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EVALUATION OF PERFORMANCE CAPABILITY OF SURFACE MINE SEDIMENT BASINS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

The Environmental Protection Agency is evaluating the following reports as part of its reconsideration of the catastrophic precipitation exemptions to effluent guidelines limitations and new source performance standards for coal mining point source discharges of water pollution. See 44 Fed. Reg. 39391 (July 6, 1979).

The Agency is distributing this report to interested members of the public for review and comment. All comments should be submitted in writing to:

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All comments must be postmarked no later than October 1, 1979.

EVALUATION OF PERFORMANCE CAPABILITY OF SURFACE MINE SEDIMENT BASINS

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Contract Number 68-03-2677

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Performed for:
INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Cincinnati, Ohio 45268

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study attempts to define the ability of best practicable technology in the design of surface mine sedimentation basins to meet the current effluent limitations for suspended solids. This subject has been under study by the Resource Extraction and Handling Division of the Industrial Environmental Research Laboratory which may be contacted for futher information.

David G. Stephan
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ABSTRACT

This document presents findings of a study to determine the effectiveness of surface mine sedimentation basins in sediment removal during the occurrence of a variety of rare storm events. Through the use of simulation techniques, a series of six sedimentation basins were studied to determine their performance during the experience of three discrete precipitation events, the 2-year, 5-year, and 10-year twenty-four hour storms. This report details findings, conclusions, and recommendations relative to a surface mine sediment basin's ability to meet the current effluent guidelines for suspended solids removal.

This report was submitted in partial fulfillment of Contract No. 68-03-2677 by Skelly and Loy under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 20, 1979 to July 27, 1979, and work was completed as of August 3, 1979.

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SECTION 1

INTRODUCTION

The Environmental Protection Agency (EPA) has promulgated effluent limitations guidelines and new source performance standards for point source discharges of water pollution in the coal mining industry. Both regulations limit the concentration of total suspended solids (TSS) which may be discharged from coal mine sediment ponds to a 24-hour maximum value of 70 mg/l. The regulations also recognize, however, that relief from the effluent limitations, including TSS, is appropriate in the event of severe storms which overwhelm properly designed, constructed, and maintained sediment ponds. Accordingly, the regulations provide that:

> "Upon satisfactory demonstration by the discharger, any overflow, increase in volume of a discharge, or discharge from a by-pass system, resulting from a 10-year 24-hour or larger precipitation event or from a snow melt of equivalent volume, from facilities designed, constructed, and maintained to contain or treat the volume of water from a 10-year 24-hour precipitation event, shall not be subject to (the otherwise applicable effluent requirements)".[1]

It is the purpose of this study to provide EPA with an assessment of the expected sediment removal efficiency of eleven sediment ponds at six representative Appalachian coal mines under the two-year, five-year and ten-year 24 hour precipitation events. A description of each mine site is contained in Section 5 of this report. They are located as follows: southwestern Pennsylvania (PA-1); northeastern West Virginia (WV-3); central West Virginia (WV-2); southwestern West Virginia (WV-1) and (WV-4); and southeastern Kentucky (KY-1) (See Figure 1).

The effectiveness of these ponds' sediment removal during various storm events has been determined through the use of a state of the art computer modelling technique, developed by the University of Kentucky, Department of Agricultural Engineering, known as the "DEPOSITS" (Deposition Performance of Sediment in Trap Structures) model.[2] A computer modelling technique to evaluate performance of sediment ponds was selected because determination of actual sediment pond efficiency based on field data obtained during a severe storm event is a difficult if not impossible task. To obtain empirical data concerning sediment pond performance in a 10-year 24-hour storm event, by definition one would have to remain on-site for years to obtain the desired effluent samples, and the costs of such a monitoring program would far outweigh the benefits.

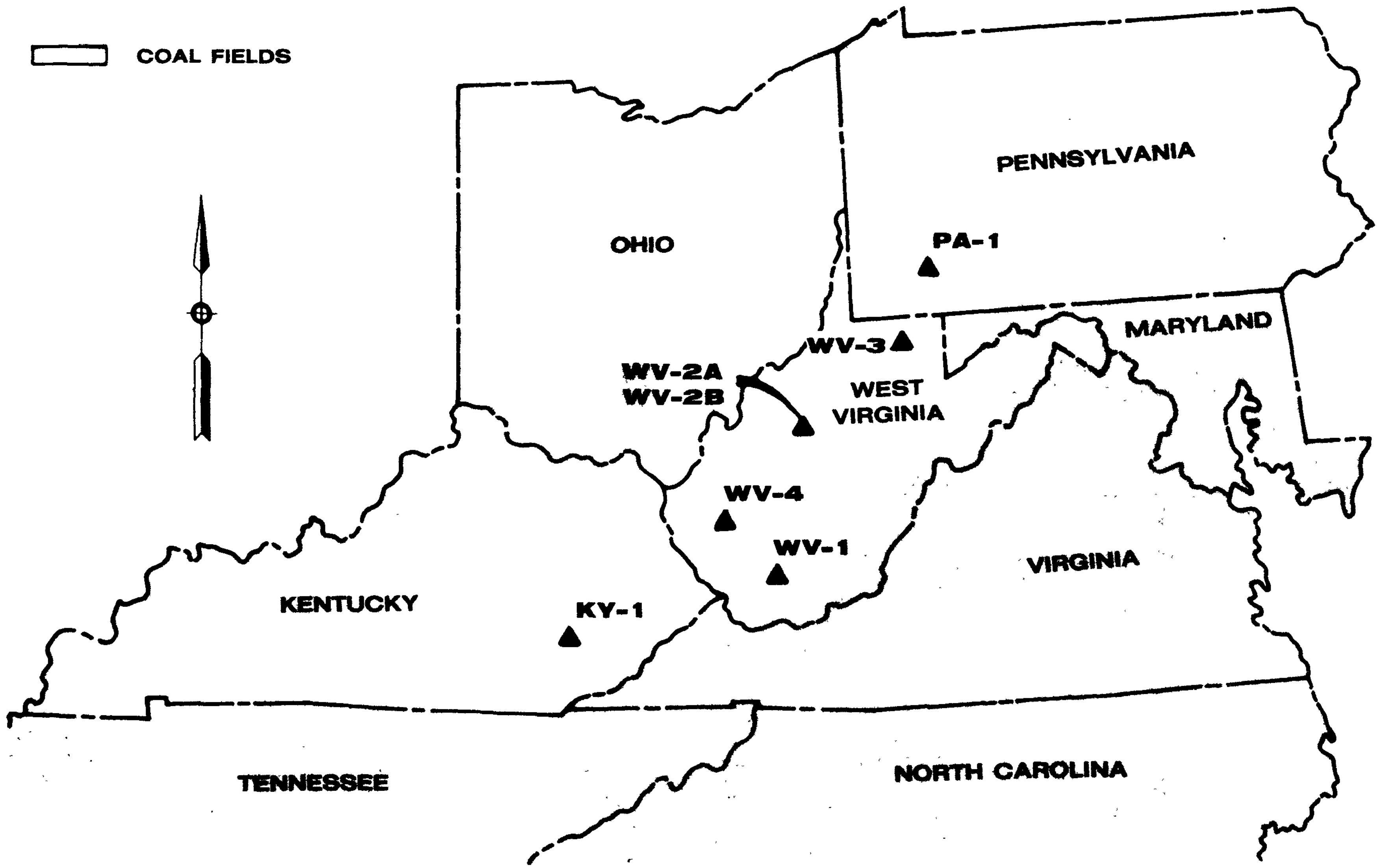

Figure 1. Location of study sediment ponds.

The use of the DEPOSITS model requires the input of certain specific information pertinent to the evaluation of sediment pond efficiency, such as:

1. inflow hydrograph of storm event under study,

2. amount of sediment delivered to the pond during the storm event,

3. characteristics of the sediment, and

4. physical characteristics of the sediment pond.

Each of these factors -- and hence the determination of sediment pond performance during various storm events -- is inherently site-specific. The DEPOSITS model will determine sediment removal efficiencies for given erosion and sediment delivery to a sediment pond under a given storm condition. The methodology used to compute input to the model is delineated in subsequent sections of this study.

Expected TSS effluent concentrations are reported for each of the six mines under different conditions relating to: (1) proximity of the pond to the disturbed area (active pit, regraded area, and valley fill); (2) detention times, and (3) return frequency of storm events. The sediment ponds were modelled at two locations at each mine. The first location, A, is the actual position of the pond as it exists at the mine site. In most cases, the pond is located a substantial distance downstream from the disturbed area where construction of a large structure is less restricted by severe topographic constraints. At this location the pond also collects runoff from undisturbed areas of the watershed.

The second location, B, was selected as close to the disturbed area as possible to minimize the storage requirement. This location was selected based on familiarity with site-specific conditions. In four out of six cases, this was immediately adjacent to the toe of a valley fill. When modelling location B, it was assumed that undisturbed drainage from above the mining area was diverted around the sediment pond.

The eleven sediment ponds were modelled to determine pond performance for detention times (time between hydrograph centers) of 24 hours and greater (up to 45 hours) for the runoff from a 10-year 24-hour storm event. As a final determination of pond removal efficiency, each sediment pond was modelled for pond performance during the passage of a 2-year and 5-year, 24-hour storm event. In all cases under study, the ponds were designed in accordance with design criteria established by the Office of Surface Mining (OSM).

In addition, this study includes an analysis of the costs for construction, maintenance and reclamation of each sediment pond, the results of which are detailed in the study results section.

SECTION 2

CONCLUSIONS

The results of the computer modelling indicate that all eleven pond designs were unable to meet the maximum 24-hour TSS limitations during the five-year and ten-year 24-hour precipitation events.

The performance of surface mine sedimentation basins depends upon several factors including:

1. hydrologic and hydraulic characteristics of the watershed in question;

2. physical characteristics of the sediment delivered to the pond; and

3. geometry of the sediment pond

As evidenced by this study, one of the most important factors in sediment pond performance is the particle size distribution of the influent sediment. The study showed that under all conditions particle sizes greater than .005 mm were removed, therefore, if the influent contains more than 70 mg/l of particles less than this size, the effluent TSS concentrations will theoretically exceed the limitations under the five and ten-year storm events in the absence of chemical treatment.

SECTION 3

RECOMMENDATIONS

Based on the results of this study, the following recommendations are presented:

1. The EPA should allow an exemption from the maximum allowable effluent standards for suspended solids (70 mg/l) during any precipitation event for sediment ponds designed, constructed, and maintained in accordance with OSM design criteria. However, as part of this exemption, the EPA should consider limiting discharges of settleable solids during precipitation events.

2. Further study is recommended to determine if the 70 mg/l total suspended solids limitation can be achieved for any precipitation event without chemical treatment.

SECTION 4

METHODOLOGY OF POND EVALUATION

Six mine sites with eleven sedimentation ponds located throughout the Appalachian coal fields were evaluated relative to sediment removal performance. The Appalachian region was selected because in this area, topographic constraints may render treatment of storm runoff most difficult; therefore, it provides a worst-case for analysis. Five of the sites were evaluated with ponds at two locations on the drainageway. The first location, "A", refers to the pond's present location downstream from the disturbed area. The second location, "B", refers to a position adjacent to the disturbed area, which consists of the active mine, valley fill and regraded areas. One sediment pond, PA-1, was evaluated at only one location, adjacent to the disturbed area, as this is the pond's present location.

In order to perform the evaluation of pond performance, a three step approach was employed. First, the gross erosion in tons from the watershed tributary to the pond was computed for the 2-year, 5-year, and 10-year 24-hour storm events for each of the sediment pond locations, A and B. Second, the inflow hydrograph for each sediment pond was computed for the 2-year, 5-year, and 10-year 24-hour storm events. Finally, the performance of each sediment pond was evaluated using the DEPOSITS computer program to model sediment removal efficiency.

All ponds were designed to meet OSM design criteria. These criteria include a sediment storage capacity of 0.1 acre-feet for each acre of disturbed area and a detention time (time between hydrograph centers) of a minimum of 24 hours for the runoff from a 10-year 24-hour storm.

SEDIMENT YIELD COMPUTATIONS

The phenomena of soil erosion from rainfall and its delivery to a stream system are very complex occurrences that are difficult to estimate accurately. The most widely used and accepted method of estimating sediment yield is the Universal Soil Loss Equation (USLE), developed by the U.S. Department of Agriculture's (USDA) Agricultural Research Service, in cooperation with Purdue University. The empirical equation was developed utilizing more than 10,000 plot-years of basic runoff and soil loss data primarily from agricultural lands. Additional data have lead to refinement of USLE parameters and expansion of data to include non-agricultural lands, especially construction sites.[3]

Because the USLE was initially developed to account for yearly sediment yields from agricultural lands, modifications of this formula are advisable to compute sediment delivery to coal mine sediment ponds during specific storm events. From analysis of runoff and soil loss from small single-cropped watersheds, Williams developed a Modified Universal Soil Loss Equation (MUSLE) that eliminated the need for sediment delivery techniques by replacing the rainfall energy factor (R) with a runoff energy factor that is a function of the volume and peak rate of storm runoff.[4] This runoff energy factor also allows the MUSLE to be used to estimate sediment yield from various storm events. This modified USLE is used in this study to estimate the total sediment delivered to the sedimentation ponds for various rainfall events.

It is recognized that the USLE, even with the modifications discussed below, is not a perfect predictive tool regarding sediment delivery to coal mine sediment ponds; it is believed that the equation will overestimate the amount of sediment delivered to a sediment pond. However, this formula is the best available, in the absence of detailed site-specific data. A recent study by Miller and Veon prepared for Pennsylvania Department of Transportation showed that MUSLE had the best correlation ($r^2 = 0.84$) and smallest error of all sediment yield models tested for over 200 highway construction sites.[5] This type of construction may closely correspond to the situation encountered at surface mines.

Soil Loss Equation

The modified USLE developed by Williams utilizing the runoff energy concept for sediment yield and delivery is shown by the following relationship:

$$Y = 95\ (VQp)^{.56}\quad K(LS)CP$$

where,

Y is the total sediment delivered from the watershed (tons)

$(VQp)^{.56}$ is the runoff energy factor consisting of V, the runoff volume (acre-feet) and Qp, the runoff peak (cfs)

K is the soil erodibility factor

LS is the slope length-steepness factor

C is the cover and management factor

P is the support practice factor

A discussion of the methodology and assumptions used to determine these parameters follows.

Runoff Energy

The runoff energy factor proposed by Williams is directly proportional to runoff volume multiplied by the peak rate of runoff and provides a mechanism for estimating both sediment yield and delivery ratio. The exponent of 0.56 may vary between watersheds and can be used for calibration if actual data is available. However, Williams found this value to be accurate for a wide range of watersheds, therefore, this same value was used for computation in this study.

The DEPOSITS model uses a subroutine, (WASH), to compute runoff volumes and peaks, and an estimate of these values was therefore needed to determine sediment load on the pond (also an input variable to DEPOSITS). Since WASH uses a Soil Conservation Service runoff curve number to simulate runoff, a similar approach was used to compute the values used in the MUSLE. The techniques that were used are documented in USDA Technical Release No. 55 "Urban Hydrology for Small Watersheds"[6] and SCS Technical Paper No. 149 "A Method for Estimating Volume and Rate of Runoff in Small Watersheds"[7] These publications contain a series of tables and graphs to determine runoff peaks and volumes using runoff curve numbers, watershed slope, and rainfall total. The land cover and soil type are used to select the runoff curve number (CN), which is used to determine runoff volume, and is used with the watershed slope to determine peak runoff rate.

Site-specific soil information was only available for the Pennsylvania site, and it was found to be predominantly B soils. Therefore, to select the CN for the four general types of land cover encountered in mine watersheds, this study assumed that all soils are hydrologic soil type B, characterized by moderate infiltration capacity when thoroughly wetted. CN's for the four land cover types with B soils were determined to be:

virgin land - 55
active pit - 84
regraded - 75
valley fill - 85

The total rainfall for 2-year, 5-year, and 10-year 24-hour events was determined to be 2.25, 3.40, and 4.00 inches respectively, using data presented in Technical Paper No. 40 "Rainfall Frequency Atlas for the U.S."[8] The composite CN for each site and runoff for each storm are summarized in Table 1. It should be noted that in some cases, especially during the 2-year precipitation events, that simulated runoff volumes from areas tributary to larger areas exceed the volumes computed for the larger areas. While this phenomenon can occur in certain geologic conditions, it is recognized that this will probably not be true at these mine sites. This anomally is because of certain inherent assumptions selected about initial abstractions and watershed storage based on composite CNs. The values are still considered to be good approximations for use in the sediment yield computations and were used as calculated.

TABLE 1. DETERMINATION OF ESTIMATED RUNOFF VOLUME AND PEAK RATE FOR DETERMINING SEDIMENT LOADS

Site*	Acres of land cover				CN	Runoff					
	Virgin (CN55)	Pit (CN84)	Regrad (CN75)	Fill (CN85)		2-YEAR (AC-FT)	2-YEAR (CFS)	5-YEAR (AC-FT)	5-YEAR (CFS)	10-YEAR (AC-FT)	10-YEAR (CFS)
PA-1	-	10	22	-	78	1.7	17	3.8	33	5.0	51
KY-1(A)	31	7	1	4	63	0.2	4	0.8	16	1.2	24
KY-1(B)	3	7	1	4	78	0.8	10	1.8	23	2.4	30
WV-1(A)	276	9	26	26	60	3.1	16	13.7	74	21.4	114
WV-1(B)	7	9	26	26	78	3.6	44	8.1	71	10.7	132
WV-2(A)	384	6	23	18	58	2.9	8	14.9	41	23.9	66
WV-2(B)	3	6	23	18	78	2.6	24	5.9	54	7.9	72
WV-3(A)	72	9	30	25	67	2.9	16	9.0	47	13.0	68
WV-3(B)	6	9	30	25	78	3.7	24	8.3	54	11.0	72
WV-4(A)	354	8	13	-	56	1.7	7	10.8	48	17.9	80
WV-4(B)	1	8	13	-	77	1.1	16	2.5	38	3.3	51

* Location A is downstream of disturbed area, location B is in closer proximity.

Soil Erodibility

Soil erodibility is a term that applies to the capacity of a particular soil to erode under fallow conditions. The value of "K" has been determined for 23 major soil groups in the United States under natural conditions on the basis of data collected since 1930 and this data has been extrapolated to other soil types by using soil characteristics such as percent silt and fines, percent sand, percent organic material, soil structure, and permeability. Nearly all soils will fall into a range of K from 0.1 to 0.7.

Although information required to determine K at particular sites is often available through the Soil Conservation Service (SCS), none of the counties in which the six ponds are located have published soil surveys. However, the area around PA-1 could be located on a General Soils Map for Pennsylvania and K values for the B and C horizons of the soil associations averages 0.28. Additionally, published national soil erodibility index maps showed that soils throughout the locations in West Virginia and Kentucky possess medium erodibility (K ranging from 0.24-0.32). Based on this information and data determined for the Pennsylvania site, a K value of 0.3 was used. Miller and Veon found that for highway construction sites in Pennsylvania K did not vary greatly between the construction subsoils and the B and C horizons.[9]

Topography

The length and steepness of the land slope have major impacts on the rate of soil erosion during a rainfall event. In past research efforts, the slope-length (L) and slope-steepness (S) have been evaluated separately, but for field application, the two have been combined into a single topographic factor (LS). The SCS has developed a graph to determine LS as a function of the slope-length and steepness.[10]

Slope length is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff enters the drainage network. For this analysis it was assumed that each component of the watershed area being considered was a rectangle having a length equal to the overland flow length and a slope-length equal to half the width, which is determined by dividing the area by the overland flow length. The area and overland flow length were determined from maps. This concept is illustrated by Figure 2.

The slope-steepness or gradient was determined by measuring the average gradient from the topographic maps for the virgin and regraded areas. The active pit and valley fill areas, however, will not have these characteristics because they drastically change the natural conditions. Both of these areas will be flatter than the surrounding terrain over the greatest portion of their area. For these areas an average gradient of 5% was assumed for active pits and 10% for valley fills.

TABLE A-1. SEDIMENT POND PA-1 (5 yr. storm)

PERMANENT POOL CAPACITY	=	2.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	3.89	ACRE-FT
STORM VOLUME DISCHARGED	=	0.96	ACRE-FT
POND VOLUME AT PEAK STAGE	=	5.50	ACRE-FT
PEAK STAGE	=	5.36	FT
PEAK INFLOW RATE	=	46.36	CFS
PEAK DISCHARGE RATE	=	1.31	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	52315.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1729.3	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	994.4	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	256.9	MG/L
BASIN TRAP EFFICIENCY	=	98.96	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	94.02	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	20.83	HRS
DETENTION TIME INCLUDING STORED FLOW	=	87.60	HRS
SEDIMENT LOAD	=	124.00	TONS

13. U.S. Weather Bureau. 1960. Rainfall Frequency Atlas for the United States, Technical Paper No. 40.

14. Ward, A., Haan T. and Tapp, J. 1979. The Deposits Sedimentation Pond Design Manual. Institute for Mining Minerals Research, Kentucky Center for Energy Research Laboratory, University of Kentucky, Lexington, Kentucky.

