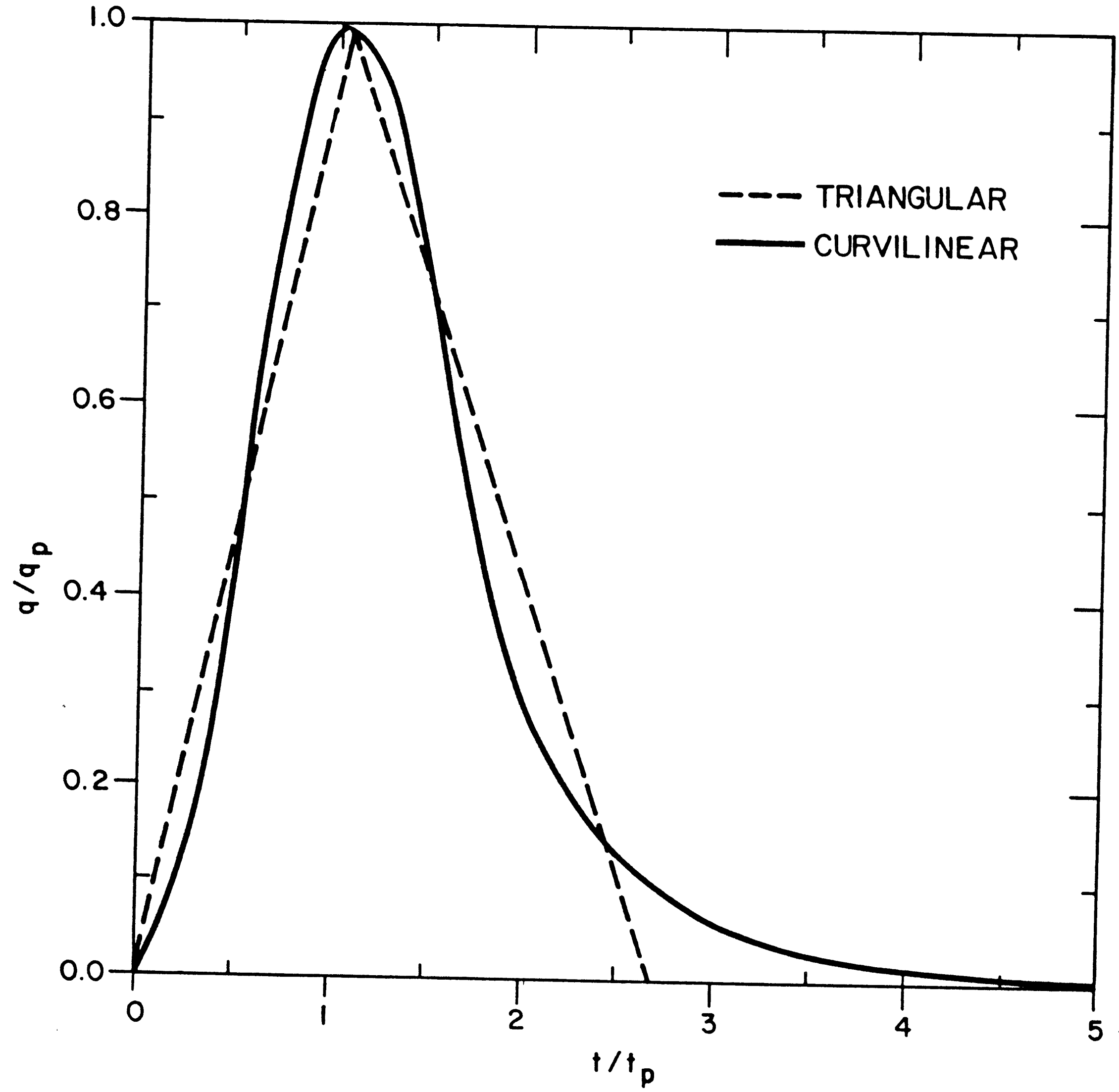
Duration of rainfall.
Time of concentration.
Lag time form the centroid of rainfall to peak discharge.

COMMENTS/APPLICABILITY:

Requires only the peak discharge, time base, and time to peak to simulate the runoff hydrograph.
Widely used and universally accepted.

REFERENCES:

Wilson, Barfield, and Moore, (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)
Gray (1973)
U.S. Bureau of Reclamation, (1974)



SCS's TRIANGULAR AND CURVILINEAR DIMENSIONLESS HYDROGRAPHS

Figure 8

Table 21. Overton and Crosby (1979)

MODEL TYPE: SYNTHETIC UNIT HYDROGRAPH

DESCRIPTION:

Uses the lag modulus concept (which lumps together the geometric and roughness characteristics of a watershed) with the double triangular hydrograph (originally developed to simulate both the quick and the delay response in the unit hydrograph shape) to develop a nonlinear unit hydrograph, (Figure 9).

COMPUTED OUTPUT:

Outflow unit hydrograph.

INPUT PARAMETERS:

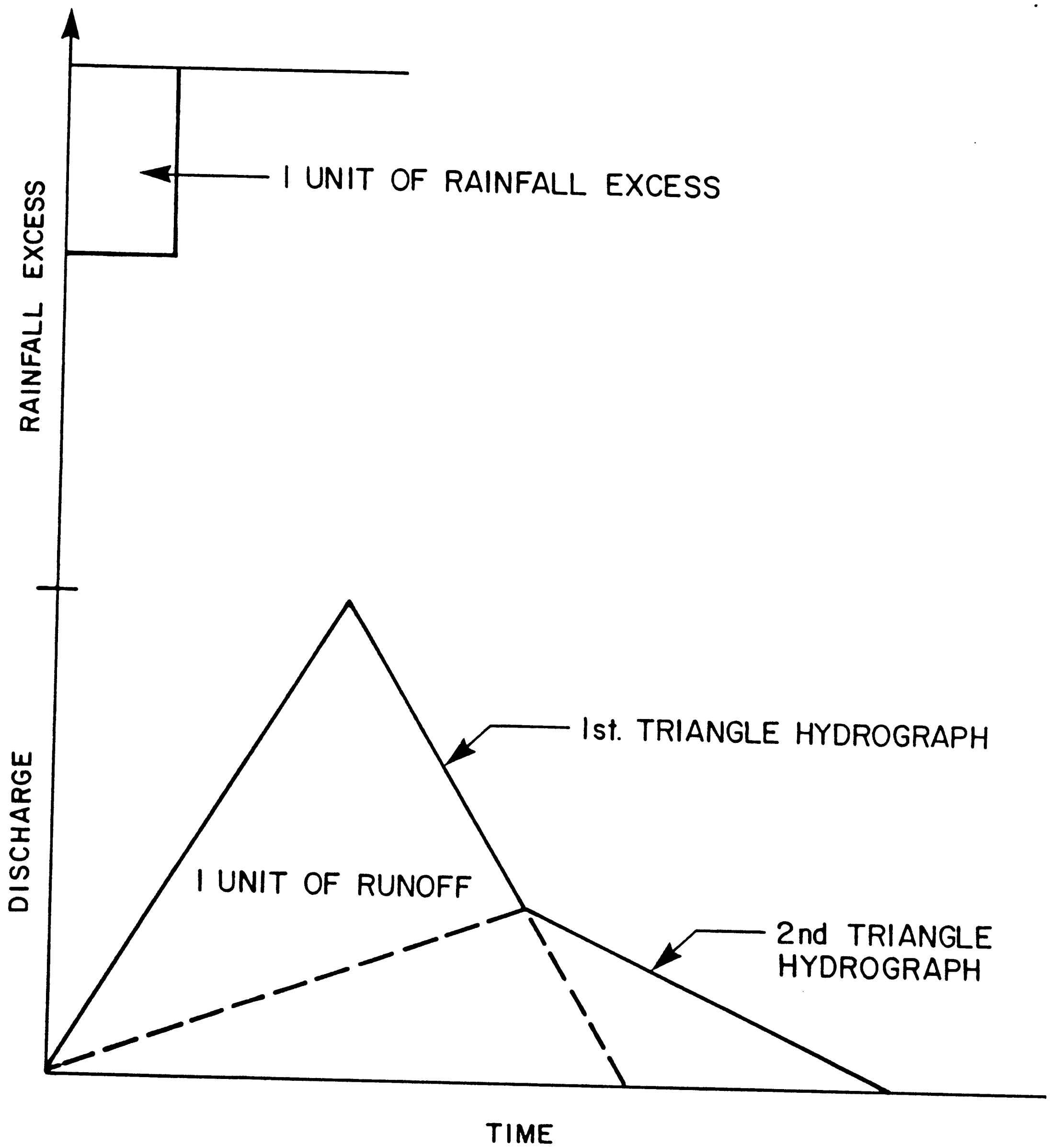
The constant or representative rainfall excess.
Delay time.
Watershed area.
Percent forest cover.

COMMENTS/APPLICABILITY:

Applicable to complex watershed geometries.
Approximates many different hydrograph shapes while maintaining a shape that is easy to define mathematically.
Equation for lag modulus developed for 6 Appalachian watersheds.

REFERENCES:

- Wilson, Barfield, and Moore (1982)



DOUBLE TRIANGLE UNIT HYDROGRAPH

Figure 9

Table 22. Muskingum method

MODEL TYPE: HYDROLOGIC CHANNEL ROUTING

DESCRIPTION:

A relationship between storage and outflow is obtained by computing the total storage as the sum of prism storage (a function of outflow discharged) and wedge storage (a function of the difference between inflow and outflow discharge).

COMPUTED OUTPUT:

Routed channel outflow.

INPUT PARAMETERS:

Inflow hydrograph
K, storage time constant for the reach
x, the weighting factor which varies between 0.0 and 0.5 for a given river section.

COMMENTS/APPLICABILITY:

For ungauged streams, K may be approximated by the travel time in the reach, and x will average about 0.2. K and x may be estimated based upon channel geometric and flow parameters.
Method assumes that the water surface in the reach is a uniform unbroken surface profile, and that K and x are constant throughout the range in stage under investigation.

REFERENCES:

Wilson, Barfield, and Moore (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)
Linsley, Kohler, and Paulhus (1975)
Gray (1973)

Table 23. Rational formula

MODEL TYPE: PEAK FLOW

DESCRIPTION:

Relates peak runoff to rainfall intensity, drainage area, and a runoff coefficient and outflow discharge).

COMPUTED OUTPUT:

The peak runoff rate.

INPUT PARAMETERS:

The runoff coefficient.
The average rainfall intensity, lasting for a critical period of time equal to the time of concentration.
The size of the drainage area.