15. Williams, J.R. 1975. Sediment-Yield Prediction with Universal Soil Loss Equation Using Runoff Energy Factor. Present and Prospective Technology for Predicting Sediment Yield and Sources. In: Proceedings of the Sediment Yield Workshop, ARS-S-40. U.S. Department of Agriculture Sedimentation Laboratory, Oxford, Mississippi. 244-252 pp.

16. Williams, J.R. 1978. A Sedimentgraph Model Based on an Instantaneous Unit Sedimentgraph. Water Resources Research, Vol. 14, No. 4, August 1978. 659-664 pp.

17. Wischmeier, W.H., and Smith, D.D. 1978. Predicting Rainfall Erosion Losses - a Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

BIBLIOGRAPHY

1. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, 1975.

2. Aron, G., Laktos, J., and Stom, L.E. 1979. Penn State Urban Runoff Model - User's Manual - Jan. 1979 Edition. The Pennsylvania State University, University Park, Pennsylvania.

3. Caterpillar Tractor Co. Caterpillar Performance Handbook, 8th Edition, Peoria, Illinois : Caterpillar Tractor Co., 1977.

4. Clyde, Calven G., et. al. 1978. Manual of Erosion Control Principles and Practices During Highway Construction. Utah Water Research Laboratory, Utah State University, Logan, Utah. UWRL/H-78102.

5. Dodge Building Cost Services, 1979 Dodge Guide for Estimating Public Works Construction Cost, Annual Edition No. 11 : McGraw-Hill Information Systems Company, New York, New York.

6. 44 Federal Register 2586 (January 12, 1979) and 44 Federal Register 19193 (April 2, 1979). This provision has been temporarily suspended in part. 44 Federal Register 39391.

7. Haan, C.T. and B.J. Barfield, 1978. Hydrology and Sedimentology of Surface Mined Lands, Office of Continuing Education and Extension, College of Engineering, University of Kentucky, Lexington, Kentucky 40546.

8. Kent, K.M. 1973. A Method for Estimating Volume and Rate of Runoff in Small Watersheds. U.S. Department of Agriculture, Soil Conservation Service, Technical Paper No. 149.

9. Miller, A.C. and Veon, W. 1979. Sediment Prediction from Pennsylvania Highway Construction Sites. Pennsylvania Department of Transportation, Harrisburg, Pennsylvania. In Print.

10. Miller, A.C. and Veon, W. 1977. Soil Properties that Affect Erosion. Transportation Research Record #642.

11. Soil Conservation Service. 1975. Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Technical Release No. 55.

12. United Mine Workers of America and Bituminous Coal Operator's Association Wage Agreement of 1978 (Three Year Contract).

13. Aron, G., Laktos, J., and Stom, L.E. 1979. Penn State Urban Runoff Model - User's Manual - Jan. 1979 Edition. The Pennsylvania State University, University Park, Pennsylvania.

14. Williams, J.R. 1978. A Sedimentgraph Model Based on an Instantaneous Unit Sedimentgraph. Water Resources Research, Vol. 14, No. 4, August 1978. 659-664 pp.

15. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, 1975.

16. Caterpillar Tractor Co. Caterpillar Performance Handbook, 8th Edition, Peoria, Illinois : Caterpillar Tractor Co., 1977.

17. United Mine Workers of America and Bituminous Coal Operator's Association Wage Agreement of 1978 (Three Year Contract).

18. Dodge Building Cost Services, 1979 Dodge Guide for Estimating Public Works Construction Cost, Annual Edition No. 11 : McGraw-Hill Information Systems Company, New York, New York.

REFERENCES

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2. Ward, A., Haan T. and Tapp, J. 1979. The Deposits Sedimentation Pond Design Manual. Institute for Mining Minerals Research, Kentucky Center for Energy Research Laboratory, University of Kentucky, Lexington, Kentucky.

3. Wischmeier, W.H., and Smith, D.D. 1978. Predicting Rainfall Erosion Losses - a Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

4. Williams, J.R. 1975. Sediment-Yield Prediction with Universal Soil Loss Equation Using Runoff Energy Factor. Present and Prospective Technology for Predicting Sediment Yield and Sources. In: Proceedings of the Sediment Yield Workshop, ARS-S-40. U.S. Department of Agriculture Sedimentation Laboratory, Oxford, Mississippi. 244-252 pp.

5. Miller, A.C. and Veon, W. 1979. Sediment Prediction from Pennsylvania Highway Construction Sites. Pennsylvania Department of Transportation, Harrisburg, Pennsylvania. In Print.

6. Soil Conservation Service. 1975. Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Technical Release No. 55.

7. Kent, K.M. 1973. A Method for Estimating Volume and Rate of Runoff in Small Watersheds. U.S. Department of Agriculture, Soil Conservation Service, Technical Paper No. 149.

8. U.S. Weather Bureau. 1960. Rainfall Frequency Atlas for the United States, Technical Paper No. 40.

9. Miller, A.C. and Veon, W. 1977. Soil Properties that Affect Erosion. Transportation Research Record #642.

10. Wischmeier and Smith. op. cit.

11. ibid.

12. Ward, Haan, and Tapp. op. cit.

TABLE 11. SUMMARY OF ESTIMATED COST FOR STUDY PONDS

Pond	Storage (ac-ft)	Cost ($)
PA-1	10.1	23,700
WV-1A	29.0	42,000
WV-1B	18.0	37,000
Wv-2A	51.3	54,000
WV-2B	13.1	27,000
WV-3A	21.1	38,000
WV-3B	18.4	38,000
WV-4A	42.7	51,000
WV-4B	5.9	17,000
KY-1A	6.4	18,000
KY-1B	4.4	16,000

REFERENCES

1. 44 Federal Register 2586 (January 12, 1979) and 44 Federal Register 19193 (April 2, 1979). This provision has been temporarily suspended in part. 44 Federal Register 39391.

2. Ward, A., Haan T. and Tapp, J. 1979. The Deposits Sedimentation Pond Design Manual. Institute for Mining Minerals Research, Kentucky Center for Energy Research Laboratory, University of Kentucky, Lexington, Kentucky.

3. Wischmeier, W.H., and Smith, D.D. 1978. Predicting Rainfall Erosion Losses - a Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

4. Williams, J.R. 1975. Sediment-Yield Prediction with Universal Soil Loss Equation Using Runoff Energy Factor. Present and Prospective Technology for Predicting Sediment Yield and Sources. In: Proceedings of the Sediment Yield Workshop, ARS-S-40. U.S. Department of Agriculture Sedimentation Laboratory, Oxford, Mississippi. 244-252 pp.

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6. Soil Conservation Service. 1975. Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Technical Release No. 55.

7. Kent, K.M. 1973. A Method for Estimating Volume and Rate of Runoff in Small Watersheds. U.S. Department of Agriculture, Soil Conservation Service, Technical Paper No. 149.

8. U.S. Weather Bureau. 1960. Rainfall Frequency Atlas for the United States, Technical Paper No. 40.

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WV-2B	13.1	27,000
WV-3A	21.1	38,000
WV-3B	18.4	38,000
WV-4A	42.7	51,000
WV-4B	5.9	17,000
KY-1A	6.4	18,000
KY-1B	4.4	16,000

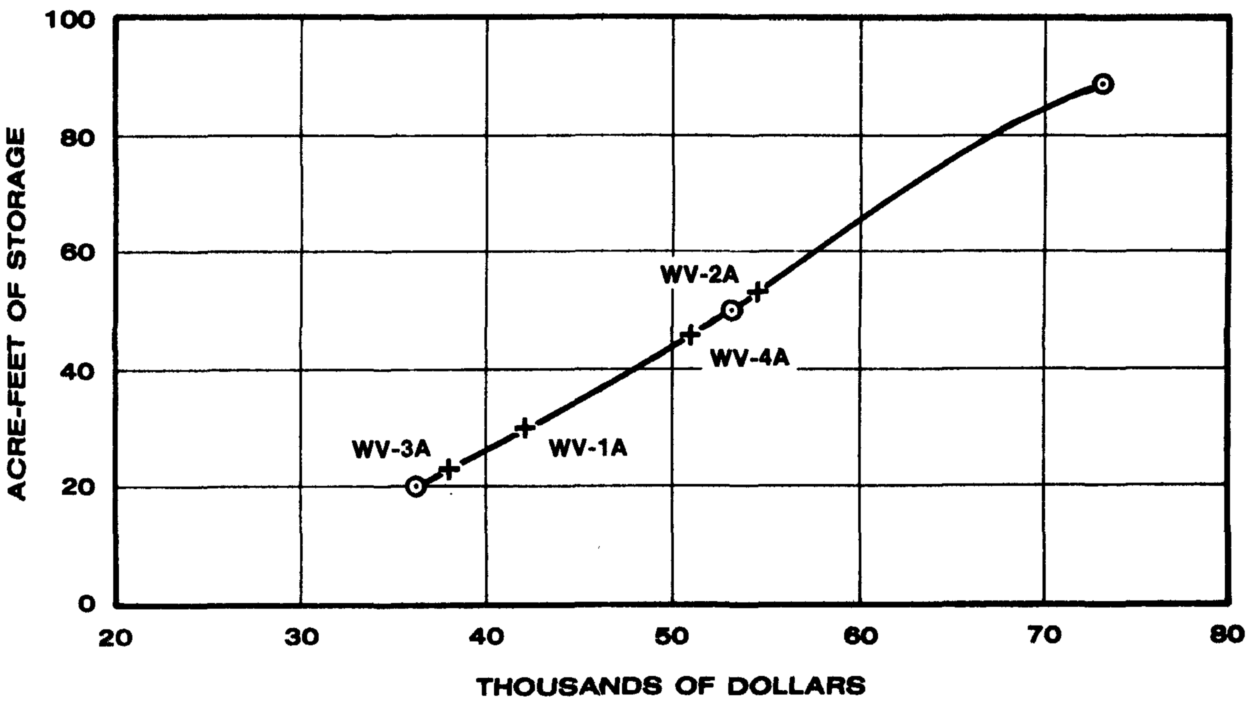

Figure 5. Cost curve for ponds at location A.

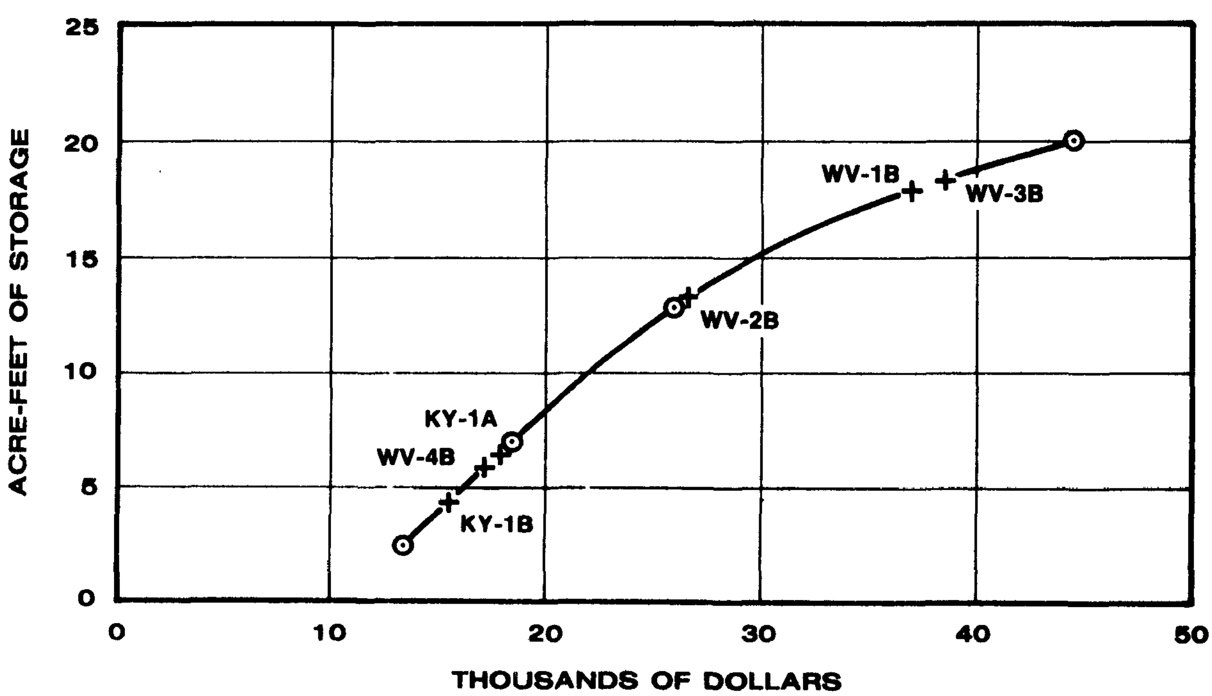

Figure 6. Cost curve for ponds at location B.

1) Equipment production rates were calculated from the "Caterpillar Performance Handbook"[16]

2) Labor costs were computed from UMW/BCOA 1979 rates.[17]

3) All construction was assumed to be performed by the operator[18] with typical mining equipment.

4) Pipe costs and installation was taken from "1979 Dodge Guide to Public Works and Heavy Construction Costs".

5) All construction materials were available from the site.

6) Access roads to the sites were not included in the costs.

7) Sediment removal was not anticipated with the yeilds predicted and the storage volume used in the designs.

8) All costs are in 1979 dollars with no inflation factor for reclamation costs.

Table 9 is a summary of costs for sediment pond construction, and reclamation for the representative pond location and sizes. The acre-feet of storage available at the respective embankment elevations for each pond is also tabulated. Figures 5 and 6 present graphs of available storage versus total cost for sediment ponds constructed at locations A and B. Table 11 is a summary of the estimated construction costs derived from Figures 5 and 6 for the ponds used in the study.

TABLE 9. ESTIMATE OF EMBANKMENT SEDIMENT POND COSTS

Site	Embankment height (ft)	Storage (ac-ft)	Cost ($) Construction*	Reclamation	Total
A	20	20.0	25100	10600	35700
	25	48.0	37800	15000	52800
	30	88.0	53500	19200	72700
B	15	2.75	10800	2800	13600
	20	7.0	15200	3400	18600
	25	13.0	21300	4900	26200
	30	20.0	37700	7100	44800

* Includes materials

TABLE 10. ESTIMATE OF EXCAVATED SEDIMENT POND COST

Size (ft)	Storage (ac-ft)	Cost ($) Construction	Reclamation	Total
200x200x10	10.1	16200	7500	23700

TABLE 8. PARTICLE SIZE DISTRIBUTION OF POND EFFLUENT

Pond	Precipitation event frequency @ 24-hr	Detention time (hrs)	Percent of particles finer .001mm	.002mm	.005mm
PA-1	10yr	25.0	83.9	100.0	100.0
	10yr	38.0	97.0	100.0	100.0
	5yr	20.8	96.4	100.0	100.0
WV-1A	10yr	26.0	47.9	90.3	100.0
	10yr	40.7	61.9	99.5	100.0
	5yr	25.7	58.7	99.0	100.0
WV-1B	10yr	36.3	52.8	98.1	100.0
	10yr	40.6	63.4	100.0	100.0
	5yr	19.2	51.9	93.7	100.0
WV-2A	10yr	24.7	45.5	88.1	100.0
	10yr	38.6	53.4	95.6	100.0
	5yr	13.9	44.3	87.6	100.0
WV-2B	10yr	25.7	52.1	97.3	100.0
	10yr	39.7	62.4	100.0	100.0
	5yr	18.7	53.1	96.4	100.0
WV-3A	10yr	26.3	61.2	99.7	100.0
	10yr	45.8	92.1	100.0	100.0
	5yr	26.3	80.0	100.0	100.0
WV-3B	10yr	26.3	48.8	93.5	100.0
	10yr	40.6	57.5	99.8	100.0
	5yr	19.0	50.5	92.6	100.0
WV-4A	10yr	25.7	44.8	85.6	100.0
	10yr	39.5	52.2	92.8	100.0
	5yr	15.4	43.5	84.5	100.0
WV-4B	10yr	28.9	64.1	100.0	100.0
	10yr	42.6	76.7	100.0	100.0
	5yr	21.6	66.5	100.0	100.0
KY-1A	10yr	26.3	53.8	98.3	100.0
	10yr	41.1	64.9	100.0	100.0
	5yr	16.2	55.7	99.8	100.0
KY-1B	10yr	24.0	60.7	99.3	100.0
	10yr	41.5	80.3	100.0	100.0
	5yr	21.4	72.5	100.0	100.0

The settleable solids (settleable matter)[15] test requires that water samples be placed in an Imhoff Cone and undergo a one hour period of quiescent settling. Based upon Stoke's Law, assuming a water temperature of 10° c and a particle density of 2.65 g/cm^3 , all particles greater than .012 mm should settle during the test. Referring to Table 8, it can be seen that in all cases that particles greater than .005 mm were removed. Therefore, under the conditions modelled, all settleable solids should be removed by ponds designed to meet OSM criteria.

SEDIMENT POND CONSTRUCTION COST ANALYSIS

A cost analysis of embankment type sediment pond construction was performed for two topographical conditions, simulating sites A and B. The topography at site A represented a location downstream of the disturbed area where a U-shaped valley and moderate slopes occur. Site B represents a V-shaped valley with steep side slopes, typical of the topography found immediately below mine areas in Appalachia.

To generate cost curves for sites A and B, three sizes of ponds were costed for site A and four sizes were costed for site B. A third site, representing a totally excavated pond for PA-1, was analyzed adjacent to the disturbed area of a modified area mine.

The sediment pond cost analyses for the representative sites included both construction and reclamation of the ponds.

The construction phase consisted of move-in and erection of equipment, clearing and grubbing, topsoil removal and storage, drill bench construction, drilling and blasting, excavation, embankment placement and grading, pipe placement, spillway construction and material costs. Reclamation included removal of the embankment, removal of spillway structures, final grading to contour, topsoil replacement and revegetation.

Since the site for PA-1 was a totally excavated pond, drill bench construction and drilling and blasting operations were excluded.

For each of the eight representative ponds, material handling requirements and equipment production rates were determined for each operation involved. From this, operation times (in hours) were determined for both equipment and labor. The hourly cost for equipment ownership and depreciation, labor, and equipment operation were applied to the operation times to arrive at a cost for each operation.

Presented below are the overall methods and assumptions entered into this cost analysis:

TABLE 7. SUMMARY OF SIMULATED SEDIMENT POND PERFORMANCE

Pond	Precipitation event frequency @ 24-hr duration	Detention time, (hr)	Suspended solids, (mg/l) Peak influent	Peak effluent	Design outflow rate (Cfs)
PA-1	10yr	25.0	54300	2310	1.31
	10yr	38.0	54300	1810	0.78
	5yr	20.8	52300	1730	1.31
WV-1A	10yr	26.1	22630	1600	6.34
	10yr	40.7	22630	1280	3.10
	5yr	25.7	21000	1240	6.34
WV-1B	10yr	26.3	125300	8000	2.31
	10yr	40.6	125300	6780	1.54
	5yr	19.2	100000	6700	2.31
WV-2A	10yr	24.7	6180	460	5.15
	10yr	38.6	6180	400	3.43
	5yr	13.9	5700	430	5.15
WV-2B	10yr	25.7	64100	3900	1.70
	10yr	39.7	64100	3340	1.13
	5yr	18.7	62500	3640	1.70
WV-3A	10yr	26.3	41300	2300	6.22
	10yr	45.8	41300	1360	1.86
	5yr	26.3	41300	1590	6.22
WV-3B	10yr	26.3	76200	5260	2.38
	10yr	40.6	76200	4590	1.58
	5yr	19.0	73300	4980	2.38
WV-4A	10yr	25.7	17100	1340	3.87
	10yr	39.5	17100	1170	2.58
	5yr	15.4	15100	1240	3.87
WV-4B	10yr	28.9	165300	8980	0.72
	10yr	42.6	165300	7380	0.48
	5yr	21.6	159800	8470	0.72
KY-1A	10yr	26.2	10400	646	0.74
	10yr	41.1	10400	559	0.49
	5yr	16.2	10700	590	0.74
KY-1B	10yr	24.0	53600	3330	0.83
	10yr	41.5	53600	2370	0.39
	5yr	21.4	51900	2600	0.83

TABLE 6. WATERSHED CHARACTERISTICS

Pond	Location*	Drainage area (acres)	Disturbed area (acres) Active pit	Regraded	Valley fill	Average watershed slope, (%)	Hydraulic flow length, (ft)	Composite curve no. (CN)
PA-1	B**	32	10	22	0	5.0	1100	78
WV-1	A	340	9	26	26	18.6	6000	60
	B	68	9	26	26	21.0	2200	78
WV-2	A	431	6	23	18	10.7	3000	58
	B	50	6	23	18	13.0	3000	78
WV-3	A	136	9	30	25	21.0	3000	67
	B	70	9	30	25	15.0	1500	78
WV-4	A	375	8	13	0	10.0	2000	56
	B	22	8	13	0	30.0	1500	77
KY-1	A	45	7	1	4	40.0	2000	63
	B	17	7	1	4	40.0	1400	78

* Location A - actual pond position, Location B - close proximity to disturbed area.
** Pond B was already located as close as possible to the disturbed area.

SECTION 5

RESULTS OF STUDY

For each of the study mine sites, two sediment pond locations were evaluated for sediment removal performance under three different conditions of rainfall. In addition, the ten-year 24-hour storm condition was modelled using a minimum detention time of twenty-four hours and a higher detention time, usually greater than thirty-six hours. These varying conditions of rainfall and detention times resulted in forty-four separate simulations. The watershed characteristics used in the simulation are listed in Table 6.