COMMENTS/APPLICABILITY:

Assumes rainfall is uniform over the entire watershed during the duration of the storm.
Assumes the return periods for rainfall and runoff to be equal.
Wide misuse of this formula is illustrated by a study where 23 designers calculated the runoff from a 342 ha watershed. The discharges varied by as much as 700%, the runoff coefficients by 400%.
Runoff coefficients should account for antecedent moisture, non-uniform rainfall, and abstractions.
Time of concentration should be computed as the sum of overland flow and flow in defined channels.
Results should be compared with other methods before use.
Should be used for areas less than 25 km^2 and preferrably less than 2 km^2.

REFERENCES:

Viessman, Knapp, Lewis, and Harbaugh (1977)
Roads and Transportation Association of Canada (1982)
Gray (1973)
Chow (1964)

Table 24. Discharge-area and regression formulas

MODEL TYPE: PEAK FLOW

DESCRIPTION:

Empirical formulas relate the discharge rate to a power function of the drainage area, (and other drainage basin physiographic parameters, if significant, in a multiple regression approach).

COMPUTED OUTPUT:

The peak discharge associated with a given return period.

INPUT PARAMETERS:

The drainage area.
Other drainage basin physiographic parameters such as slope, length of channel, vegetation cover, percentage of lakes, etc.
Regression constants based on regional data.

COMMENTS/APPLICABILITY:

Applicable to region with same physiographic and climatic characteristics as area of interest.
care should be taken in extrapolating to larger or smaller drainage areas than that covered by the regression data base.

REFERENCES:

Gray (1973)
Chow (1964)
Roads and Transportation Association of Canada (1982)
Viessman, Knapp, Lewis, and Harbaugh (1977)

Table 25. Index flood method

MODEL TYPE: PEAK FLOW

DESCRIPTION:

A graphical regional correlation of recurrence intervals (or return periods) to the index (commonly the mean annual flood) for a homogeneous region.

COMPUTED OUTPUT:

Peak discharge rates for a range of recurrence intervals.

INPUT PARAMETERS:

Frequency curves for hydrometric stations within a hydrologically homogeneous region.

COMMENTS/APPLICABILITY:

Assumes all stations analysed have some skew coefficients for their frequency curves.
Requires a homogeneity test to justify the definition of the region.
A method should be used for extending short records to place all stations on the same base period.
If the index curves have been based on mean daily station records, these should be converted to instantaneous discharges for design purposes.

REFERENCES:

Viessman, Knapp, Lewis, and Harbaugh (1977)
Roads and Transportation Association of Canada (1982)

8.3 EROSION MODEL TYPES

The following sections describe the model types included in Figure 3. Specific predictive techniques that fall into one of these model categories are described in Section 8.4.

8.3.1 Gross Erosion and Delivery Ratio Models

Gross erosion models estimate the amount of sediment moved on a watershed. Delivery ratio models are then applied to predict the portion of this sediment that is deposited as it moves through the watershed. Gross erosion and delivery ratio models are normally used to predict the average annual soil loss from a given area. They can however be modified to estimate single storm event erosion.

8.3.2 Sediment Yield Models

Sediment yield models combine gross erosion and sediment transport components within a single framework to predict the amount of soil actually discharged from a watershed. These models typically simulate single storm effects rather than average annual effects.

8.3.3 Sediment Routing Models

The watershed outlet is quite often not coincident with the sediment control structure inlet. Sediment routing models are used to characterize the change in sediment load as water moves from the watershed outlet to the control structure inlet via ditches or natural streams.

8.3.4 Eroded Sediment Particle Size Distribution Models

The particle size distribution of sediment immediately after it is eroded from the watershed is usually markedly different from that of the parent material. Eroded sediment paricle size distribution models attempt to quantify the difference between in-situ and eroded particle size distributions.

8.3.5 Eroded Size Distribution Routing Models

Eroded size distribution routing models predict how the eroded size distribution changes as it moves from upland areas towards the settling pond inlet.

8.3.6 Sedimentgraph Models

The realistic evaluation of sediment basin performance requires the consideration of the time variation in incoming sediment load during a storm event. Sedimentgraph models estimate how the total storm sediment yield is distributed over the storm duration.

8.4 PREDICTIVE MODELS

8.4.1 Model Summary Table

There are a variety of specific predictive models for each of the generic model categories described previously. Tables 26 to 37 summarize some of the models that have been proposed by various researchers. Much of the information included in these tables has adapted from two previous literature reviews on erosion and sediment yield models (Monenco Consultants Limited 1986; Wilson, Barfield, and Moore 1982).

8.4.2 Eroded Particle Size Distributions

Tables 26 to 37 do not include a description of a model for predicting eroded sediment particle size distributions. The estimation of size distributions is one of those important parts of the sedimentologic component of settling pond design for which no generally applicable predictive models exist. This places significant limitations on the accuracy of all sediment models since it has been demonstrated that size distribution is the single most important parameter affecting the trapping efficiency of any sediment control structure (Barfield, Moore, and Williams 1979).

Foster et al. (1980) developed regression equations from a limited amount of data that predicted the fractions of clay, silt, sand, and large and small aggregates in storm runoff. Particle size distributions were estimated as a function of the fractions of these components in the parent material. The Foster et al. model suffers from the same disadvantage as all approaches based on regression equations in that it is inherently site

Table 26. Universal soil loss equation (USLE)

MODEL TYPE: GROSS EROSION MODEL

DESCRIPTION:

The Universal Soil Loss Equation (USLE) is an empirical relationship originally developed to estimate the average annual soil loss from agricultural areas (Wischmeier and Smith 1965). Because of its simplicity it has since been applied to the analysis of a wide variety of erosion control problems. The USLE takes the following form:

$$Y = R\ K\ LS\ C\ P$$

where Y is the average annual soil loss (mass/area), R is a rainfall erosion factor (usually expressed as the product of rainfall energy times the maximum thirty minute intensity for a given rainstorm), K is a soil erodibility factor (mass/area - R unit), LS is a combined plot length and slope factor (dimensionless), C is a cropping management factor (dimensionless), and P is an erosion control practice factor (dimensionless).