SIMULATION RESULTS

The results of the pond performance simulation are listed in Table 7. The Table itemizes the detention time, concentration of peak influent suspended solids and concentration of peak effluent suspended solids for each of the eleven sediment ponds modelled during the inflow from a 5-year and 10-year 24-hour precipitation event. The results from the 2-year precipitation event are not included in this summary because the computer model simulated 100% trap efficiency for the total runoff. Because of the plug flow concept, the model assumes that the runoff from the 2-year storm event merely displaces the standing pool of clear water. In an actual field situation, the pre-storm contents of the permanent pool which will be discharged prior to storm discharge will contain an unknown amount of colloidal material contributing to suspended solids in the effluent.

The results presented in Table 7 indicate that none of the sediment ponds meets the daily maximum effluent limitations for suspended solids, 70 mg/l. The effluent particle size distribution for each of the simulations shows that all particles greater than .005 mm were removed from suspension under all scenarios for all ponds. The simulation which has the least detention time (WV-2A - 5 year storm, 13.9 hours), showed that 87.6% of the particles less than .002 mm remained in solution. The simulation which has the greatest detention time (WV-3A - 10 year storm, in excess of 45 hours) showed that 92.1% of particles less than .001 mm remained. These two pieces of data indicate the dramatic effect of particle size on sediment removal performance. The simulation with a detention time in excess of 45 hours still showed a peak effluent suspended solids concentration of 1362 mg/l, clearly in violation of the effluent guidelines.

Peak Effluent Sediment Concentration

Peak sediment concentration contained in the flow being discharged from the pond as determined by the model.

Storm Average Effluent Concentration

Average concentration of the sediment in the effluent measured from the initial discharge of sediment until the end of the simulation period (does not include clear water discharged by the precipitation event).

Average Effluent Sediment Concentration

Average sediment concentration contained in the effluent during the entire simulation period (including the period before any sediment is discharged). Clear previously stored flow which might be discharged has been included in the determination of this average.

Basin Trap Efficiency

The percentage of the sediment inflow which has remained in the pond at the end of the discharge event. It should be noted that most of the fine colloidal particles will have remained in suspension in the permanent pool and may well be discharged during the next storm event.

Detention Time of Flow with Sediment

This definition gives a volume weighted average detention time of the design storm event. Credit is given for previously stored flow being discharged initially and also for part of the design flow remaining in the permanent pool following the event. This definition will give the longest theoretical detention time of the three presented.

Detention Time From Hydrograph Centers

This definition of detention time gives the detention time between the centers of the inflow and outflow hydrographs, which conforms to the definition contained in OSM regulations. Occasionally, the computer simulation will end before the end of the discharge event. When this occurs, the reported detention time will be underestimated. In all cases, however, the simulation period included the peak effluent TSS concentration.

Detention Time Including Stored Flow

This definition gives a volume weighted detention time based on the time between the hydrograph centers but also gives credit for some of the flow remaining in the permanent pool.

Sediment Load

The sediment load is the amount of sediment entering the basin during the design event, derived from MUSLE.

for a partial reduction in permanent pool storage due to sediment depositions. In this case it was assumed that the pond was new or recently cleaned of sediment and thus the full sediment storage volume was available. In addition, it was assumed that the pond had no dead storage. This assumption is on the conservative side for this study because, in actuality as much as 50% of the pond volume may be dead storage.

Storm Runoff Volume

The volume of runoff from the design storm event as computed by the WASH model.

Storm Volume Discharged

The volume of the design storm runoff which has been discharged during the simulation period -- that is, either 24 hours or longer if a greater detention time has been modelled. It should be remembered that if the basin has a permanent pool, previously stored flow will be discharged initially and part of the design storm flow will remain in the basin. This study assumed a permanent pool of 0.1 acre-foot per acre of disturbed land (sediment storage volume).

Pond Volume at Peak Stage

The capacity of the pond at the peak stage reached during the routing of the design event by the computer model.

Peak Stage

The highest water surface elevation reached during the routing of the design event as determined by the model.

Peak Inflow Rate

Peak inflow rate of storm runoff into the pond, as determined by WASH.

Peak Discharge Rate

Peak discharge rate from the pond during the routing of the design event. In this study, a constant discharge rate was assumed since a floating discharge structure was used.

Peak Inflow Sediment Concentration

Peak sediment concentration entering the pond, based upon total sediment delivered to the pond as determined by MUSLE.

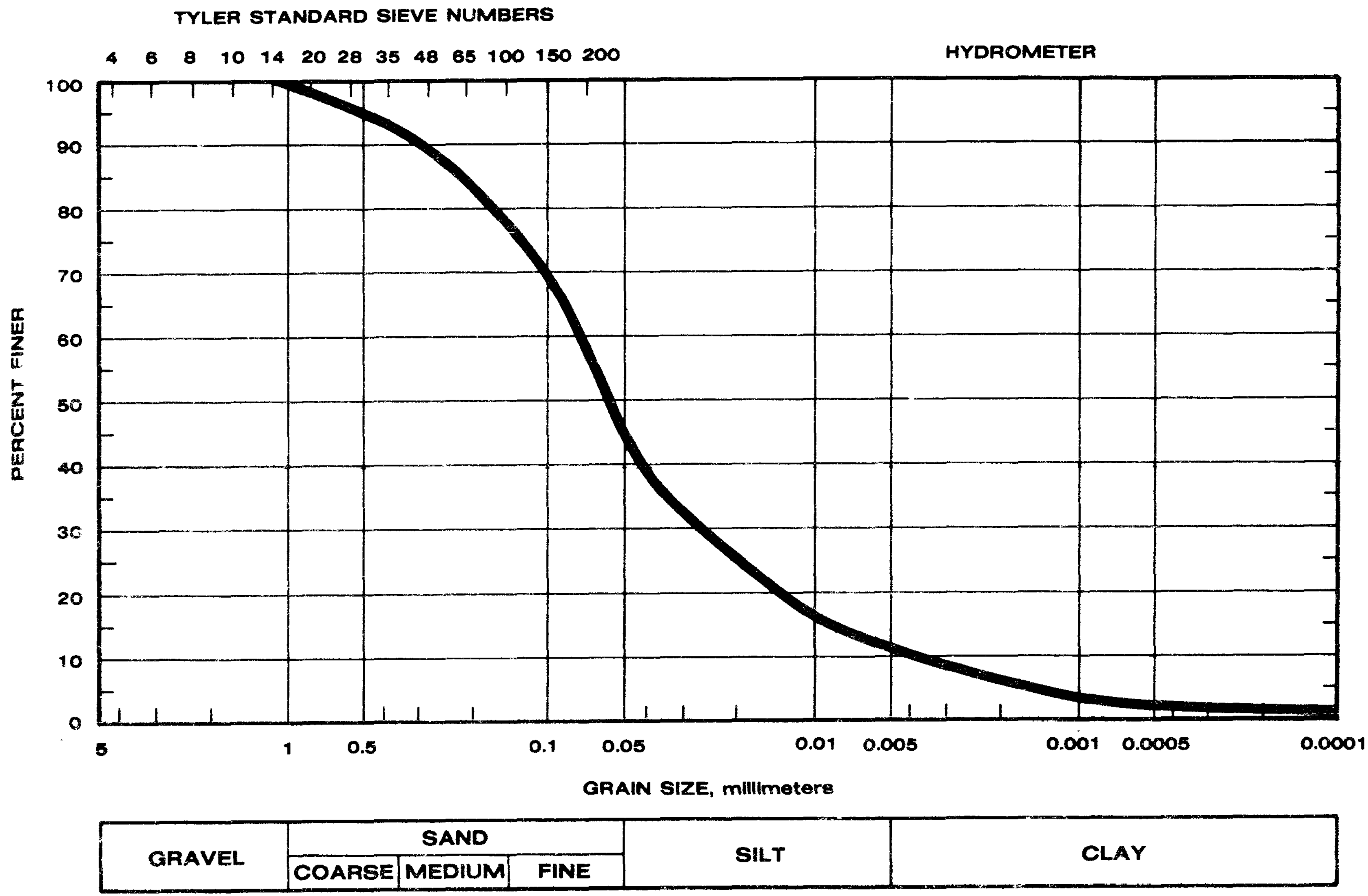

Figure 4. Particle size distribution of influent.

The modified universal soil loss equation (MUSLE) was used to determine the total sediment load to the pond. The DEPOSITS model computes the inflow sedimentgraph (time vs sediment concentration) by making the inflow sediment concentration proportional to the square of the incremental water inflow volume. This method was compared to a more sophisticated approach developed by Williams which used an instantaneous unit sedimentgraph applied to an optimized unit hydrograph to predict sediment concentrations.[14] When Williams hydrograph and sediment yield data were evaluated using DEPOSITS sedimentgraph analysis, the result was found to closely approximate the measured data and Williams simulation if the sediment load is lagged two time increments before the hydrograph values. This showed that the DEPOSITS analysis can give a good approximation of sediment inflow concentration with an optimized hydrograph and sediment load. The lag time of sediment load to hydrograph is site-specific, therefore, no lag was used in the study's simulation because site-specific information was not available.

A particle size distribution covering the size range of particles from coarse sand to clay particles, as depicted in Figure 4, was used and held constant for each performance simulation. This distribution assumes a more uniform concentration over a wider size range than was actually measured on grab samples taken at the six sites during moderate precipitation events because of the potential scour velocity and carrying capacity of runoff associated with more severe storm events. Ideally, one would collect site-specific data concerning particle size distribution (and the other factors discussed above). Such an undertaking would, however, require considerable resources. Moreover, particle size distribution will vary not only from one site to the next, but also at the same site under different storm conditions, and during the same storm event. The choice of a "typical" particle size distribution was arbitrary but consistent with observed values and with those in the literature. All assumptions were conservative with respect to pond performance.

A summary table of results from the computer simulations is included in the appendix. A brief description of the factors addressed in the summary table follows:

Permanent Pool Capacity

This term refers to the volume below the stage of the lowest dewatering device and is equal to the sediment storage.

Dead Storage

The volume of the permanent pool that is bypassed at the beginning of discharge from the pond. The variable DEAD may also be used to account

1) Inflow hydrograph,
2) Viscosity of the storm water,
3) Stage-area curve for the basin,
4) Stage-discharge curve for the basin,
5) Stage-discharge distribution curve,
6) Degree of dead storage or short circuiting,
7) Sediment inflow graph or total load,
8) Particle size distribution and specific gravity of the suspended sediment.

The inflow hydrograph to each sediment pond for each of the three storms evaluated was generated by using the WASH hydrograph model. The viscosity of the water used in the evaluation was .012 cm^2 /sec at 56°F. This value represents viscosity at a typical winter temperature. The stage area curve for each sediment basin location, A and B, was determined from a topographic map. The stage discharge curve for each basin modelled was based upon four objectives:

1) provide 0.1 acre foot of sediment storage for each acre of disturbed area in the watershed (in accordance with OSM minimum requirements),

2) provide a system of constant discharge rate with surface withdrawal from the elevation of the permanent pool to the crest of the principal spillway through the use of a floating weir or similar device,

3) provide a minimum theoretical detention time of 24 hours for the runoff from a 10-year 24-hour storm event (in accordance with OSM requirements), and

4) provide a detention time in excess of 24 hours for the runoff from a 10-year 24-hour storm event to determine the effect of longer detention times on peak effluent suspended solids.

Complete surface withdrawal was used in the pond modelling for the stage-discharge-distribution curve. For the evaluation of the sediment ponds in question, it was assumed that each pond had no dead storage (volume of pond not used for sediment removal) and did not exhibit short circuiting (flowing directly from inlet to outlet). Thus, the results represent the pond's performance at its peak sediment removal efficiency.

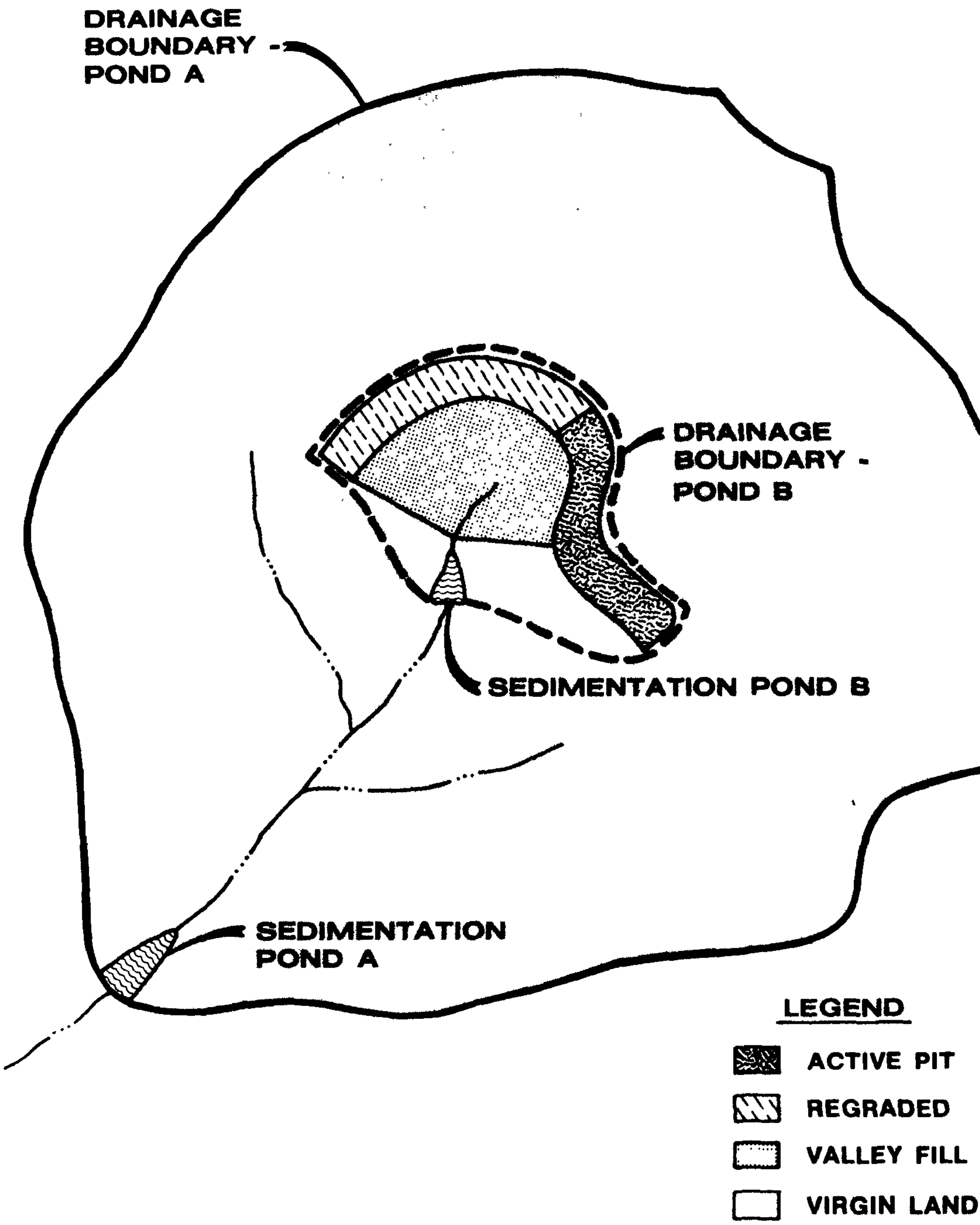

Figure 3. Generalized map of mine sites.

(Figure 3). For all sites, the design storm duration in each case was 24 hours. The design storm rainfall was 2.25 inches for the 2-year storm, 3.4 inches for the 5-year storm, and 4.0 inches for the 10-year storm event. A composite (CN) curve number was computed for each drainage area based upon the acreage of active pit, regraded area, valley fill, and virgin land within the watershed. The composite curve numbers for the watersheds of each sediment pond are listed in Table 5.

Table 5. WATERSHED COMPOSITE CURVE NUMBERS

Mine site	Sediment pond location	
	A	B
PA-1		78
WV-1A	60	78
WV-2A	58	78
WV-3A	67	78
WV-4A	56	77
KY-1A	63	78

The WASH computer program generates the storm hydrograph, the volume of runoff, and the peak runoff rate for the watershed under study. These results are then used in the computer model to determine sediment pond performance.

SEDIMENTATION POND PERFORMANCE MODEL

To evaluate the performance of the sediment ponds under various conditions, this study used the "DEPOSITS" model. DEPOSITS describes the sediment transport and deposition process in a reservoir as a function of the basin geometry, inflow hydrograph, the inflow sedimentgraph, the sediment characteristics, the outlet spillway design, and the hydraulic behavior of the flow within basin. The DEPOSITS model has been evaluated on data from eleven different ponds and reservoirs and explained over 90% of the variation in trap efficiency of these basins. It is considered to be a state of the art model for estimating sediment pond trap efficiency (percentage of sediment in inflow to the pond which was settled out of solution in the pond) and effluent quality.

In the modelling of the flow within the basin, the DEPOSITS model uses a plug flow concept. Plug flow assumes no mixing between plugs and routes the flow on a first-in first-out basis. Settling of the sediment within the basin is calculated by Stoke's Law of Settling and particles are considered trapped when they reach the bed of the reservoir. The model subdivides each plug into four layers to account for the variation in sediment concentration with depth. The DEPOSITS model requires the following information regarding sediment and flow characteristics and the physical characteristics of the pond:

$Y = 95 \, (VQp)^{.56} \, K \, (LSC) \, P$

Y	- sediment load (tons)
$(VQp)^{.56}$	- runoff energy factor, see Table 1 for V, volume (acre-feet) and Qp, peak runoff rate (cfs)
K	- soil erodibility (0.28 for PA-1, 0.3 for all other sizes)
LSC	- composite length - steepness - cover-management factor, see Table 3 for LS values and Table 4 for C values
P	- support practice (1.0)

* Maximum tons/acre of 16.9 equivalent to 0.056 inches of soil loss over entire watershed.

STORM HYDROGRAPH COMPUTATION

The inflow hydrographs for the 2-year, 5-year, and 10-year 24-hour storm events were determined using the Watershed Storm Hydrograph (WASH) model as developed by the University of Kentucky, Department of Agricultural Engineering.[12] The WASH model is based upon the procedures for developing runoff rates and volumes currently used by the SCS for small watersheds, which are generally adequate for surface mined areas. In order to verify the WASH hydrograph model, each watershed hydrograph was also calculated using a computer model entitled the Penn State Urban Runoff Model.[13] For each hydrograph generated, a correlation between peak flows generated by the two models was within ten percent. For use of the WASH model in hydrograph generation, the following watershed parameters need to be determined:

1) The watershed drainage area in acres,
2) The average watershed slope,
3) The watershed flow length in feet,
4) The design storm duration in hours,
5) The design storm rainfall in inches, and
6) The composite curve number for the watershed (CN value).

For each of the eleven sediment ponds modelled, the watershed drainage area, average watershed slope, and flow length were determined from a USGS quadrangle map of the area. For location A, it was assumed the entire drainage area above the pond contributed to pond inflow. For location B, it was assumed that diversion ditches were constructed above the disturbed area to limit the contributing drainage area to the active mining area, regraded area, valley fill, and virgin land adjacent to the pond

Sediment Yield Application

A standard procedure was used in this analysis for estimating sediment yields from each site for the 2-year, 5-year, and 10-year recurrence interval storms. The procedure used the following steps:

1) Compute the runoff volume and peak rate of runoff from the watershed during the 2, 5 and 10-year storm events.

2) Compute or assume a soil erodibility (K).

3) Determine LS values for each land cover at the site.

4) Multiply the LS values by the designated C factors to compute a LSC for each land cover.

5) Weight the LSC values based on the percent of watershed area of each land cover to compute a composite LSC for the watershed.

6) Compute the sediment yield in tons using the modified USLE.

The results of this analysis are summarized in Table 4.

Sediment load for WV-4 (B) pond site resulted from the highest calculated soil loss. The 16.9 tons of sediment per acre during the 10 year event equates to a loss of 56 thousandths of an inch of soil from the entire watershed. Although this is a small volume, it can cause very high suspended solids concentrations in the receiving stream, as will be shown later when the results of the DEPOSITS model are presented.

TABLE 4 - SUMMARY OF SEDIMENT LOADS USING MODIFIED USLE

Area	Composite LSC	Sediment load (tons) 2-Year	5-Year	10-Year
PA-1	0.26	50	124	170
KY-1(A)	0.12	3	14	22
KY-1(B)	0.31	28	71	97
WV-1(A)	0.13	32	180	294
WV-1(B)	0.52	253	520	861
WV-1(C)	0.28	81	194	260
WV-2(A)	0.05	8	50	85
WV-2(B)	0.31	89	223	308
WV-3(A)	0.24	59	202	306
WV-3(B)	0.45	158	392	539
WV-4(A)	0.10	11	94	167
WV-4(B)	0.74	105	270	372*

Cover and Management

The cover and management factor (C) in the USLE is the ratio of soil loss from land under specific conditions to the corresponding loss from clean-tilled, continuous fallow. The factor measures the combined effect of all the interrelated cover and management variables.

A large number of C values are presented in Agriculture Handbook No. 537,[11] and one must select the situation that most closely fits field conditions. This study utilizes a C factor for each of the four cover types, and the same values are used at all pond site locations for each cover type.

Virgin lands were assumed to be undisturbed forest land with 70 percent of the area covered by canopy and 85 percent covered by duff (leaves, branches, and other organic matter covering the forest floor) at least 2 inches deep (C=0.002). The active pit area was considered to be construction slopes with no mulch cover, which would yield a C of 1.0. The area was, however, also assumed to be 30-percent impervious nonerodible rock so a C=0.7 was used. Valley fill areas were also assumed to be equivalent to construction sites using straw mulch at 1.0 tons per acre (C=0.20). Regraded areas were assumed to be partially revegetated with no appreciable canopy but with approximately 50-percent cover (C=0.10). The following table summarizes the C factors assumed for each land cover type at each of the mine site locations.

TABLE 3 - COVER AND MANAGEMENT FACTORS (C) FOR EACH LAND COVER TYPE

Land cover	C
Virgin land	0.002
Active pit	0.7
Valley fill	0.20
Regraded area	0.10

Support Practice

The support practice factor (P) in the USLE is used to show the effects of specific soil loss prevention practices. These support practices, which are generally used in agricultural applications, include contouring, contour listing, contour strip-cropping, and controlled row ridge planting. Since they are not practiced in mine development and reclamation, a P value of 1.0 was assumed for this analysis.

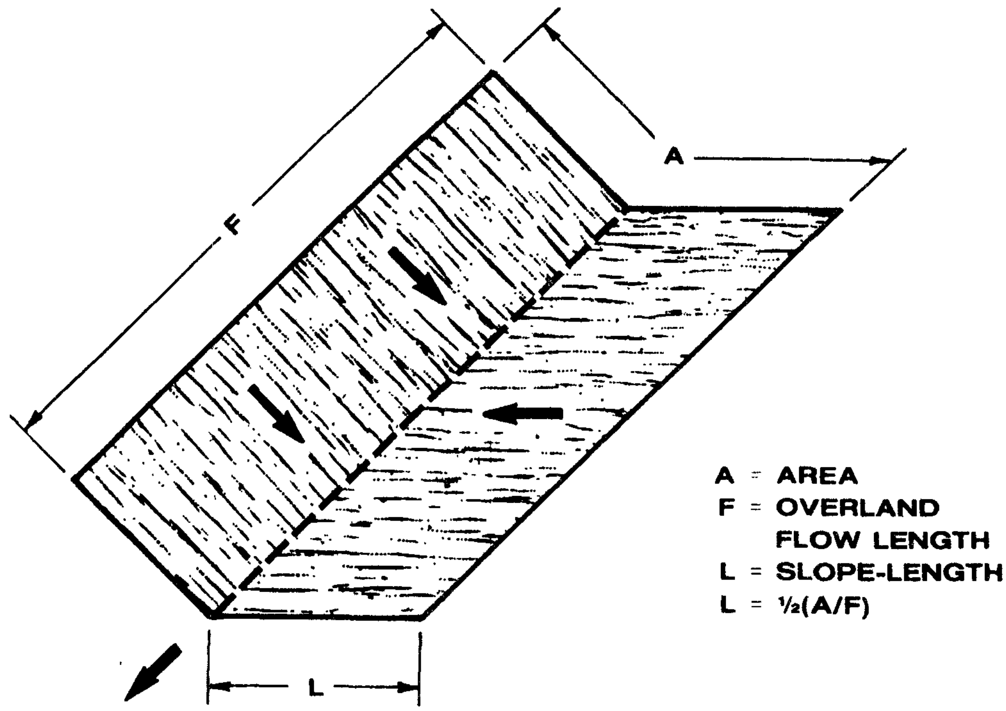

Figure 2. Determination of slope-length for modified USLE.

Once these values are derived, the LS factor can be determined for each area according to the SCS graph. Table 2 summarizes the LS values computed for each site.

TABLE 2 - SUMMARY OF TOPOGRAPHIC FACTOR (LS) FOR MODIFIED USLE

	LS			
Area	Virgin land	Active pit	Regraded	Valley fill
PA-1	-	0.57	1.9	-
KY-1(A)	5.5	0.64	4.6	1.4
KY-1(B)	4.6	0.64	4.6	1.4
WV-1(A)	13.0	0.57	7.5	2.3
WV-1(B)	5.7	0.57	7.5	2.3
WV-1(C)	5.7	0.57	7.5	2.3
WV-2(A)	6.5	0.50	2.6	2.1
WV-2(B)	1.5	0.50	2.6	2.1
WV-3(A)	5.7	0.53	5.0	2.6
WV-3(B)	5.7	0.53	5.0	2.6
WV-4(A)	28.0	0.57	10.0	-
WV-4(B)	28.0	0.57	10.0	-

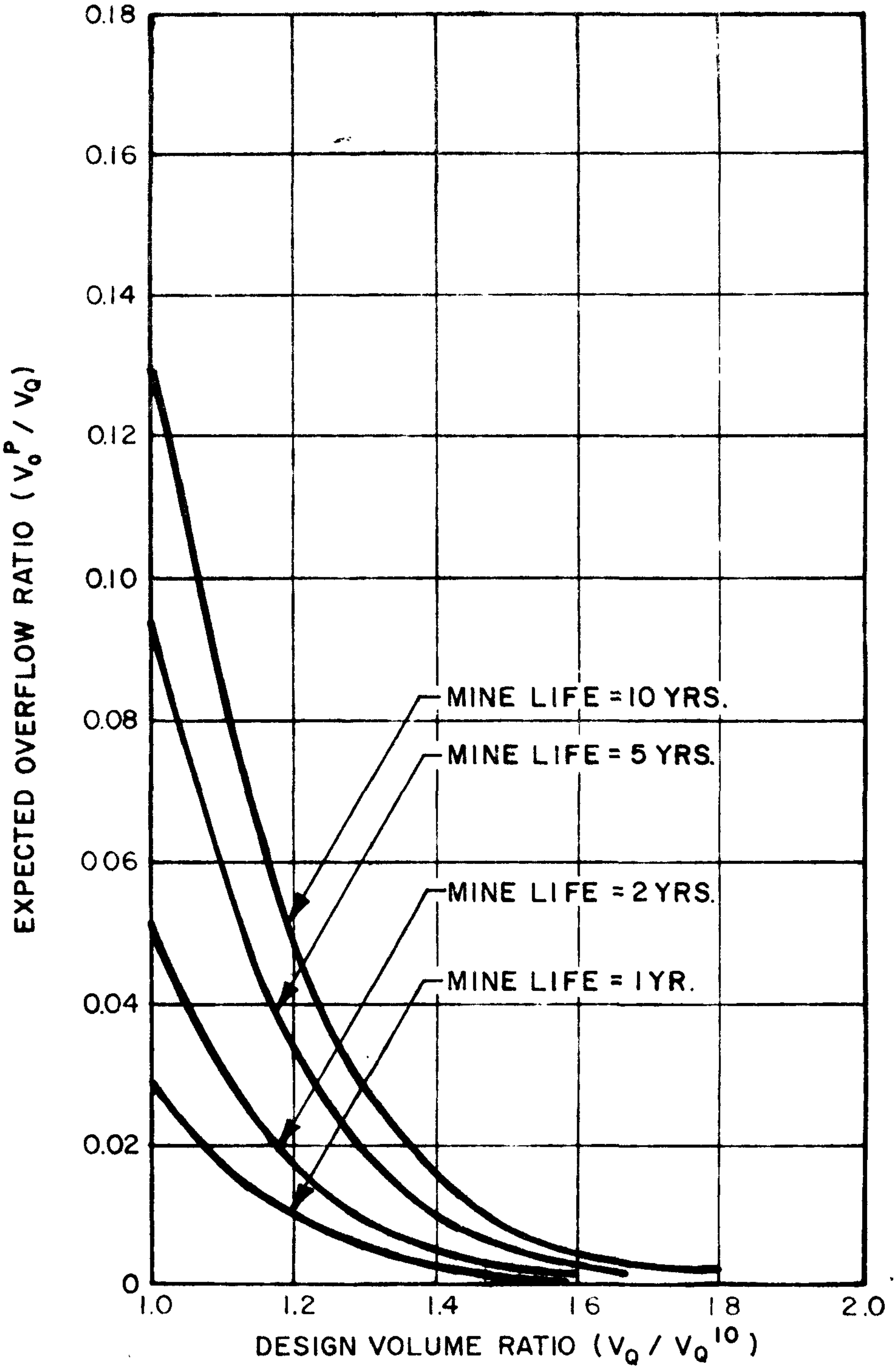

FIGURE 5

MINE 3

EXPECTED OVERFLOW
VS.
DESIGN VOLUME

PREPARED FOR

U.S DEPARTMENT OF THE INTERIOR
OFFICE OF SURFACE MINING

D'APPOLONIA

NOTES:

1. V_Q = DESIGN VOLUME OF POND FOR MULTIPLE EVENTS.
2. V_Q^{10} = DESIGN VOLUME FOR 10-YEAR STORM.
3. COST RATIO = DESIGN VOLUME RATIO.

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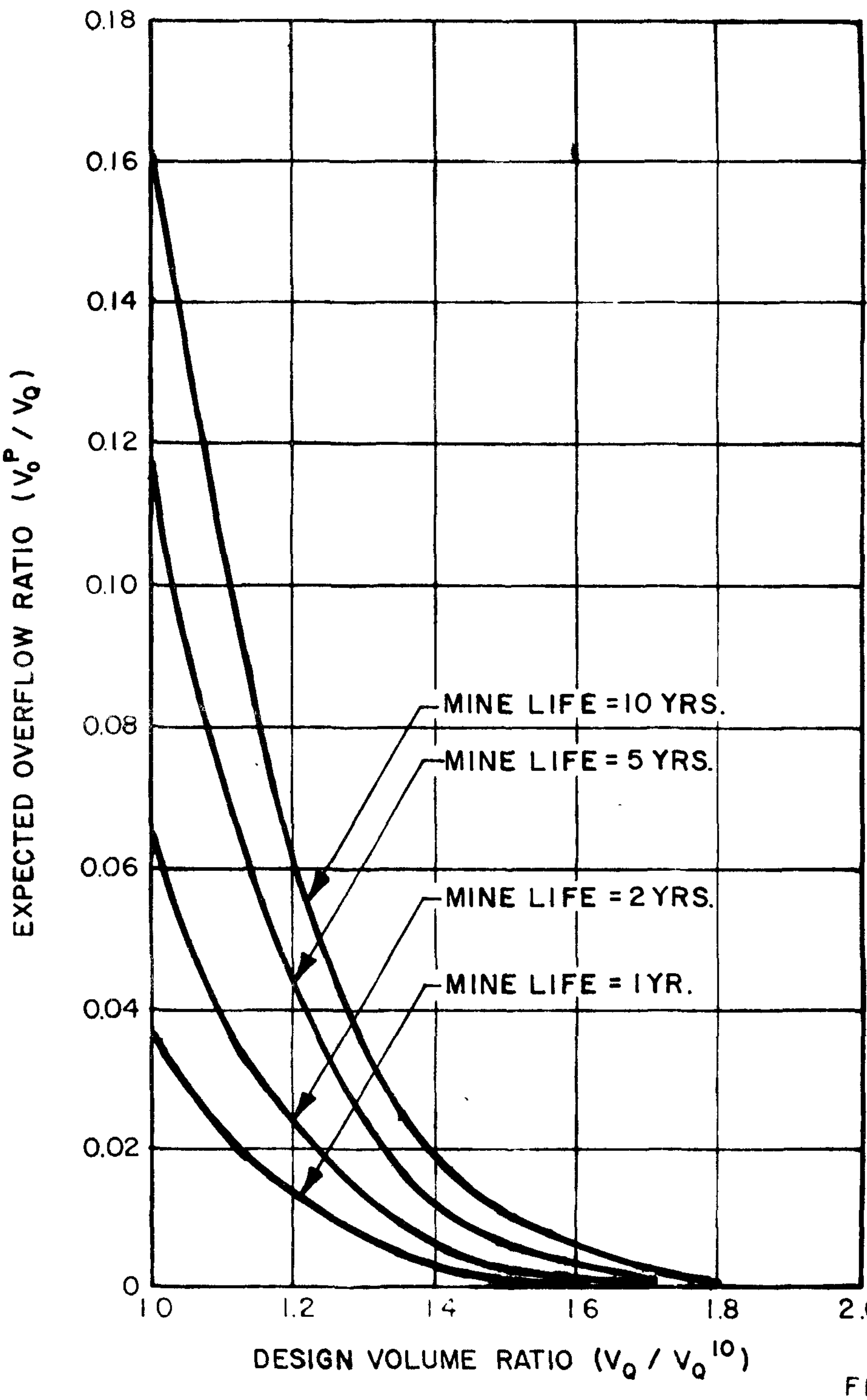

FIGURE 4

MINES 1 AND 2

EXPECTED OVERFLOW VS. DESIGN VOLUME

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NOTES:

1. V_Q = DESIGN VOLUME OF POND FOR MULTIPLE EVENTS.
2. V_Q^{10} = DESIGN VOLUME FOR 10-YEAR STORM.
3. COST RATIO = DESIGN VOLUME RATIO.

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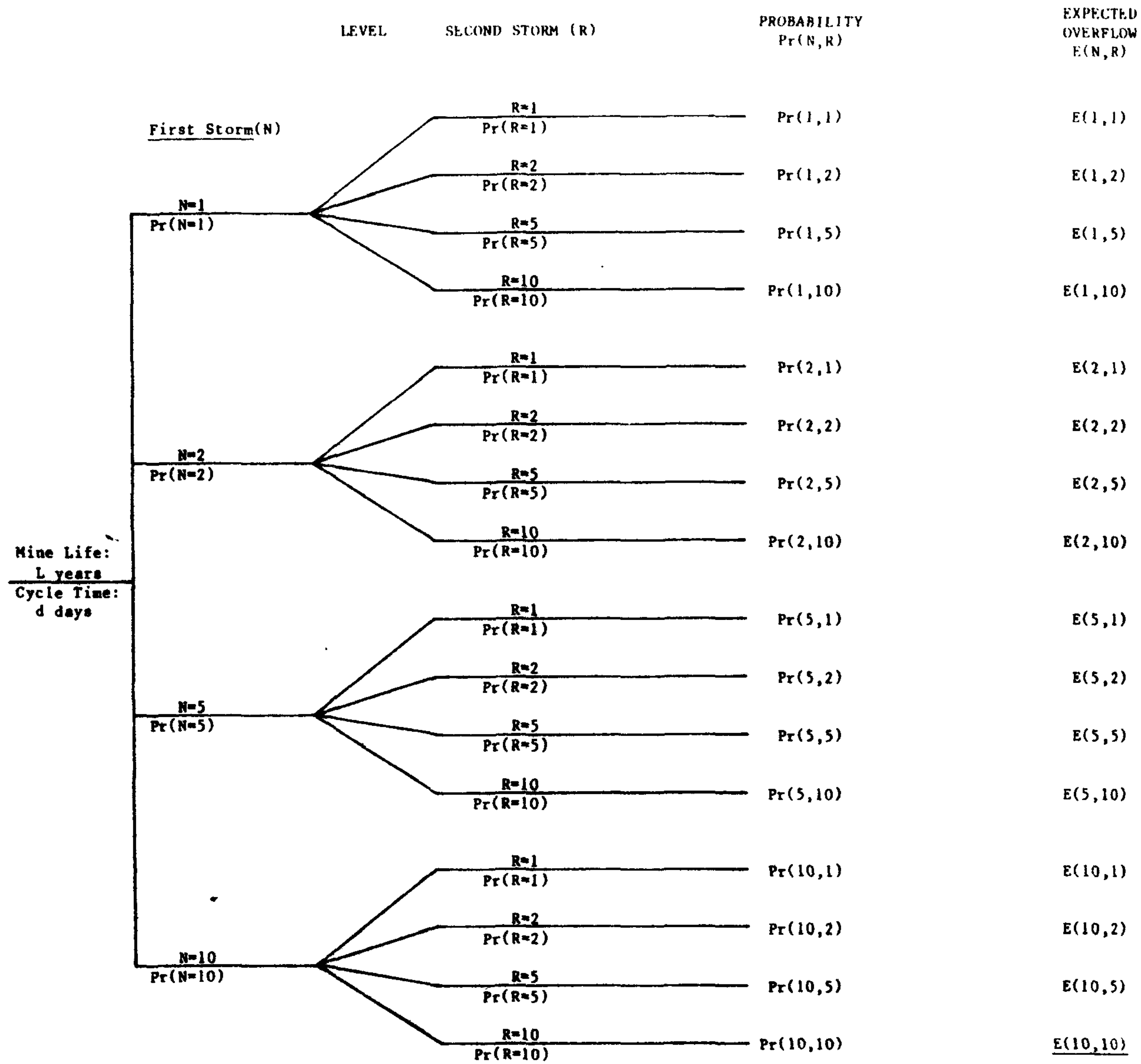

E_{max} (L,d) = Σ E(N,R)

Pr(N,R) = Probability of a N-YR storm followed by a R-YR storm with mine Life L years and cycle time d days = Pr(N) Pr(R)

E(N,R) = Expected overflow due to occurrence of a N-YR storm followed by a R-YR storm within cycle time of d days and mine Life of L years = $Pr(N,R)[R_N + R_R - V_Q]$

R_N = Run-off volume of the first storm having a return period of N-Years

R_R = Run-off volume of the second storm having a return period of R-Years

V_Q = Volume of storage pond

E_{max} (L,d) = Maximum expected overflow for a pond of capacity V_Q, mine Life of L Years and cycle time of d days

FIGURE 38

DECISION TREE CONCEPT USED TO DERIVE MAXIMUM EXPECTED OVERFLOW

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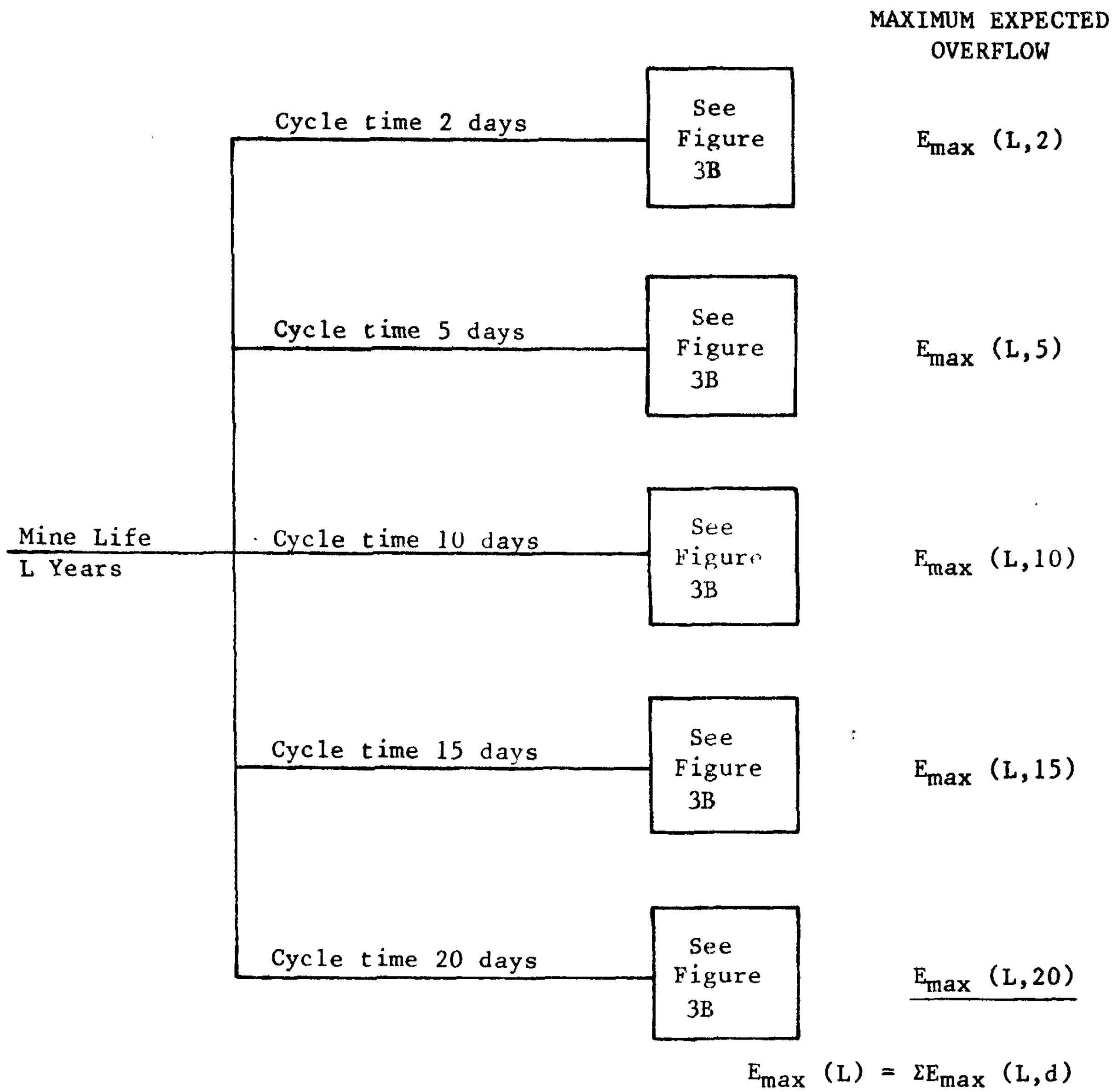

E_{max} (L,d) = Maximum expected overflow for a pond of capacity V_Q, mine life L years and cycle time of d days.