COMPUTED OUTPUT:

Average annual gross erosion in terms of mass per unit area.

INPUT PARAMETERS:

As noted above.

COMMENTS/APPLICABILITY:

The USLE would be an appropriate model for estimating settling pond sediment storage requirements. For this application, it must be used in conjunction with a delivery ratio model (Table 24) to convert gross erosion to delivered sediment estimates.

The USLE is based on an extensive data base and considerable experience has been gained in developing input parameters for non-surface mining applications. Unfortunately little information is available on the variation of these parameters for surface mined watersheds. Appropriate K factors for exposed spoil have not been widely researched and current relationships for the LS factor have not been extensively tested on slopes greater than 20 percent.

For Alberta locations, the USLE will underestimate soil losses unless rainfall erosion factors include both rainfall and snowmelt components. Tajek and Pettapiece (1984) have developed R factors appropriate for Alberta conditions. The USLE's limitation for slopes greater than 20 percent should not go unrecognized when applying the equation in Alberta's eastern slopes. USLE outputs for high slopes are best viewed as approximations that should not be used for applications that are highly sensitive to soil loss estimates.

REFERENCES:

Tajek and Pettapiece (1984)
American Society of Civil Engineers (1975)
Barfield, Moore, and Williams (1979)
Monenco Consultants Limited (1986)
Israelsen and Israelsen (1982)

Table 27. Modified universal soil loss equation (MUSLE)

MODEL TYPE: SEDIMENT YIELD MODEL

DESCRIPTION:

Williams (1975) modified the USLE to predict sediment yields generated by single storm events. This modified USLE, or MUSLE, predicts sediment yield by using a runoff erosivity factor instead of the rainfall erosivity factor R. Williams MUSLE takes the following form:

$$Y = 95(Q q_p)^{0.56} K\ LS\ C\ P$$

where Y is sediment yield in tons, Q is the volume of runoff in acre-feet, q_p is the peak flow rate in cubic feet per second, and K, LS, C, and P are area weighted USLE (Table 16) values for a homogeneous watershed.

COMPUTED OUTPUT:

Watershed sediment yield during a storm event.

INPUT PARAMETERS:

As noted above.

COMMENTS/APPLICABILITY:

The MUSLE has been shown to provide good estimates of sediment yields from homogeneous agricultural watersheds. However, the equation should not be applied directly to surface mined watersheds which are highly non-homogeneous. For mining applications, watersheds should be divided into homogeneous subwatersheds and the MUSLE treated as a distributed parameter model rather than a lumped parameter model (Barfield, Moore and Williams 1979). Calculated sediment yields from each subwatershed must then be routed to the reservoir site using a routing model (Tables 22 and 23).

The MUSLE suffers from the same limitations as the USLE with respect to availability of input parameters appropriate for surface mining applications. Reliable K and LS factors for Alberta conditions are not available at present.

REFERENCES:

Barfield, Moore, and Williams (1979)
Barfield, Warner, and Haan (1981)
Monenco Consultants Limited (1986)
Warner, et al. (1982a)

Table 28. Onstad and Foster's model

MODEL TYPE: SEDIMENT YIELD MODEL

DESCRIPTION:

The method proposed by Onstad and Foster (1974) is a single storm event sediment yield model. The model is based on a modified form of the USLE developed by Foster and Wischmeier (1974) to account for a nonuniform slope and/or a nonuniform soil erodibility factor, K. In Onstad and Foster's model, the watershed is divided into plots of relatively uniform characteristics for which slope and erodibility effects are evaluated individually. The transport of soil from one plot to another is simulated and the erosion from each plot combined to predict the total sediment yield from the watershed.

COMPUTED OUTPUT:

Watershed sediment yield during a storm event.

INPUT PARAMETERS:

- For the watershed as a whole:

Q - storm runoff volume;
q - peak storm runoff rate;
C - USLE cropping management factor; and
P - USLE erosion control practice factor.

- For each plot (sub-watershed):

L - plot length;
K - USLE soil erodibility factor; and
S - plot slope.

COMMENTS/APPLICABILITY:

Onstad and Foster's model has predicted sediment yields with reasonable accuracy when applied to relatively small agricultural watersheds. Its suitability for heavily disturbed watersheds has not been established.

REFERENCES:

Wilson, Barfield, and Moore (1982)
American Society of Civil Engineers (1975)

Table 29. Kuh, Reddell, and Hiler's model

MODEL TYPE: SEDIMENT YIELD MODEL

DESCRIPTION:

Kuh, Reddell, and Hiler (1976) developed a two-dimensional sediment yield model for which the watershed is divided into a grid. The grid spacing is selected to maximize the uniformity of conditions within each grid square. The erosion potential for each grid is estimated using a model developed previously by Foster and Meyer (1972). In the Kuh, Reddell and Hiler model, sediment is routed from grid to grid using a variety of erosion and transport algoritms which evaluate both the horizontal and vertical components of total soil loss. (Wilson, Barfield, and Moore 1982).