E_{max} (L) = Maximum expected overflow for a pond of capacity V_Q and mine life L years.

FIGURE 3A

DECISION TREE CONCEPT USED TO DERIVE MAXIMUM EXPECTED OVERFLOW

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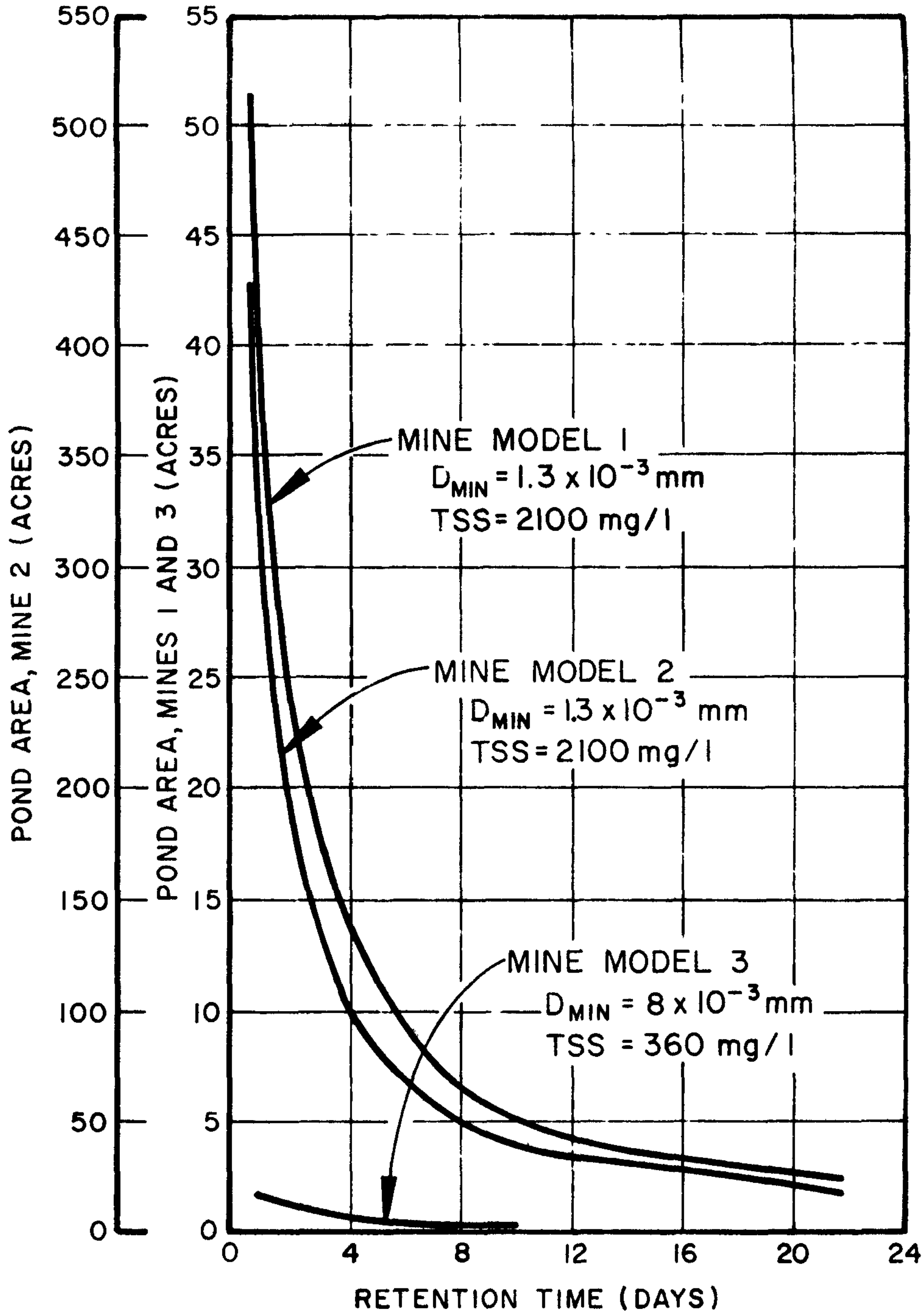

NOTE:

D_{MIN} = MINIMUM PARTICLE SIZE TO BE REMOVED TO OBTAIN 35 mg/l TSS IN EFFLUENT FOR IDEAL CONDITIONS.

FIGURE 2

MINES 1, 2, & 3

THEORETICAL AREA REQUIREMENTS FOR RUN-OFF RETENTION OF A 10-YEAR STORM

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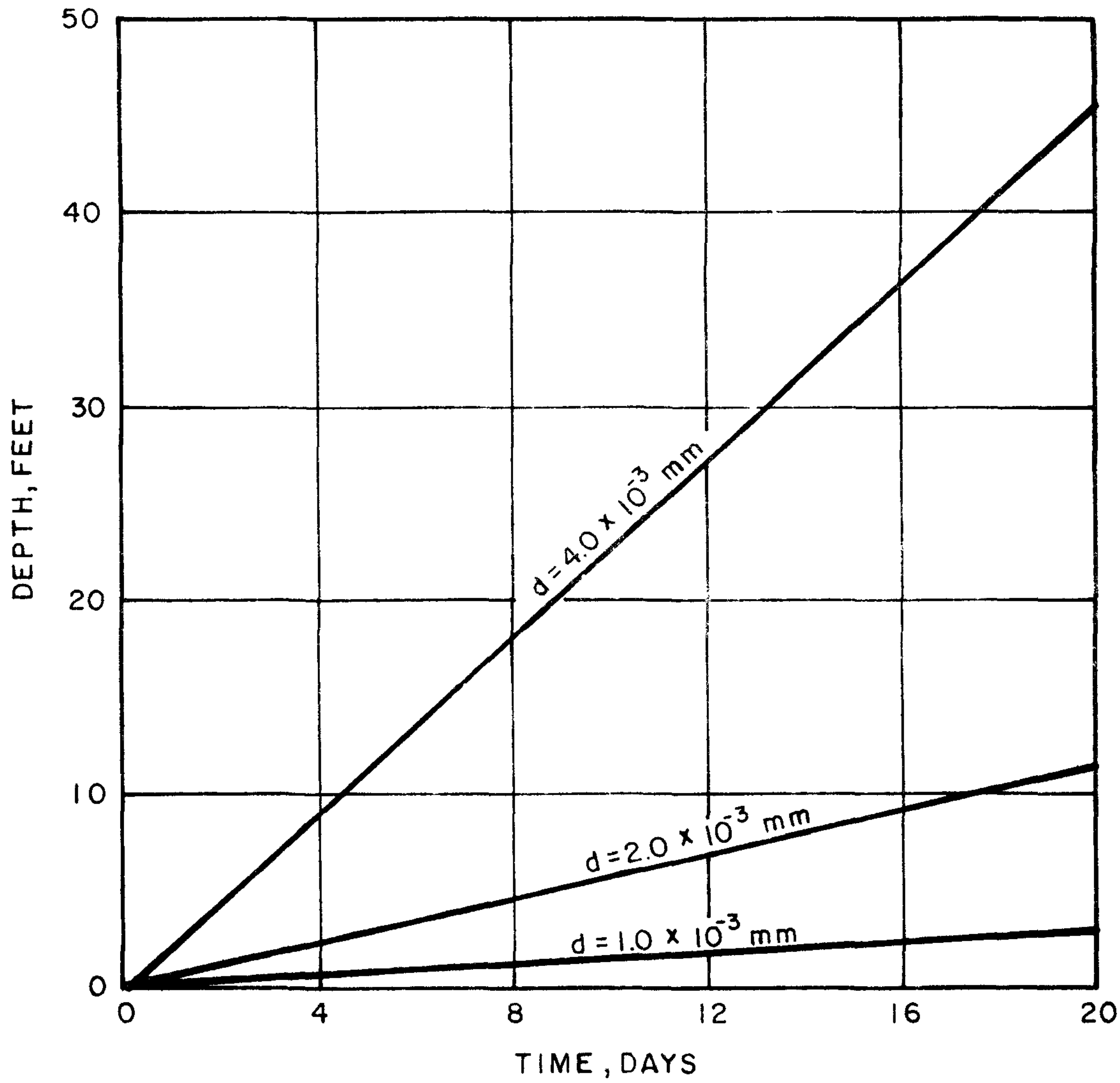

d = DIAMETER OF PARTICLE

FIGURE I

DEPTH OF FALL OF PARTICLES THROUGH WATER VERSUS TIME

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FIGURES

TABLE 2
(Continued)

Mine Life	Return Period of First Storm N-years	Return Period of Second Storm R-years	Pr (N, R) for cycle time = 2 days	Pr (N, R) for cycle time = 10 days
5	1	1	0.541×10^{-2}	0.265×10^{-1}
		2	0.271×10^{-2}	0.134×10^{-1}
		5	0.109×10^{-2}	0.541×10^{-2}
		10	0.544×10^{-3}	0.271×10^{-2}
	2	1	0.500×10^{-2}	0.245×10^{-1}
		2	0.251×10^{-2}	0.124×10^{-1}
		5	0.100×10^{-2}	0.500×10^{-2}
		10	0.503×10^{-3}	0.251×10^{-2}
	5	1	0.344×10^{-2}	0.169×10^{-1}
		2	0.173×10^{-2}	0.854×10^{-2}
		5	0.692×10^{-3}	0.344×10^{-2}
		10	0.346×10^{-3}	0.173×10^{-2}
	10 (0.393)*	1	0.214×10^{-2}	0.105×10^{-1}
		2	0.108×10^{-2}	0.532×10^{-2}
		5	0.431×10^{-3}	0.214×10^{-2}
		10	0.215×10^{-3}	0.108×10^{-2}
10	1	1	0.545×10^{-2}	0.267×10^{-1}
		2	0.273×10^{-2}	0.135×10^{-1}
		5	0.109×10^{-2}	0.545×10^{-2}
		10	0.548×10^{-3}	0.273×10^{-2}
	2	1	0.541×10^{-2}	0.265×10^{-1}
		2	0.271×10^{-2}	0.134×10^{-1}
		5	0.109×10^{-2}	0.541×10^{-2}
		10	0.544×10^{-3}	0.271×10^{-2}
	5	1	0.471×10^{-2}	0.230×10^{-1}
		2	0.236×10^{-2}	0.117×10^{-1}
		5	0.947×10^{-3}	0.471×10^{-2}
		10	0.474×10^{-3}	0.236×10^{-2}
	10 (0.632)*	1	0.344×10^{-2}	0.169×10^{-1}
		2	0.173×10^{-2}	0.854×10^{-2}
		5	0.692×10^{-3}	0.344×10^{-2}
		10	0.346×10^{-3}	0.173×10^{-2}

TABLE 2

Combined Probabilities, Pr (N, R), of Two Storms Occurring Within a Given Cycle Time and Mine Life

Mine Life	Return Period of First Storm N-years	Return Period of Second Storm R-years	Pr (N, R) for cycle time = 2 days	Pr (N, R) for cycle time = 10 days
1	1	1	0.344×10^{-2}	0.169×10^{-1}
		2	0.173×10^{-2}	0.854×10^{-2}
		5	0.692×10^{-3}	0.344×10^{-2}
		10	0.346×10^{-3}	0.173×10^{-2}
	2	1	0.214×10^{-2}	0.105×10^{-1}
		2	0.108×10^{-2}	0.532×10^{-2}
		5	0.431×10^{-3}	0.214×10^{-2}
		10	0.215×10^{-3}	0.108×10^{-2}
	5	1	0.988×10^{-3}	0.483×10^{-2}
		2	0.495×10^{-3}	0.245×10^{-2}
		5	0.198×10^{-3}	0.988×10^{-3}
		10	0.993×10^{-4}	0.495×10^{-3}
	10 (0.095)*	1	0.519×10^{-3}	0.254×10^{-2}
		2	0.260×10^{-3}	0.129×10^{-2}
		5	0.104×10^{-3}	0.519×10^{-3}
		10	0.521×10^{-4}	0.260×10^{-3}
2	1	1	0.471×10^{-2}	0.230×10^{-1}
		2	0.236×10^{-2}	0.117×10^{-1}
		5	0.947×10^{-3}	0.471×10^{-2}
		10	0.474×10^{-3}	0.236×10^{-2}
	2	1	0.344×10^{-2}	0.169×10^{-1}
		2	0.173×10^{-2}	0.854×10^{-2}
		5	0.692×10^{-3}	0.344×10^{-2}
		10	0.346×10^{-3}	0.173×10^{-2}
	5	1	0.180×10^{-2}	0.879×10^{-2}
		2	0.901×10^{-3}	0.445×10^{-2}
		5	0.361×10^{-3}	0.180×10^{-2}
		10	0.181×10^{-3}	0.901×10^{-3}
	10 (0.191)*	1	0.988×10^{-3}	0.483×10^{-2}
		2	0.495×10^{-3}	0.245×10^{-2}
		5	0.198×10^{-3}	0.988×10^{-3}
		10	0.993×10^{-4}	0.495×10^{-3}

* Numbers in parentheses are the probability of having a 10-year, 24-hour storm within the mine life.

TABLE 1

DESIGN PARAMETERS OF THE
THREE REPRESENTATIVE SURFACE MINES

Design Parameters		Mine #1	Mine #2	Mine #3
Effective Drainage Area (acres)(1)		80	650	80
Disturbed Area (acres)		20	425	40
10-YR, 24-HR	Precipitation (inches)	4.3	4.3	3.8
	Run-off (inches)	1.904	1.904	1.528
5-YR, 24-HR	Precipitation (inches)	3.8	3.8	3.3
	Run-off (inches)	1.528	1.528	1.173
2-YR, 24-HR	Precipitation (inches)	2.9	2.9	2.55
	Run-off (inches)	0.898	0.898	0.681
1-YR, 24-HR	Precipitation (inches)	2.6	2.6	2.15
	Run-off (inches)	0.712	0.712	0.461
TSS in Runoff (mg/ℓ)		2100	2100	360
Percentage Passing for 70 mg/ℓ		3.3	3.3	20
Minimum Particle Size (mm)		1.3×10^{-3}	1.3×10^{-3}	8×10^{-3}

(1) Effective drainage area accounts for runoff which is diverted and not allowed to enter the sedimentation pond.

TABLES

- **The probability of a multiple storm event is significantly less than the probability of having a 10-year, 24-hour storm.**

Very truly yours,

Satyananda Chakrabarti

Donald E. Shaw

SC/DES:asm
Enclosures

the larger pond, the same depth would have to be maintained. Thus, the areas shown on Figure 2 as a function of retention time for treating the 10-year storm would have to be increased by 30 to 40 percent. Site-specific considerations may render it impossible to provide such additional area if the pond to hold the 10-year storm has been designed for maximum available area.

Conclusions

Based on the assumption that runoff from multiple storm events can be treated by sedimentation alone, the following conclusions have been reached:

- It is impossible to design a pond which guarantees that there is no possibility that its capacity will be exceeded by some storm scenario. When overflow occurs from a multiple storm event which leads to greater runoff than for the 10-year storm, the effluent limitations will not be met. While some mixing will occur which would tend to reduce the TSS from the influent TSS, it is doubtful that such a reduction would ever be sufficient to meet the effluent limitations for the overflow. The amount of overflow is determined by the total precipitation and is not equal to the expected overflow but is proportional to expected overflow.

- Increasing pond size to retain runoff from multiple storm events obeys a law of diminishing returns. As the pond size increases in order to reduce the expected overflow, large incremental cost increases are anticipated for decreasing increments of protection. Figures 4 and 5 may be used to judge the point at which cost increases compared with decreased overflows became excessive. This would appear to be in the range of an additional 30 to 40 percent capacity.

- Without regulations which recognize the probability of extreme events in terms of numerical values, there is no event for which the probability is zero so that a penalty would always be levied for multiple storm events even if a 10-year storm does not occur. This makes interpretation of a design criteria difficult or impractical.

"Probability of Occurrence	Points
None	0
Insignificant	1-4
Unlikely	5-9
Likely	10-14
Occurred	15"

This appears to state that the larger the storm event for which a pond is designed such that the probability of the event is considered, the lesser the penalty in case of a violation. However, because no probability values are given and there is no event with a probability of zero, there will always be a penalty if a pond capacity is exceeded. This makes it difficult to decide on a design criteria in view of probabilities calculated above. This is important because Figures 4 and 5 show that the incremental cost for additional capacity becomes very large compared with incremental benefits as measured by the decreased expected overflow once the pond reaches a certain size. In other words, the cost/benefit ratio increases greatly as the design is based on events with smaller and smaller probabilities.

Because there is always a probability of having a pond overflow from multiple storm events and the total suspended solids in the overflow will not meet the effluent limitations, there is no basis for selecting a pond size which, even theoretically, will treat all runoff from every possible single or multiple storm event. For the case of single storm events, this fact has been recognized in the regulations by the release from the effluent limitations if a 10-year, 24-hour storm or greater occurs. However, for the case of multiple storms leading to overflow from the second storm before the required retention time is complete for the first storm, there is no release from the effluent limitations.

On a practical basis, an operator is faced with deciding how large a sedimentation pond should be, recognizing that no matter how large he makes it, he must always accept a risk of exceeding the capacity due to multiple storm events even though that risk is small and becomes smaller as the pond capacity increases. If a risk-benefit approach is used to select pond capacity, Figures 4 and 5 can provide guidance. For a 20 percent increase in capacity ($V_Q/V_Q^{10} = 1.2$), there is a significant reduction in risk of overflow. From a 20 percent increase to a 40 percent increase, there is a lesser but still significant reduction in risk of overflow. Beyond a 40 percent increase, the risk reduction diminishes greatly from the same incremental costs. On the basis of Figures 4 and 5, it would appear that the optimum risk-benefit decision would be to increase pond capacity about 30 to 40 percent.

Based on optimizing the risk-benefit, the increased costs for designing for a multiple storm event are approximately 30 to 40 percent higher than the costs for a pond designed to meet existing regulations for the 10-year, 24-hour storm. To maintain the same treatment cycle time for

R_N = Runoff volume of the storm having return period of N-years;

R_R = Runoff volume of the storm having return period of R-years; and

V_Q = Storage capacity of the pond.

Typical values of Pr (N, R) are given in Table 2 for mine lives of 1, 2, 5, and 10 years for 2-day and 10-day cycle times. The probability of having a 10-year storm within the life of the mine is also shown in Table 2 for comparison. The results indicate that the probability of a multiple storm event is always lower than a single 10-year storm event during the mine life.

Figures 3A and 3B show the decision tree which was constructed for all possible combinations of storms considered in the analysis for a given cycle time. The maximum expectation of the overflow for a given cycle time is obtained by summing the respective expected overflows for all possible storm combinations.

The process was repeated for all cycle times considered in the analysis, i.e., 2-, 5-, 10-, 15- and 20-day cycles. The maximum expectation of overflow for all cycle times was then obtained by summing respective maximum expected overflows for each specified cycle time.

The analysis was then repeated for increased storage capacities (V_Q) of the pond and the maximum expected overflow (V_oP) for all cycle times was evaluated. The results of these analyses were then normalized by dividing the maximum expected overflow (V_oP) by the storage capacity (V_Q) and by dividing the storage capacity (V_Q) by the storage capacity (V_Q^{10}) required to store one 10-year storm. The variation of (V_oP/V_Q) and (V_Q/V_Q^{10}) is shown in Figure 4 for Mines 1 and 2 and in Figure 5 for Mine 3 for the four different mine lives, respectively.

Figures 4 and 5 show that the probability of an overflow never goes to zero regardless of how large the pond may be. This results from the fact that there is always a probability, however small, of a multiple storm scenario which would exceed the capacity of any pond. Thus, it is impossible to design a pond which absolutely guarantees that the capacity will never be exceeded. While the wording is unclear, it appears that Paragraph 845.13 of the OSM regulations does recognize this fact in that penalty points for violations are assigned based on a qualitative assessment of probabilities of event occurrence. Specifically, Paragraph 845.13 states:

> "The office shall assign up to 15 points based on the probability of the occurrence of the event which a violated standard is designed to prevent. Points shall be assessed according to the following schedule:

of all combinations of the storm events considered and evaluating the potential overflow for varying pond sizes which are greater than that required to hold the 10-year storm. Using this technique, the utility of a given decision and possible outcomes was taken to be the expected value of overflow for a given pond size. Expected value from any given event is defined as the quantity of overflow times the probability of the overflow occurring. It is noted that expected overflow is a measure of utility for decision making and has no physical significance once any particular event occurs. Summed over all possible outcomes, the expected overflow represents the most probable amount of overflow. The physical significance of additional pond capacity is designated by the ratio of the total design volume to the 10-year-storm volume where this ratio is always greater than or equal to 1.0.

For estimating the increased costs associated with large pond sizes, the methods used for the OSM cost impact study for the Regulatory Analysis were followed. In the absence of site-specific information relative to topography and general mine layout, the cost estimate was found to be essentially directly proportional to volume. Site-specific consideration could, of course, lead to significant variations compared with this methodology on a case-by-case basis. Because the costs are essentially directly proportional to pond capacity, the ratio of total design volume to the 10-year-storm volume is also the ratio of cost for the larger volume compared to cost for the pond designed to hold the 10-year storm. This is true whether the increased pond capacity is provided as a single larger pond or as two separate ponds. Consequently, the determination of expected overflow as a function of increased pond size is also a measure of the cost effectiveness of providing additional pond capacity for multiple storm events.

Knowing the combined probability, the expected overflow for any combination of two storms is given by:

$$E\ (N,\ R) = Pr\ (N,\ R) * (R_N + R_R - V_Q)$$

where

E (N, R) = Expected overflow due to two storms having return periods N- and R-years, respectively, occurring within a specified cycle time and mine life;

Pr (N, R) = Combined probability of occurrence of two storms within a given cycle time and mine life having return periods N- and R-years, respectively;

This retained generality of the probabilistic analysis because the incorporation of a range of cycle times avoids the need to have site-specific data on the available pond area which affects the cycle time.

To evaluate the probabilities of multiple storm occurrences, it was assumed that the occurrence of a storm having a return period equal to N-years within a given time period of L-years is governed by the Poisson's probability distribution given by:

$$Pr(n) = \frac{e^{-\lambda L} \; (\lambda L)^{n}}{n!}$$

where

$$\lambda = \frac{1}{N}$$

n = number of occurrences of the storm event.

The encounter probability of any such storm during a specified mine life can then be calculated following a procedure as outlined by Borgman.[1] Similarly, the probability of such storms occurring within a given cycle time can also be calculated. The combined probability of these two storm events occurring within a given cycle period can then be calculated using the laws of probability.

For the probabilistic analysis it was assumed that the combined probability for two storms could be determined from the joint probabilities of two independent events. There is reason to believe that two storms are not independent such that the probability of a second storm within a period of N-days from the first would require a conditional probability based on the first storm occurring. A Markov process could be used to approximate such a probability, but sufficient data are not available on conditional probabilities to render the results meaningful. The approach used for determining combined probabilities in this study is believed to overestimate the joint probability because the probability of the second storm occurring within N-days was computed for any N-day period and not necessarily for the exact N-day period following the first storm. This probability will be larger than for a second storm occurring within exactly N-days of the first storm.

Because additional volume requirements affect costs and also determine the amount of overflow (volume in excess of pond capacity) and there are numerous possible combinations of storm events, a decision theory approach was used to perform a risk-benefit analysis of any additional volume requirements. This approach is based on forming a decision tree

---

[1] Borgman, L. E., August 1963, "Risk Criteria," ASCE, WW 3.

and neglecting the effects of the time of inflow and outflow requirements. Site-specific conditions of topography, mining operations, pond location and geometry, influent rate and location and discharge rate must all be considered in an actual situation to judge the ability to meet given influent limitation by sedimentation alone. Also, detailed fluid dynamic considerations relative to mixing and induced turbulence will affect the theoretical efficiency of a sedimentation pond. Rigorous treatment of all of these parameters are beyond the scope of this study. Thus, the area requirements shown in Figure 2 may be considered as the minimum requirements for the respective sites.

If the volume of runoff from a multiple storm event leads to additional pond volume, it has been assumed that the additional volume would be provided in a second pond so that influx from the second storm would not mix with it until at least some time has been allowed for sedimentation of the additional water to minimize the effect of mixing on sedimentation that had already taken place in the basic pond. Thus, any overflow of pond capacity resulting from a second storm has been assumed to occur in the second pond providing additional storage so as not to mix with water already partially treated. The effect of this assumption on costs is no different than if a single pond is used because total cost is basically proportional to total storage volume without detailed knowledge of site-specific conditions. The basic pond volume was considered to be that required to hold the 10-year, 24-hour storm in accordance with OSM regulations plus 0.1 acre-foot of sediment storage.

Multiple Storm Events

A probabilistic approach was used to evaluate the effects of a multiple storm scenario. It was decided that a maximum combination of two storms having return periods as specified below, occurring within a specified cycle time, would be considered. More storms can, of course, be postulated and may even occur. However, the probabilities of more than two storms occurring within the cycle times are sufficiently small to be considered too remote for consideration. The methods used can, however, be applied to any number of storms desired.

Four storm return periods were used in the analysis. They are:

- One-year, 24-hour storm (1-year storm),
- Two-year, 24-hour storm (2-year storm),
- Five-year, 24-hour storm (5-year storm),
- Ten-year, 24-hour storm (10-year storm).

Because the probability of occurrence of two storms within a given cycle time is also dependent on the life of the surface mining project, the mine life was used in the analysis. Four different mine lives, respectively spanning 1, 2, 5 and 10 years, were considered in the analysis.

that it does not reach either the disturbed area or the sedimentation pond. Table 1 shows the effective drainage area for each of the representative mine models used for the OSM cost impact analysis referred to previously. The maximum rainfall associated with 24-hour storms having return periods of 1, 2, 5, and 10 years are also shown in Table 1. For a multiple storm event, the total runoff is the sum of that given by each individual storm considered.

The total suspended solids (TSS) in the storm runoff in conjunction with the particle-size distribution of the TSS determines the amount of the TSS which must be removed by sedimentation to meet a given effluent limitation and the minimum particle size which must be removed. The lower the effluent limitation which must be satisfied, the greater the percentage of total suspended solids which must be removed. This percentage then determines the percent fines passing which can be used with the particle-size distribution to determine minimum particle size. In general, lower effluent limitations lead to smaller particles to be removed from suspension. Table 1 shows typical values of TSS and minimum particle size for each of the three model mines assumed in the analyses.

The retention time required to remove a given particle size from suspension is determined by the settling velocity from Stoke's Law and the depth over which sedimentation must occur. Because the settling velocity is a function of particle size and the retention time is determined by the pond area and depth for a constant volume, there is no single retention time associated with a required pond volume. This parameter may be chosen by the designer through appropriate adjustments of pond area and depth for a given minimum particle size. However, for multiple storm events, the retention time adds an additional variable in that as the retention time following an initial storm increases, the probability of having a second storm also increases. Figure 1 shows a plot of retention time versus depth for various minimum particle sizes.

For the drainage areas, total suspended solids, minimum particle sizes, and disturbed areas for each of the three model mines shown in Table 1, Figure 2 shows the variation of required area with retention time. For simplicity in this study, the parameter "cycle time" has been used where:

Cycle time = time of runoff + retention time
+ discharge time.

Thus, cycle time represents that period during which treated water is in the pond and susceptible to the influx from a second storm. The difference between retention time and cycle time is a function of the site-specific design, including influent and effluent rates, but is taken to represent the length of time required for treatment.

Figure 2, therefore, may be considered to represent the area requirements as a function of cycle time based on theoretically treating the water by retaining it for a time based on pond depth and minimum particle size pond, no consideration has been included in the regulations for the case in which a combination of lesser storms may occur such that their combined runoff would exceed the capacity of the pond. It is theoretically possible to postulate storm scenarios which would not individually equal the 10-year storm but collectively could result in greater runoff which would then require treatment to meet the effluent limitations. The objective of this evaluation was to study whether the costs to design for these scenarios would be greater than for the 10-year storm for which effluent limitations do not have to be met.

It is important to note that this study was based on the assumption that storm runoff could be treated by sedimentation to remove suspended particles. It is emphasized that this assumption does not imply that such treatment is either possible or practical on a site-specific basis. The study was directed at the potential impact of multiple storm occurrences on sedimentation pond capacities and not on specific design methods to meet effluent requirements.

Theoretical Design Basis

Runoff treatment to theoretically meet a given effluent criteria by sedimentation alone depends on the following five factors:

- Runoff volume which is determined by rainfall from a storm event,
- Total suspended solids (TSS) in the runoff which is a function of site-specific conditions including the mining operation,
- Particle size distribution of the TSS which determines the minimum particle size which must be settled out and is dependent on site-specific conditions and mining operations,
- Length of time for which runoff is stored depends upon pond area and depth that can be practically realized at a specific site and the minimum particle size to be removed to meet the effluent limitations, and
- Settling velocity which depends upon the minimum particle size that must be removed, as given by Stoke's Law.

Runoff volume is a function of the storm event and the effective drainage area for a site-specific sedimentation pond. The effective drainage area may be less than the total drainage area for a given site because diversion ditches may be used to divert influent from above a mining area so

D'APPOLONIA

CONSULTING ENGINEERS, INC.

August 2, 1979

Project No. 78-334-D

Dr. Mark Boster
Office of Surface Mining
Branch of Environmental Services
Department of the Interior
Washington, DC 20240

Letter Report
Task 8
Evaluation of Sedimentation Pond Design
Relative to Capacity and Effluent Discharge

Dear Dr. Boster:

D'Appolonia Consulting Engineers, Inc. (D'Appolonia) is pleased to submit this report on the evaluation of sedimentation pond design criteria relative to capacity and effluent discharge. The objective of this evaluation was to assess the impact of multiple storm occurrences on the design requirements for the sedimentation ponds for surface mine facilities. The study has been performed by evaluating the capacity requirements of the three representative surface mines in the Northern and Southern Appalachian regions which were used for the study of cost impacts for discretionary alternatives for the Regulations Analysis. Table 1 describes these mines relative to data required for sedimentation pond design.

Sedimentation Pond Design Requirements

Paragraph 816.42 of the Office of Surface Mining (OSM) Reclamation and Enforcement regulations specifies effluent limitations of total suspended solids (TSS) for discharges from sedimentation ponds. Broadly, the regulation specifies a maximum TSS discharge of 70 mg/ℓ and an average discharge of 35 mg/ℓ measured over a period of 30 consecutive days.

Additionally, Paragraph 816.42 of the OSM regulations also has a provision which releases the operator from meeting the effluent limitations if a 10-year, 24-hour (10-yr storm) or larger storm event has occurred. However, the effluent criteria must be met if a 9.9-year storm (10^--yr storm) having rainfall characteristics which are basically the same as that of a 10-year storm, occurs. Furthermore, even if a storage equal to the total runoff of a 10-year storm is provided for the sedimentation

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ADDENDUM B

Haan, C. T. 1976. Urban Runoff Hydrographs - Basic Principles. Mini-Course, National Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, Lexington, Kentucky.

McCarthy, R. E. 1977. Erosion and Sediment Control for Coal Surface Mine Areas. National Symposium on Soil Erosion and Sedimentation by Water, Chicago, Illinois.

Mynear, D. K. and C. T. Haan. 1978. Systems Analysis of Urban Storm Water Detention Basins. ASAE Paper 78-2069 presented at 1978 Summer Meeting, American Society of Agricultural Engineers, Logan, Utah, June 27-30.

Rausch, D. L. and H. G. Heinemann. 1975. Controlling Reservoir Trap Efficiency. Transactions American Society of Agricultural Engineers 5:1105-1113.

Rendon-Herrero, O. 1974. Estimation of Wash Load Produced on Certain Small Watersheds. Proc. American Society of Civil Engineers 100(HY7): 835-848.

Soil Conservation Service. 1972. A Method for Estimating Volume and Rate of Runoff in Small Watersheds. SCS-TP-149, U.S. Department of Agriculture, SCS, Washington, D.C.

Soil Conservation Service. 1972. Hydrology. Section 4, National Engineering Handbook, U.S. Department of Agriculture, Washington, D.C.

U.S. Weather Bureau. 1963. Rainfall Frequency Atlas of the United States. Technical Paper 40, U.S. Department of Commerce, Washington, D.C.

Ward, A. D., C. T. Haan and B. J. Barfield. 1977a. Simulation of the Sedimentology of Sediment Bssins. Technical Report 103, University of Kentucky Water Resources Institute, Lexington, Kentucky.

Ward, A. D., C. T. Haan and B. J. Barfield. 1977b. Prediction of Sediment Basin Performance. Paper presented at 1977 Winter Meeting American Society of Agricultural Engineers, Chicago, Illinois.

Williams, J. R. 1975. Sediment-Yield Prediction with Universal Equation using Runoff Energy Factor. Present and Prospective Technology for Predicting Sediment Yield and Sources. Proceedings of the Sediment-Yield Workshop, USDA Sedimentation Laboratory, Oxford, Mississippi. ARS-S-40, pp. 224-252.

Williams, J. R. 1977. Sediment Delivery Ratios Determined with Sediment and Runoff Models. Proceedings of the Paris Symposium on Erosion and Solid Matter Transport in Inland Waters, Paris, France.

DEPOSITS and WASH. The costs of studies with such programs is low and computer access in most areas can be obtained easily.

The objectives of the new legislation appear sound. The wording of the law makes it sufficiently flexible that compliance by mine operators is feasible in most areas. Much of the terminology used in the law however needs defining and parts of the legislation need amending. Sizing of basins is based upon several conflicting criteria. If basins are designed to comply with all the requirements of the new legislation, the hydrologic balance on most watersheds will be severely affected, as large impoundments will be required to satisfy water quality standards. The long term effects of using chemical agents needs to be studied. Compliance with the 70 mg/ℓ water quality standard appears difficult. The price will be high and the long term benefits dubious. It is doubtful that sediment ponds will provide the solution to better downstream water quality over the long term.

REFERENCES

Brune, G. M. 1953. Trap Efficiency of Reservoirs. Trans. American Geophysical Union 34(3):407-418.

Curtis, D. C. 1976. A Deterministic Urban Storm Water and Sediment Discharge Model. Proc. National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Kentucky. July 27-29.

Environmental Protection Agency. 1976. Erosion and Sediment Control. Surface Mining in the Eastern U.S., EPA-625/3-76-006.

Graf, W. H. 1971. Hydraulics of Sediment Transport. McGraw-Hill, New York.

Haan, C. T. 1970. A Dimensionless Hydrograph Equation. Unpublished Paper, Agricultural Engineering Department, University of Kentucky, Lexington, Kentucky.

simulation model has been outlined in several publications and has not been described here. Several revisions have been made to the program and further information may be obtained by contacting the authors.

It appears that trap efficiencies greater than 90% will be required if water quality standards are to be obtained. If the runoff into the basin contains more than 20% finer than 20 microns, it is unlikely that water quality standards will be achieved unless flocculating agents are used or storage in excess of 24 hours is possible.

Basin storage may be increased through partial dewatering between storm events. It should be noted however that the permanent pool acts as a stilling basin and if the basins are dewatered to a shallow depth, considerable turbulence and resuspension of deposited sediment will occur during the next storm event. Trickle spillways may prove to be a viable alternative to drop inlet risers but have not been evaluated in this study. In this paper little attention has been paid to the surface area requirement of one square foot for each 50 gallons of flow per day as sizing of most basins under this criteria is not possible. For an inflow event of 8 acre-ft, for example, a surface area of 1.25 acres would be required. In Eastern Kentucky two or three basins on a 75 acre watershed would be required as surface areas on single basins seldom exceed one acre and are usually much smaller than this.

RECOMMENDATIONS

Although several predictive equations have been developed for estimating basin performance it is recommended that where possible mine operators conduct field research and utilize simulation models such as flocculating agents provide an economic solution to meeting water quality goals even on large surface mine areas. On three watersheds near Centralia, Washington, water quality was maintained within the new Federal limits for an estimated cost of $10/acre-ft of runoff. Suppliers of chemical agents indicate that they are now being used widely through the U.S.

Multiple Basins

Frequently several basins in series are used instead of a single basin. In Eastern states this practice is common because of the difficulty of locating large structures on the small steeply sloping watersheds found in these areas. Large operators may have over 50 basins within their permit area. In general water quality from the lower basin is good but one of the problems with this type of practice is that the upper basins quickly become filled and the deposited sediment tends to be washed out of the basin at a later time (often after active mining has ceased). Under the new legislation most of these ponds will require cleaning and eventually will be removed completely. How this may be accomplished is beyond the scope of this paper and appears a difficult question. Design for multiple basins can perhaps be best determined through routing with a simulation method such as DEPOSITS.

SUMMARY

Predictive equations have been presented for estimating basin trap efficiency and peak effluent sediment concentrations. All the predictive equations were generated from use of the DEPOSITS model. This

$$E = 93.1 + 27.6(3.4/12.7) + 0.046(21.2 - 7.1)(10.5/24) - 1.4(21.2)(36/75)^{0.3},$$

when evaluated E = 77.6%.(DEPOSITS estimate 78.5%). If these values are substituted into equation 14 it is determined that the peak inflow concentrations may not exceed 95 mg/ℓ if the effluent standard of 70 mg/ℓ is to be maintained. If this value is then substituted into equation 5 an estimate of the maximum permissible sediment delivery to the basin may be obtained. For this storm event only 0.054 tons of sediment may be delivered to the basin. Clearly onsite measures will have to be very effective, flocculation must be induced through use of chemical agents or a series of basins must be employed. If it was possible to obtain a trap efficiency of 95% with the same basin and flow characteristics, the permissible sediment delivery would be increased to 0.68 tons and the permissible peak inflow concentration would be 630 mg/ℓ.

ALTERNATIVE WATERSHED PRACTICES

Chemical Flocculating Agents

The use of chemical flocculating agents is beginning to see more widespread use. Flocculation occurs due to the electrokinetic potential of the soil particles. It may either be induced through the use of chemical flocculating agents or may occur naturally by the collision of rapidly settling particles with slower particles. In the past, polymer electrolytes and several other chemical agents have been widely used in water treatment facilities. McCarthy (1977) however indicates that with a slope of 30% and during mining the composite curve number for the watershed is 60. The watershed has a drainage area of 75 acres. A 36 inch diameter drop inlet riser is to be placed in the basin with the crest of the riser at an elevation of 12 feet above the bed of the basin.

From Table 2 it can be seen that the principal spillway and emergency spillway must handle a peak runoff rate of 104 cfs for the 100-year, 6 hour event. The peak for the 10-year, 24-hour event is 75 cfs and 8.3 acre-ft of runoff is produced. If it is assumed that active mining disturbs about 5 acres, then nearly 9.3 acre-ft of storage below the riser crest would be required to provide a 24-hour detention time (8.3 + 0.2 x 5). When the inflow hydrograph is estimated and the flow routed through the basin, the peak outflow rate is estimated to be 36 cfs and the average detention time a little over 10 hours. If we assume that field monitoring on the watershed indicates that at a flow rate of 50 cfs, 8% of the particles are finer than 5 microns and 24% are finer than 20 microns, it is possible to make an evaluation of the basin performance.

Using equation 4, $P_5^* = (50/75)^{0.3}$ (8), therefore $P_5^* = 7.1$ and similarly $P_{20}^* = 21.2$. From Table 3 the permanent storage S = 3.4 acre-ft. The volume of runoff is determined from Table 1 and by assuming base flow equivalent to the dead storage

$$Q = 8.3 + 3.4 = 11.7 \text{ acre-ft}$$

Then by using equation 12, an estimate can be made of the trap efficiency.

basin. For the water quality standard of 70 mg/ℓ to be met, a trap efficiency of 99% will be required.

DISCUSSION

It can be seen from tables 1 and 2 that even for small, shallow sloping watersheds a minimum basin capacity of over 5 acre-ft will be required to provide a volume weighted average detention time of 24 hours. This is because, for a 24-hour detention time, the basin must essentially store the entire runoff volume. Most basins in the Eastern U.S. are fairly small (1-10 acre-ft) and will in general provide an average detention time less than 12 hours. In Figure 3 curves have been drawn which relate trap efficiency with detention time and the particle size distribution at the peak runoff rate. For clarity the data points have been omitted but there was much scatter in the points. It appears however that if the percent finer than 20 microns is greater than 30 percent, trap efficiencies will not exceed 80% in basins which provide a detention time of less than 12 hours for the 10-year, 24-hour design event. Figure 3 was developed based on the data generated for a basin with a permanent pool at the riser crest and base flow following the design storm event.