COMPUTED OUTPUT:

Watershed sediment yield during a storm event.

INPUT PARAMETERS:

- For each gride square:

ERW - effective rainfall width of grid;
EFW - effective flow width of grid;
AREA - area of grid;
TD_{rf} - time duration of rainfall;
TD_{ro} - time duration of runoff;
Q - storm runoff volume;
Q_p - peak storm runoff rate;
R - USLE rainfall erosion factor;
K - USLE soil erodibility factor;
C - USLE cropping management factor;
P - USLE erosion control practice factor; and
S - Slope.

COMMENTS/APPLICABILITY:

The Kuh, Reddell, and Hiler model has provided more accurate estimates of sediment yield than the USLE or MUSLE, however it has not been widely applied to watersheds disturbed by surface mining activities.

REFERENCES:

Wilson, Barfield, and Moore (1982)

Table 30. Overton and Crosby's model

MODEL TYPE: SEDIMENT YIELD MODEL

DESCRIPTION:

The Overton and Crosby (1979) model calculates watershed sediment yield by mutliplying a parameter called the load modulus by the storm runoff volume. The load modulus is a measure of the mass of sediment per unit volume of flow. The watershed load modulus is estimated by evaluating a mass balance of the watershed sediment load which considers both the erosion from heavily disturbed areas and deposition in heavily forested areas.

COMPUTED OUTPUT:

Watershed sediment yield during a storm event.

INPUT PARAMETERS:

Q - storm runoff volume;
C_1 - an index of the percent of watershed erosion from areas that are surface mined;
C_2 - an index of the amount of sediment deposited in the watershed;
C_3 - an index of the sediment that is available for transport when the transport capacity is not exhausted;
U - a lag time modulus designed to represent the geometry and roughness characteristics of the watershed;
PS - the percent of the watershed which has been disturbed by surface mining activity; and
PF - the percent of the watershed covered by forested areas.

COMMENTS/APPLICABILITY:

The Overton and Crosby model was developed specifically for surface mined watersheds and has been shown to provide reasonable estimates of sediment yield if the parameters C_1, C_2, and C_3 are properly correlated to site specific conditions. Unfortunately these parameters exhibit a very substantial site to site variation that has not been exhaustively researched or quantified.

REFERENCES:

Wilson, Barfield, and Moore (1982)

Table 31. SLOSS

MODEL TYPE: SEDIMENT YIELD MODEL

DESCRIPTION:

SLOSS is a subroutine of the SEDIMOT II watershed model (Section 3.3.1) that estimates sediment yields using algorithms developed by Knisel (1980) and Foster, Meyer, and Onstad (1977a, 1977b). When using SLOSS the watershed is divided into subwatersheds with relatively homogeneous characteristics. These subwatersheds are then further subdivided into slope segments that are selected to follow the topography. Erosion and sediment transport are evaluated for each slope segment individually to predict the total sediment yield from the subwatershed. SLOSS can also route the sediment from the subwatershed discharge to the settling pond inlet.

COMPUTED OUTPUT:

Watershed sediment yield during a storm event.

INPUT PARAMETERS:

For each subwatershed:
r - number of slope segments.

For each slope segment:
K - USLE soil erodibility factor;
L - length of slope segment measured along the flow path;
S - slope of the slope segment measured along the flow path;
CP - USLE erosion control practice factor;
PSD - eroded particle size distribution;
SC - surface condition; the program distinguishes between disturbed, agricultural, and forest surface conditions;
A - segment area;
SF - segment steepness factor.

COMMENTS/APPLICABILITY:

SLOSS has a more physically realistic basis than other more common sediment yield models (e.g., MUSLE) and also incorporates an algorithim designed to adjust for steep slopes. This steep slope adjustment factor improves the accurracy of SLOSS sediment yield estimates over those provided by most empirically based models in mountain top surface mining applications where slopes often exceed 20%.

SLOSS is a relatively new sediment yield model and its accurracy has not yet been well documented. The current data base for slope adjustment factors applicable to slopes greater than 20% is limited.

REFERENCES:

Monenco Consultants Limited (1986)
Warner, et. al., (1982b)

Table 32. Williams Model I

MODEL TYPE: SEDIMENT ROUTING MODEL

DESCRIPTION:

Williams (1975) developed a mathematical model that can be used to route the sediment yield predicted by the MUSLE from the subwatershed discharge to a downstream sediment control structure (eg. settling pond). The model assumes that the sediment load changes as the runoff moves through streams and valleys and that the change of this load with time is a function of the square root of a representative sediment particle diameter, the amount of sediment load in the flow, and the time available for settling.

COMPUTED OUTPUT:

Sediment yield at a control structure inlet during a single storm event.

INPUT PARAMETERS:

For each subwatershed:
Y - gross erosion from a subwatershed;
B - routing coefficient which is a function of the hydraulic characteristics of the watershed; and
D - representative sediment particle size diameter.

COMMENTS/APPLICABILITY:

Williams Model I is commonly used in conjunction with the MUSLE to predict the sediment yield from a subwatershed whose discharge is not coincident with the settling pond inlet. Its primary advantages are that it is relatively simple to use and it does not require observed data to calibrate its parameters.

REFERENCES:

Barfield, Warner, and Haan (1981)
Warner, et. al., (1982a)
Barfield, Moore, and Williams (1979)

Table 33. Williams Model II

MODEL TYPE: SEDIMENT ROUTING MODEL

DESCRIPTION:

Williams (1978a) and Williams and Haan (1978) modified Williams' first model to route sediment by particle size classes and to allow the routing coefficient, B, to vary within the watershed. Williams' second model also allows for re-entrainment of deposited sediment and for degradation of the flow channel (Wilson, Barfield, and Moore 1982).