Design Example

The use of the equations described in this paper can perhaps be best illustrated by an example. Assume it is desired to evaluate the suitability of basin B to control sediment discharge for a design storm of 5 inches of rainfall in 24 hours. The basin is located on a watershed

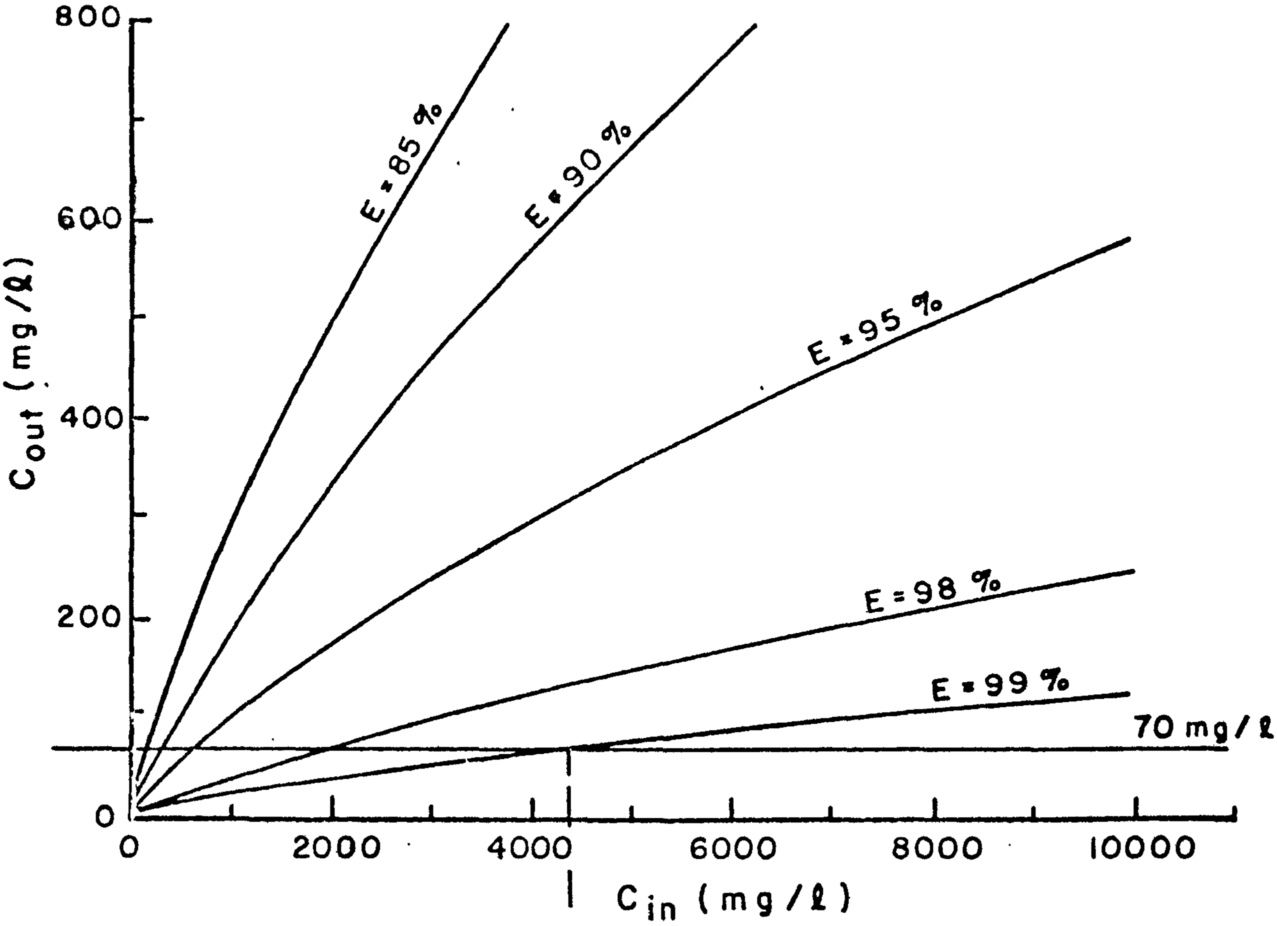

Figure 4a. Estimation of Peak Outflow Concentration.

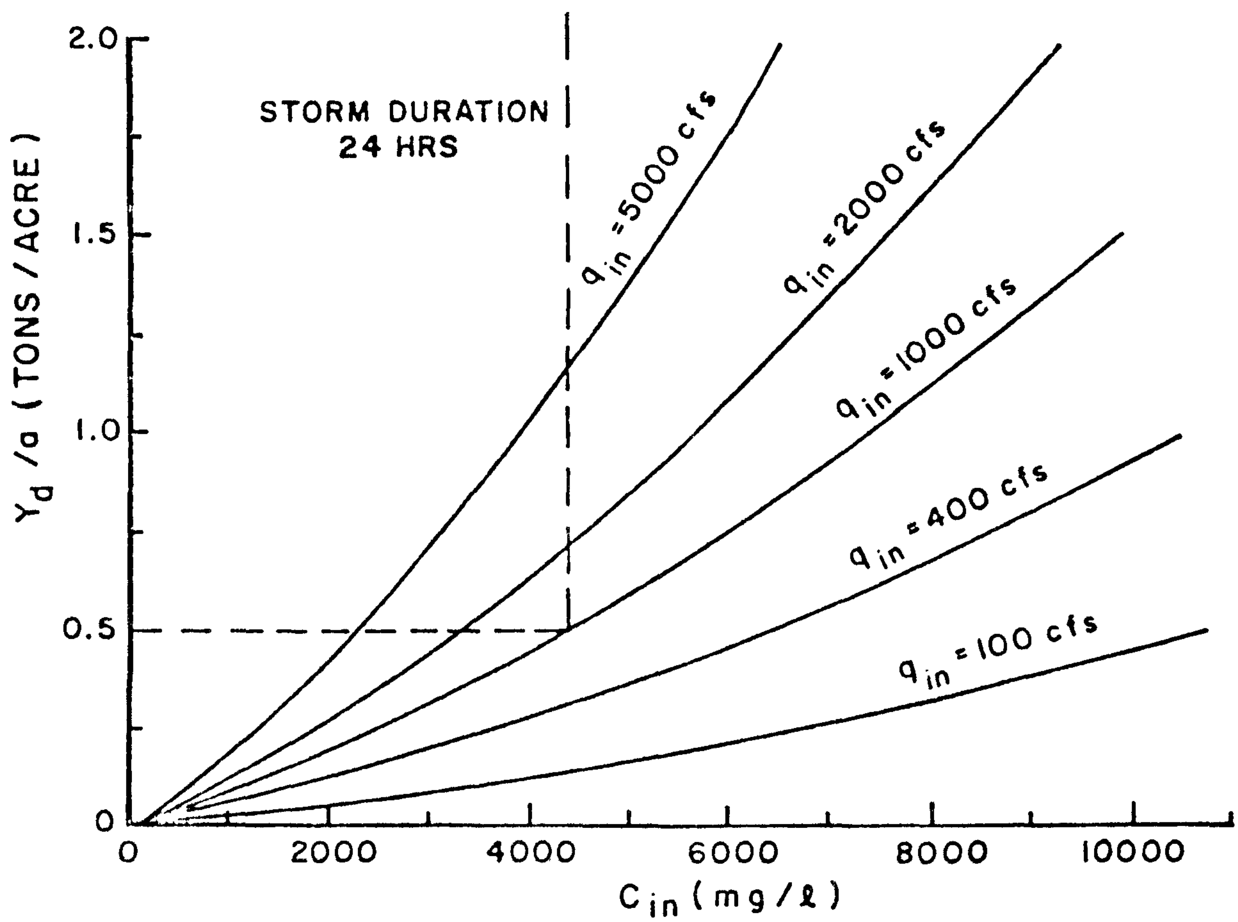

Figure 4b. Determination of Peak Inflow Concentration.

Basin with a Permanent Pool

Base flow following the storm event will not usually affect the peak outflow concentration as the peak will normally occur during the runoff event for the design storm. Because of 'flooding' of one of the basins only 258 data values were used in the analysis for the permanent pool condition. A much simpler equation than that for the dry basin was obtained:

$$C_{out} = 0.11\ (100.0 - E)^{0.94}\ C_{in}^{\ 0.75}\ (q_{out}/q_{in})^{-0.142} \qquad (14)$$

The R^2 value for this equation is 0.96 and again all the variables are significant at the 99.5% confidence level. Using estimates of E from equations 11 or 12 and estimates of C_{in} calculated with equation 5, values of C_{out} calculated with equation 14 had an R^2 value of 0.86. This is more typical of the correlation that might be expected if knowledge of the actual basin trap efficiency and peak inflow concentrations is not available.

For most small basins the ratio q_{out}/q_{in} will probably vary between 0.2 - 0.8. The term $0.11\ (q_{out}/q_{in})^{-0.142}$ will therefore vary between 0.11 - 0.14 and equation 14 may be approximated by the equation:

$$C_{out} = 0.13(100 - E)^{0.94}\ C_{in}^{\ 0.75} \qquad (15)$$

A graphical solution to equation 15 is presented in Figure 4A. Estimates of the peak inflow concentrated (C_{in}), based upon equation 5, may be obtained from Figure 4B. An example of how the figures may be used is shown. In the example, a 24-hour storm event has a peak runoff rate of 1000 cfs and 0.5 tons/acre of sediment is delivered to the detention

In this case the volume of base flow is included in the runoff volume Q, and td is the average detention time of the entire event including the base flow condition. t_{st} is still the duration of the design storm event. The coefficient of determination for this equation is 0.91, and all the variables are again significant at the 99.5% confidence level.

PEAK EFFLUENT SEDIMENT DISCHARGE

In developing equations to estimate peak outflow concentrations, it was felt that these concentrations would be closely correlated to the basin trap efficiency and the peak inflow concentration. If an equation could be developed based upon these two variables, an estimate could be made of the peak outflow concentration which is independent of the methods adopted in this study. Trap efficiency may either be determined through regression equations for the particular area or through use of methods outlined earlier. Peak inflow concentration may also be estimated by equations based upon actual field monitoring or through use of equation 5.

Dry Basin

288 data points were used and the following equation developed:

$$C_{out} = 0.0114\ P_5^{*0.34}\ P_{20}^{*\ 1.1}\ (td/t_{st})^{0.21}\ (P_{20}^* - P_5^*)^{0.21} \qquad (13)$$

where C_{out} is the peak effluent sediment concentration (mg/ℓ). The coefficient of determination R, is equal to 0.96 and all variable are significant at the 99.5% confidence level. The equation, however, is difficult to use, as a good estimate is required of the particle size distribution at the peak flow rate.

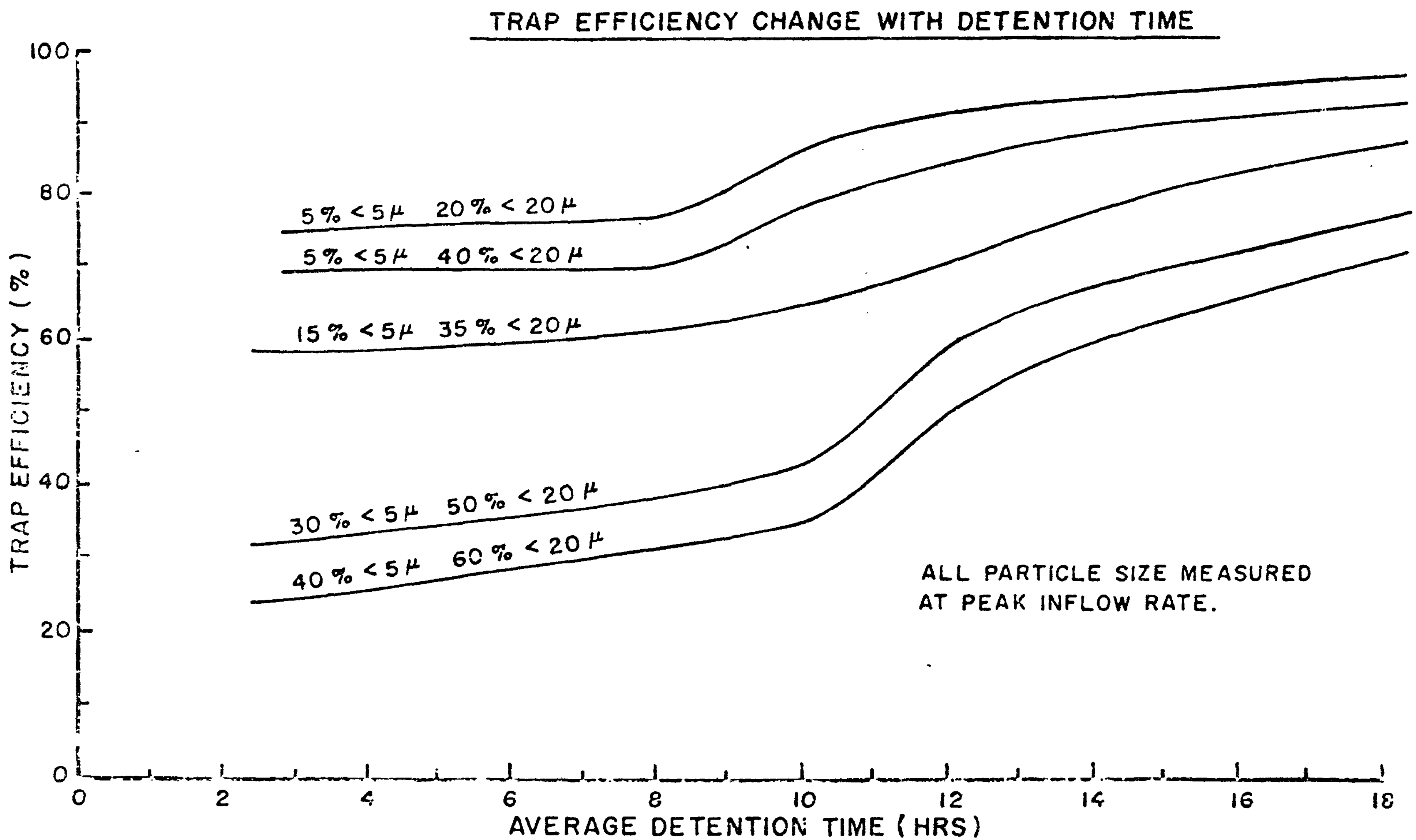

Figure 3. Effect of Detention Time on Trap Efficiency.

the 99.5% level. When developing the design criteria, sediment contained in the permanent pool prior to the design event should be allocated to the base flow or storm events prior to the event being evaluated. The volume of flow stored in the basin should be included in the routing of the storm event through the basin.

Basin with a Permanent Pool and Base Flow

If no flow is considered following the design event, a portion of the design storm equivalent in volume to the permanent storage of the basin will remain in the basin. Frequently this remaining volume will contain a very high suspended sediment load. If a flow condition occurs within a few days of the storm event much of this suspended load will be discharged from the basin. For a perforated riser there is normally discharge from the basin most of the time except in very dry periods. Even with a drop inlet riser there is usually flow between storm events due to pumping from mine areas or due to the fact that most basins are located on small streams and creeks. The amount and rate of the base flow following a storm event will determine how much additional sediment discharge will occur. In this study a base flow of 1 cfs for 48 hours was simulated for basins A, B and C and a flow rate of 2 cfs for 48 hours on basins D and E. Except for basin D which has a permanent storage of nearly 16 acre-feet, the base flow replaced all or most of the storm flow previously stored in the basins.

The following predictive equation was obtained:

$$E = 93.1 + 27.6(S/Q) + 0.046(P^{*}_{20} - P^{*}_{5})\ (td/t_{st}) - 1.4\ P^{*}_{20}(q_{out}/q_{in})^{0.3} \quad (12)$$

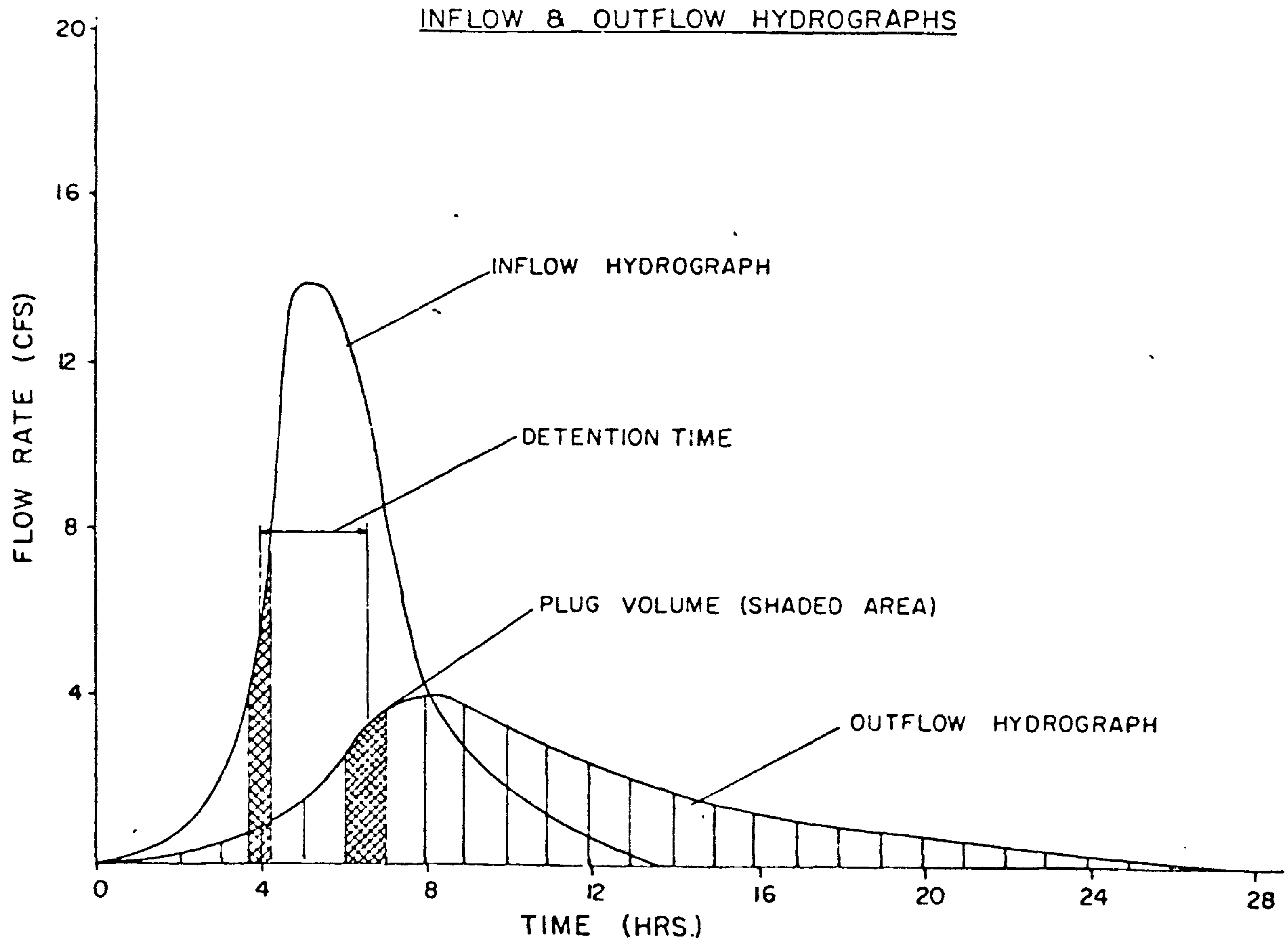

Figure 2. Typical Detention Basin Hydrographs.

than 5 microns at the peak inflow rate. The equation is dimensionless, and units other than those indicated may be used. The equation explains 93% of the variation in the trap efficiency and all the variables are significant at the 99.5% confidence level. Values for P^*_{20} and P^*_5 may be estimated using equation 4. The volume weighted average detention time is given by:

$$td = \sum_{i=1}^{n} \Delta Q \Delta t_i / \sum_{i=1}^{n} \Delta Q_i \tag{10}$$

where Δt_i is the detention time of each plug of flow as shown in Figure 2. ΔQ_i is the volume of each plug i, and n is the number of plugs.

Basin with a Permanent Pool

In this study no sediment was associated with the water contained in the permanent pool. Sediment was partitioned to the design storm event as in the case of the dry basin. Normally the permanent pool would contain a suspended sediment load but the purpose of this study was to evaluate the effect of a permanent pool on the design criteria.

The following equation was developed:

$$E = 89.2 + 25.4(S/Q) + 1.77(P^*_{20} - P^*_5)\,(td/t_{st}) - 1.23(q_{out}/q_{in})^{.3}\,(P^*_{20}) \tag{11}$$

The equation is very similar to equation 9 for a dry basin except that the permanent storage S is more significant and the last term of the equation will be larger as the peak outflow rate q_{out} is increased if a permanent pool exists. The equation explains 90% of the variation in the trap efficiency and again all the variables are significant at

Table 4. Trap Efficiency Equation for a Dry Basin (Ward, Haan & Barfield, 1977b).

Riser Type	Outflow Withdrawal	R^2	Trap Efficiency (%) (E)
Perforated	Surface	0.89	$102.7 + 0.55Q - 0.76q_{out} - 0.02P_{20}^* - 0.65P_5^* - 1.30D + 0.11t_{out}$
	Uniform	0.94	$100.6 + 0.92Q - 0.89q_{out} - 0.31P_{20}^* - 0.58P_5^* - 1.00D + 0.13t_{out}$
	Bed	0.95	$100.3 + 1.12Q - 1.05q_{out} - 0.53P_{20}^* - 0.67P_5^* - 1.05D + 0.14t_{out}$
Drop Inlet	Surface	0.98	$95.2 + 1.47(t_{out} - t_{in}) - 0.65P_5^* - 0.19P_{20}^* - 1.57D^* + 0.74S + 25.52(Q/q_{out}) - 1.04t_{out}$

Where S = Permanent storage (acre-ft)

Q = Volume inflow (acre-ft)

P_{20}^* = % finer 20 microns (measured at peak inflow rate)

P_5^* = % finer 5 microns (measured at peak inflow rate)

D = Stage at outlet riser crest (ft)

D^* = Peak depth above riser crest (ft)

t_{in} = Base time of inflow hydrograph (hrs)

t_{out} = Time for 95% of possible withdrawal (hrs)

q_{out} = Peak outflow rate (cfs)

2. Q_o is equal to the peak inflow rate q_{in} (in the appropriate units.

If the particle size distribution of the inflowing sediment is estimated at or near the peak inflow rate, the second method may give a good estimate of the actual basin performance. Several predictive equations have been developed by Ward, Haan and Barfield (1977). These equations are shown in Table 4. The equations are fairly difficult to use, and care should be taken to read the original publication. In this study dimensionless equations have been developed based upon the simulation conditions described earlier. No 'bad' points were removed from the analysis. Several basins however were 'flooded' by the design event and no data points were generated for this condition. Flooding occurred when the peak discharge of the outlet riser was exceeded - indicating flow through the emergency spillway.