COMPUTED OUTPUT:

Sediment yield at a control structure inlet during a single storm event.

INPUT PARAMETERS:

For each subwatershed:
Y - gross erosion;
PSD - eroded particle size distribution;
BT - routing coefficient which is a function of the hydraulic characteristics of the watershed;
K - USLE soil erodibility factor;
C - USLE cropping management factor; and
S - slope.

COMMENTS/APPLICABILITY:

Williams Model II incorporates algorithims which similate the physical processes involved in sediment transport more realistically than Williams' Model I. However the modest improvement in accuracy exhibited by the second model usually does not justify the considerable time required to complete the more tedious calculations associated with it, particularly in view of the fact that Williams' Model I has been shown to provide relatively good results against observed erosion data.

REFERENCES:

Barfield, Moore, and Williams (1979)
Wilson, Barfield, and Moore (1982)

Table 34. Haan and Barfield Model

MODEL TYPE: DELIVERY RATIO MODEL

DESCRIPTION:

Haan and Barfield (1978) developed a delivery ratio model in which the final sediment yield was assumed to be influenced by watershed drainage area, vegetation, degree of channelization, and sediment particle size. Their delivery ratio is normally used with the USLE as part of a two-stage empirical equation for the estimation of average annual sediment production. Haan and Barfield's delivery ratio takes the following form:

$$DR = D_A \, D_V \, D_C \, D_P$$

where DR is the delivery ratio and D_A, D_V, D_C, and D_P account for the effects of watershed area, vegetation, channelization, and pit deposition, respectively. Various empirical techniques are used to estimate these coefficients.

COMPUTED OUTPUT:

Percentage of gross erosion delivered to the watershed outlet over a given time period (usually one year).

INPUT PARAMETERS:

As noted above.

COMMENTS/APPLICABILITY:

The Haan and Barfield delivery ratio is simple to apply but its accuracy is limited by the aproximate methods used to estimate its input parameters. When used in conjunction with the USLE· it provides estimates of average annual sediment production that can be used to size the sediment storage volume for a settling pond.

REFERENCES:

Monenco Consultants Limited (1986)
Haan and Barfield (1978)
Barfield, Moore, and Williams (1979)

Table 35. Barfield et al. model

MODEL TYPE: ERODED SIZE DISTRIBUTION ROUTING MODEL

DESCRIPTION:

Barfield et al. (1979) suggested an indirect procedure for the estimation of size distribution changes which is illustrated in Figure 11. The technique assumes that all particle sizes greater than the percent finer equivalent to the watershed delivery ratio are removed by deposition. a new size distribution curve for the remaining sediment is then obtained by dividing the original coordinates for these materials on the eroded sediment size distribution curve by the delivery ratio.

COMPUTED OUTPUT:

Particle size distribution at the watershed outlet or sediment control structure inlet.

INPUT PARAMETERS:

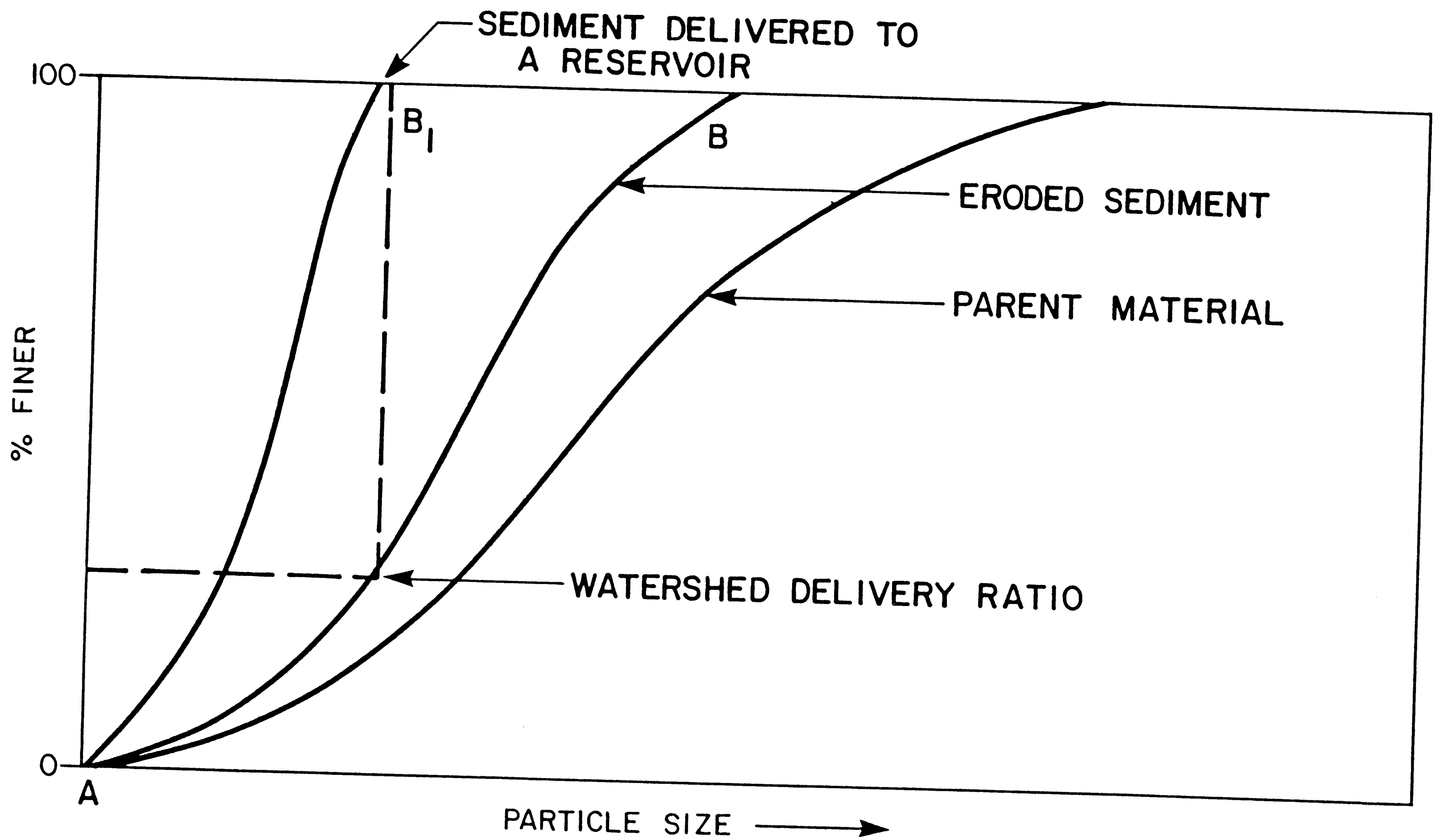
EPSD - eroded particle size distribution
DR - delivery ratio at watershed outlet or sediment control structure inlet.

COMMENTS/APPLICABILITY:

The Barfield et al. technique is a rough approximation that has been experimentally verified for a limited number of applications. However it is one of the very few models available for the routing of eroded sediment particle size distributions.

REFERENCES:

Barfield, Warner, and Haan (1981)
Wilson, Barfield, and Moore (1982)
Barfield, Moore, and Williams (1979)



CHANGE IN SIZE DISTRIBUTION DUE TO DEPOSITION

(From Barfield et al., 1979)

Figure 10

Table 36. Williams (1978) model

MODEL TYPE: SEDIMENTGRAPH MODEL

DESCRIPTION:

Williams (1978b) proposed a method for developing a sedimentgraph which is analogous to using an instantaneous unit hydrograph (IUH) to estimate the runoff hydrograph. In William's method, the rainfall excess pattern is divided into incremental runoff volumes and a sedimentgraph is generated for each increment volume based on the instantaneous unit sedimentgraph (IUSG). These sedimentgraphs are logged and summed to determine the sedimentgraph for the entire runoff event (Wilson, Barfield, and Moore 1982).

COMPUTED OUTPUT:

Sedimentgraph at the inlet to a sediment control structure.

INPUT PARAMETERS:

- Q - incremental runoff volumes resulting from the rainfall excess pattern;
- d_{50} - median particle size diameter;
- B - routing coefficient which is a function of the hydraulic characteristics of the watershed;
- UH - unit hydrograph discharge coordinates;
- IC_0 - initial sediment concentrations resulting from each unit of incremental runoff volume.

COMMENTS/APPLICABILITY:

Although the Williams model has been shown to provide good predictions of sedimentgraph shapes it has not been widely applied because of its complexity.

REFERENCES:

Wilson, Barfield, and Moore (1982)

Table 37. Ward, Williams, and Haan model

MODEL TYPE: SEDIMENTGRAPH MODEL

DESCRIPTION:

Ward, Williams, and Haan (1979) proposed a relatively simple method for developing sedimentgraphs in which the watershed sediment yield is distributed in the runoff hydrograph by assuming that load rate is proportional to discharge. The precise nature of the relationship between sediment concentration and discharge can be varied to suit site specific conditions.

COMPUTED OUTPUT:

Sedimentgraph at the inlet to a sediment control structure.

INPUT PARAMETERS:

Y - storm sediment load;
q_s - load rate;
q_j - discharge rate at the jth time increment;
t - time increment of the storm hydrograph;
n - number of hydrograph points; and
a - input coefficient varying between 0.0 and 1.0.

COMMENTS/APPLICABILITY:

The Ward, Williams, and Haan model is simple to use and has therefore gained wider acceptance than more complicated approaches. It also allows designers to account for the fact that sediment concentration in runoff varies during a storm event. Concentrations that vary linearly with flow rate can be similated by setting the input coefficient 'a' noted above equal to 1.0. An 'a' value of 0.0 will provide an approximately constant concentration.

REFERENCES:

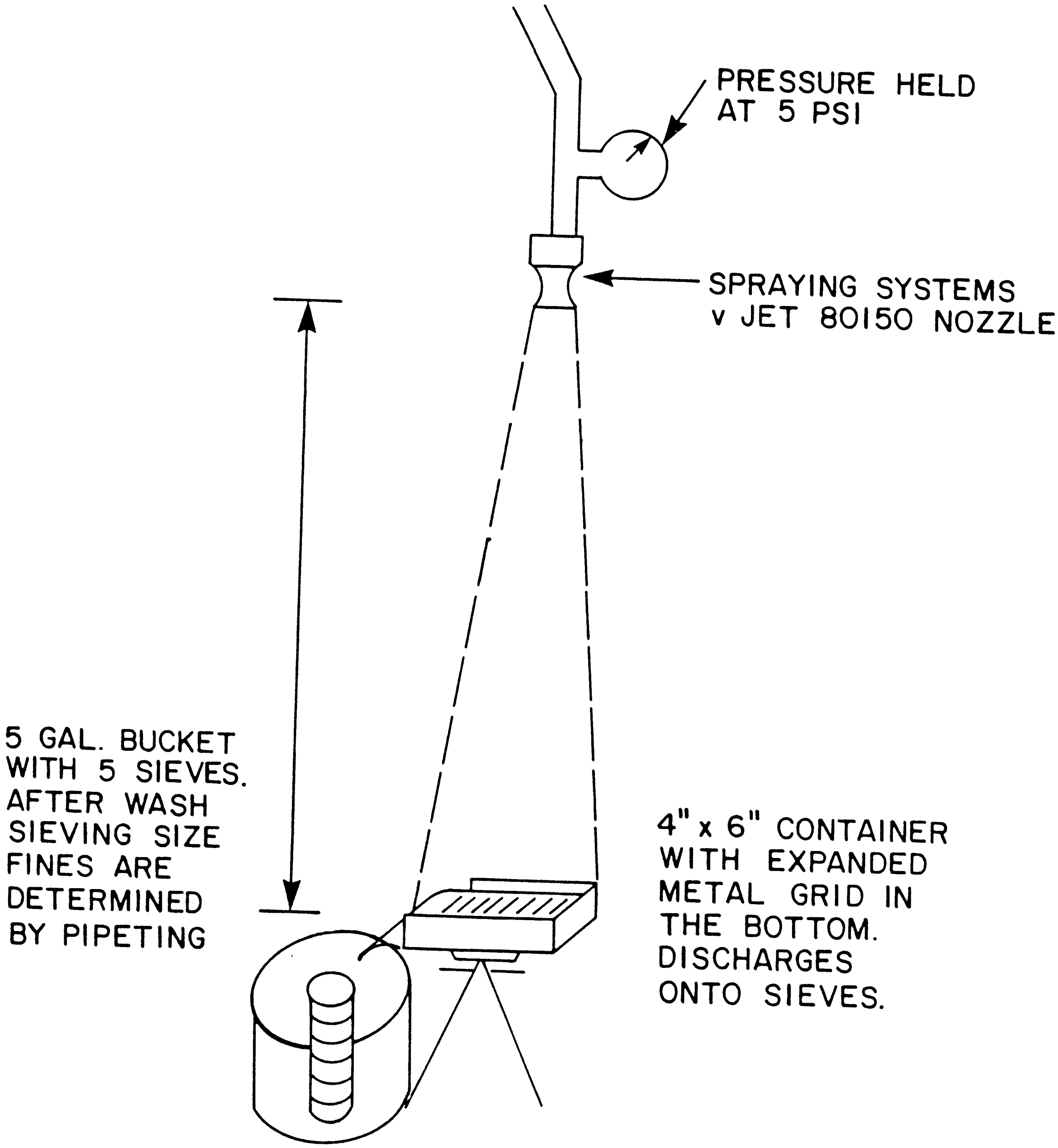
Barfield, Moore, and Williams (1979)
Barfield, Warner, and Haan (1981)

specific. The model cannot be applied to soils which differ significantly from those included in the regression equation data base.

In the absence of established procedures for the estimation of eroded particle size distributions, Barfield, Moore, and Williams (1979) developed a method which makes use of a rainfall simulator resembling the one shown in Figure 11. This device subjects a disturbed watershed soil sample to a simulated rainfall that creates runoff which can be collected for analysis. The system is operated until the volume of rainfall equals that of the design storm event. Particle size distribution estimates developed using this method should not be viewed as definitive. The procedure has not been verified against large volumes of field data and its predictions should be considered as first estimates, at best.

For existing mining operations it should be possible to develop site specific eroded particle size distributions for each type of disturbed area. Runoff collectors (eg. modified plastic pails) could be placed immediately downstream of spoil sites, soil stockpiles, reclaimed areas and haul roads to collect runoff samples during storm events for which durations and intensities have been documented. The results of sample particle size analyses could then be correlated to storm and disturbed area characteristics.

Particle size analyses should focus on the size distribution of the aggregated particles rather than the primary particles. Aggregate analyses account for the natural flocculation of primary soil particles and are much more relevant for settling pond design. Aggregate size distributions should be run shortly after sampling to prevent the aggregates from breaking down due to being held in suspension for long periods of time.



RAINFALL SIMULATOR USED TO ESTIMATE SIZE DISTRIBUTION

(After BARFIELD et al. 1979)

Figure 11

8.4.3 Model Limitations

Virtually all erosion models incorporate coefficients designed to account for the site specific characteristics of individual watersheds. The primary objective of research to date has been to reduce the sensitivity of model outputs to variations in these coefficients, and in so doing, to increase the range of applications for which the models can provide realistic outputs. This objective is being met by replacing site specific correlations with physically based algorithms that model erosion processes as a function of easily defined watershed characteristics.

While much progress has been made in the development of physically based erosion models over the last 30 years, current techniques still rely heavily on site specific coefficients for the characterization of important parameters such as soil erodibility and slope and surface treatment effects. This reliance on site specific variables places significant limitations on the reliability of model outputs which should not go unrecognized.

The bulk of erosion research has always concentrated on problems of soil loss from agricultural areas. Models proposed for disturbed watersheds often rely on site specific coefficients that were initially developed for agricultural conditions. Much work remains to be done in the investigation and identification of coefficients appropriate for disturbed watersheds.