Dry Basin

Based on 288 sets of data the following regression equation was developed:

$$E = 92.5 + 13.2(S/Q) + 1.9(P^*_{20} - P^*_5)\ (td/t_{st}) - 1.4(q_{out}/q_{in})^{0.3}\ (P_{20}{}^*) \qquad (9)$$

where E is the trap efficiency (%), S is the basin capacity up to the riser crest (acre-ft), Q is the inflow volume (acre-ft), td is the volume weighted average detention time (hrs), t_{st} is the storm duration (hrs), q_{out} is the peak outflow rate (cfs), q_{in} the peak inflow rate (cfs), P^*_{20} the % finer than 20 microns at the peak inflow rate and P^*_5 the % finer to provide a 24-hour detention time for a 10-year, 24-hour storm event. The feasibility of placing large size basins on most Eastern surface mines is remote.

BASIN TRAP EFFICIENCY

Conventionally, basin trap efficiency has been estimated either through use of an empirical curve developed by Brune (1953) or by a method adopted by the EPA (1976). Brune's curve are based upon large reservoir data and give poor estimates of small basin performance. The EPA method, if used carefully, may give reasonable estimates of basin performance for steady flow conditions. The following equations describe the method:

$$A = Q_o/V_s \qquad (6)$$

where A is the basin size in m^2, Q_o is the overflow rate through the pond (m^3/sec) and V_s is the critical settling velocity m/sec. The EPA recommend that the desired basin size be multiplied by 1.2 to account for non-ideal settling. V_s may be calculated for a particular particle size by using Stoke's Law:

$$V_s = (g/18\mu)\ (S - 1)\ D^2 \qquad (7)$$

where g is the acceleration of gravity (981 cm/sec^2), μ is the kinematic viscosity of a fluid (cm^2/sec^2) and D is the particle diameter (cm). Q_o is frequently determined in two ways:

1. Q_o = volume inflow/storm duration (8)

   = Q/t_{st} where Q and t_{st} are converted to the appropriate units.

c. Condition b. followed by a base flow event of 1 or 2 cfs for 48 hours following the storm event.

Unless a dewatering drawdown device is used, a permanent pool will be formed in basins with a drop inlet riser. Basins are frequently designed based on condition "a", although in fact conditions similar to "b" or "c" actually occur. The following assumptions were made in the study:

1. The effects of turbulence or short circuiting in the basin were not significant.

2. No flocculation occurred within the basin.

3. Inflow sediment concentrations are proportional to the inflow rate.

4. A winter or spring water viscosity of 0.015 cm^2/sec.

5. Sediment delivery proportional to $95(Qxq_{in})^{0.56}$.

6. Particle size variation with storm intensity could be represented by equation 4.

Five different basin geometries were considered, together with four different riser configurations. Table 3 describes the combination of basin sizes, riser configurations and storm events used to generate the data for the regression analysis. The 6 particle size distributions shown in Figure 1 were used for each combination illustrated in Table 3. It was assumed that the distributions had all been determined at a flow rate of 20 cfs. Basins A, B and C are all typical of sediment basins found on Eastern surface mines and are based on actual basin geometries. Basins D and E represent the larger size basins that might be found in Western states, large agricultural watersheds and urban basins. All basins are in general smaller than the size basin that might be required

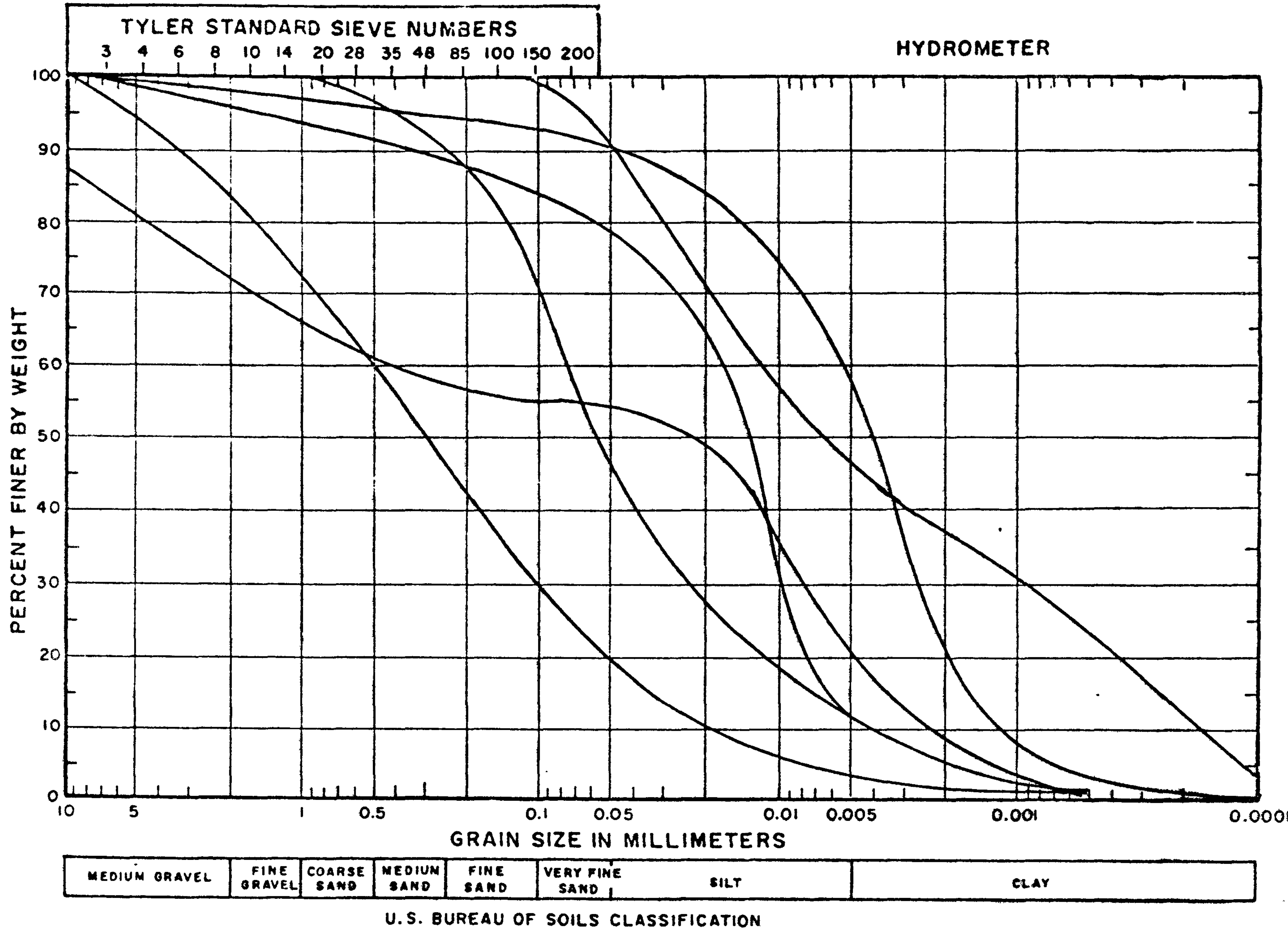

Figure 1. Grain Size Distribution Diagram.

$$C_{in} = 63577(Y_d/a)^{0.74} (q_{in})^{-0.394} t_{st}^{0.177} \qquad (5)$$

where C_{in} is the peak inflow concentration (mg/ℓ), Y_d is sediment delivery to the basin for the storm event (tons), a is the watershed area (acres), q_{in} is the peak runoff rate (cfs), and t_{st} is the storm duration (hours). The coefficient of determination for the equation is $R^2 = 0.97$. The conditions for which equation 5 was developed are outlined in the next section. All the variables are significant at the 99% confidence level and 288 data points were used in the analysis.

In developing equation 5, C_{in} was determined by making the inflowing sediment concentration proportional to the inflowing runoff rate. Thus by knowing the runoff hydrograph and the total sediment yield, Y_d, the inflowing sediment concentration at any time can be determined. The concentration corresponding to the peak runoff rate is C_{in}.

SIMULATION STUDY CHARACTERISTICS

An attempt was made in this study to develop predictive equations which might be employed by the mine design engineer to estimate basin trap efficiency and peak effluent sediment concentrations. It was felt that effluent standards could probably not be met with a perforated riser and, as they are no longer required by law, only drop inlet risers were evaluated.

The following flow conditions were evaluated:

a. Dry basin prior to the storm event.

b. Permanent pool below the riser crest prior to the design storm event.

Table 3. Variable Combinations used in Simulations.

Basin	Pool Storage (acre-ft)	Stage at Riser Crest (ft)	Surface Area at Riser Crest (acres)	Shape Factor[1]	Riser Config. (inches)				10-Year, 24-Hour[2]									100-Year 6 hr	
					24 dia.	30 dia.	36 dia.	36 sides	75/15 4/80	75/15 5/60	75/15 6/80	75/30 5/60	75/30 6/70	200/15 4/60	200/15 5/60	200/15 6/60	200/15 5/70	75/15 5/70	75/30 6/60
A	1.6	12.0	0.20	0.65			✓	✓	✓	✓			✓		✓			✓	
B	3.4	12.0	0.51	0.56		✓	✓		✓		✓	✓		✓				✓	
C	7.2	10.0	0.09	0.66	✓		✓				✓			✓		✓		✓	✓
D	15.9	8.0	6.00	0.33		✓		✓					✓		✓	✓	✓		✓
E	4.9	4.0	24.00	0.51	✓		✓								✓	✓	✓	✓	✓

1 Shape Factor:

$$\frac{\text{volume pool at crest}}{(\text{stage})(\text{surface area})}$$

All measurement at riser crest.

2 Example

75/15
4/80

75 acres
15% slope
4 in. rainfall
80 curve number

Inflow Sedimentgraph

The sediment concentrations associated with a storm hydrograph will vary depending on the same factors as affected sediment yield, sediment delivery and particle size distribution. Usually the inflow sedimentgraph will have a similar shape as the inflow hydrograph, with a peak at about the same time as the peak runoff rate. On some watersheds the peak may preceed that of the inflow hydrograph (Graf, 1971). Through field monitoring on a particular watershed, an estimate of the relationship between the runoff rate and sediment concentrations can be made. If knowledge on this relationship is unavailable, the sediment concentrations may be assumed proportional to the flow rate. Based on studies by Rendon-Herrero (1974) and Curtis (1976), it appears that this assumption will give reasonable estimates for small, moderately sloping watersheds.

Peak Inflow Sediment Concentration

Mine engineers are required to design sediment basins to meet effluent water quality standards. It was felt that peak effluent sediment concentrations would be closely correlated with basin trap efficiency and peak inflow sediment concentrations. Inflow sediment concentrations for a given watershed might be estimated by developing predictive equations based on field sampling for several storms of different intensity. An attempt was made in this study to correlate peak inflow sediment concentrations to the design storm characteristics and its associated sediment delivery to the basin. The following equation was developed:

factors and will vary throughout the storm event. Detachment and transport of sediment is very dependent on the following factors:

Rainfall intensity
Depth of runoff on the watershed
Watershed topography
Onsite control practices
Soil particle characteristics
Hydraulic characteristics of the watershed
Ground cover on the watershed

Rausch and Heinemann (1975) found that the percent finer for a given particle size may be related to the storm peak runoff rate by the equation:

$$P_d = C(q_{in})^{-M} \tag{3}$$

where P_d is the percent finer for a particular particle size d, and q_{in} is the peak inflow rate to a reservoir. The coefficient C will vary with the particle diameter and each watershed. The coefficient M will vary from watershed to watershed. For Callahan Reservoir in Missouri, M had a value of 0.33. Callahan reservoir is located on a 3600 acre agricultural watershed. In this study a value of 0.3 was used for M and the equation

$$P_d^* = (q_b/q)^{0.3}\ P_d \tag{4}$$

where P_d is the percent finer for a given particle size measured at a flow rate q_b (cfs) and q is the runoff rate (cfs), at any given time during the storm event. In all the regression equations developed during this study, the percent finer P_d* has been related to the peak runoff rate q_{in}.

of the amount of erosion occurring for a single storm may be obtained with equation 1 but this knowledge is only of value if accurate estimates of the delivery ratio to the downstream sediment basin can be obtained.

Delivery Ratio

Williams (1977) suggests that estimates of delivery ratios may be obtained by dividing predicted average annual values of sediment yield by sheet erosion. Average annual sheet erosion can be determined through the use of the Universal Soil Loss Equation (USLE). In a study on Little Elm Creek basin, Williams developed a predictive equation for delivery ratio of the form:

$$DR = k\ (DA)^{a}\ (ZL)^{b}\ (CN)^{c} \qquad (2)$$

where DR is the delivery ratio, DA is the drainage area, ZL is the relief-length ratio, and CN is the curve number. The coefficients k, a, b and c would need to be determined for the given location. Predictive equations of this nature were developed for 15 Texas basins, and good estimates of downstream sediment delivery were obtained. It appears that in large surface mine areas, determination of a predictive equation of this nature would be of considerable importance to the mine engineers.

Particle Size Distribution

Although the particle size gradation of soil found on a disturbed area may be fairly uniform, the distribution of coarse and fine material being transported downstream to a sediment basin will depend on many

Table 2 – continued

100-Year, 6-Hour Storm

Watershed Area (acres)	Slope (%)	Curve Number CN	Rainfall (inches)	Runoff (inches)	Peak Rate (cfs)	Volume Runoff (acre-ft)
500	5	60	2.0	.05	9.6	2.1
			3.0	.29	49.6	12.1
			4.0	.68	116.2	28.3
		70	2.0	.23	39.6	9.6
			3.0	.70	131.9	29.2
			4.0	1.30	260.7	54.2
		80	2.0	.56	131.0	23.3
			3.0	1.25	316.9	52.8
			4.0	2.04	537.2	85.0
500	10	60	2.0	.05	11.4	2.1
			3.0	.29	56.1	12.1
			4.0	.68	142.0	28.3
		70	2.0	.24	44.8	10.0
			3.0	.71	159.7	29.6
			4.0	1.32	321.4	55.0
		80	2.0	.56	178.1	23.3
			3.0	1.25	436.7	52.8
			4.0	2.04	740.3	85.0
1000	5	60	2.0	.05	13.0	4.2
			3.0	.29	104.2	24.2
			4.0	.68	278.0	56.7
		70	2.0	.23	142.1	19.2
			3.0	.70	482.4	58.3
			4.0	1.30	983.9	108.3
		80	2.0	0.56	611.4	46.7
			3.0	1.25	1403.1	104.2
			4.0	2.04	2322.2	170.0
1000	10	60	2.0	.05	19.0	4.2
			3.0	.29	99.1	24.2
			4.0	.68	232.4	56.7
		70	2.0	.23	79.3	19.2
			3.0	.70	263.7	58.3
			4.0	1.30	521.3	108.3
		80	2.0	.56	261.9	46.7
			3.0	1.25	633.8	104.2
			4.0	2.04	1074.5	170.0

Table 2. Rainfall and Runoff for 100-Year, 6-Hour Rainstorms.

Watershed Area (acres)	Slope (%)	Curve Number CN	Rainfall (inches)	Runoff (inches)	Peak Rate (cfs)	Volume Runoff (acre-ft)
			100-Year, 6-Hour Storm			
75	15	60	4.0	.76	43.8	4.8
			5.0	1.30	83.3	8.1
			6.0	1.91	130.4	11.9
		70	4.0	1.33	112.9	8.3
			5.0	2.03	179.1	12.7
			6.0	2.80	252.6	17.5
		80	4.0	2.04	233.0	12.8
			5.0	2.89	332.6	18.1
			6.0	3.78	435.1	23.6
75	30	60	4.0	.76	54.9	4.8
			5.0	1.30	104.0	8.1
			6.0	1.91	161.9	11.9
		70	4.0	1.33	147.5	8.3
			5.0	2.03	230.6	12.7
			6.0	2.80	319.7	17.5
		80	4.0	2.04	233.0	12.8
			5.0	2.89	332.6	18.1
			6.0	3.78	435.1	23.6
200	15	60	4.0	.76	85.6	12.8
			5.0	1.30	161.3	21.6
			6.0	1.91	252.1	31.7
		70	4.0	1.33	201.4	22.1
			5.0	2.03	327.0	33.9
			6.0	2.80	462.0	46.7
		80	4.0	2.04	496.2	34.1
			5.0	2.89	711.5	48.3
			6.0	3.78	933.9	62.9
200	30	60	4.0	.76	116.7	12.8
			5.0	1.30	222.2	21.6
			6.0	1.91	347.8	31.7
		70	4.0	1.33	301.1	22.1
			5.0	2.03	477.5	33.9
			6.0	2.80	673.5	46.7
		80	4.0	2.04	621.4	34.1
			5.0	2.89	886.9	48.3
			6.0	3.78	1160.3	62.9

Table 1 -- continued

10-Year, 24-Hour Storm

Watershed Area (acres)	Slope (%)	Curve Number CN	Rainfall (inches)	Runoff (inches)	Peak Rate (cfs)	Volume Runoff (acre-ft)
500	5	60	2.0	.06	3	2.5
			3.0	.33	26	14.0
			4.0	.77	72	32.1
		70	2.0	.24	21	10.1
			3.0	.72	87	30.1
			4.0	1.34	186	56.0
		80	2.0	.56	91	23.7
			3.0	1.26	233	52.7
			4.0	2.06	395	85.8
500	10	60	2.0	.06	3	2.5
			3.0	.33	29	14.0
			4.0	.77	89	32.1
		70	2.0	.24	24	10.1
			3.0	.72	107	30.1
			4.0	1.34	231	56.0
		80	2.0	.56	126	23.7
			3.0	1.26	323	52.7
			4.0	2.06	549	85.8
1000	10	60	2.0	.06	6	5.1
			3.0	.33	53	28.1
			4.0	.77	145	64.2
		70	2.0	.24	43	20.2
			3.0	.72	175	60.2
			4.0	1.34	372	112.1
		80	2.0	.56	183	47.4
			3.0	1.26	466	105.3
			4.0	2.06	795	171.9
1000	5	60	2.0	.05	26	4.8
			3.0	.32	154	27.2
			4.0	.74	380	62.4
	5	70	2.0	.24	130	20.2
			3.0	.72	440	60.0
			4.0	1.34	867	111.8
	5	80	2.0	.56	431	47.4
			3.0	1.26	1031	105.3
			4.0	2.06	1731	171.9

Table 1. Rainfall and Runoff for 10-Year, 24-Hour Rainstorms.

10-Year, 24-Hour Storm						
Watershed Area (acres)	Slope (%)	Curve Number CN	Rainfall (inches)	Runoff (inches)	Peak Rate (cfs)	Volume Runoff (acre-ft)
75	15	60	4.0	0.77	29	4.8
			5.0	1.32	59	8.3
			6.0	1.94	95	12.1
		70	4.0	1.35	83	8.4
			5.0	2.06	133	12.9
			6.0	2.84	187	17.8
		80	4.0	2.06	169	12.9
			5.0	2.92	241	18.3
			6.0	3.82	314	23.9
75	30	60	4.0	0.77	37	4.8
			5.0	1.32	74	8.3
			6.0	1.94	118	12.1
		70	4.0	1.35	104	8.4
			5.0	2.06	165	12.9
			6.0	2.84	231	17.8
		80	4.0	2.06	169	12.9
			5.0	2.92	241	18.3
			6.0	3.82	314	23.9
200	15	60	4.0	0.77	56	12.8
			5.0	1.32	113	22.0
			6.0	1.94	183	32.3
		70	4.0	1.35	149	22.5
			5.0	2.06	242	34.3
			6.0	2.84	344	47.3
		80	4.0	2.06	368	34.3
			5.0	2.92	525	48.7
			6.0	3.82	688	63.7
200	30	60	4.0	0.77	78	12.8
			5.0	1.32	159	22.0
			6.0	1.94	255	32.3
		70	4.0	1.35	221	22.5
			5.0	2.06	355	34.3
			6.0	2.84	500	47.3
		80	4.0	2.06	452	34.3
			5.0	2.92	643	48.7
			6.0	3.82	839	63.7

WATERSHED HYDROLOGY

The procedures for developing runoff rates and volumes currently used by the SCS for small watersheds should prove adequate for surface mined areas (Soil Conservation Service, 1972). Care must be exercised in determining curve numbers (CN) for the disturbed portions of mined watersheds since the exposed spoil and soil may bear little resemblance to the original soil. The WASH hydrograph model was used to generate expected peak runoff rates and volumes for a variety of conditions. The results of these simulations are shown in Tables 1 and 2. The WASH program is a modified version of the HYDRO simulation model (Mynear and Haan, 1978) and allows for the simulation of storm hydrographs for a storm duration of 1-24 hours. The model is essentially based on SCS procedures and a copy may be obtained from the authors.

SEDIMENT PRODUCTION & YIELD

Sediment Yield

Determination of the rate of sediment production for a given storm event is difficult and perhaps the best method which is available is MUSLE (Williams, 1975):

$$Y = 95(Q x q_{in})^{0.56} K \; LS \; C \; P \qquad (1)$$

where Y is the sediment yield for an individual storm (tons), Q is the runoff volume (acre-feet), q_{in} is the peak runoff rate (cfs), K is soil erodibility factor, LS the slope-steepness factor, C is the crop management factor, and P is the erosion control practice factor. Good estimates

Guidelines as to how these parameters may be estimated are presented in this paper. Clarification on some sections of the law have been attempted, and several amendments have been made since passage of the law in 1977. The 24-hour detention period restriction has been relaxed provided mine operators can demonstrate that basins will satisfy the quality standards of 70 mg/ℓ during storm events and 35 mg/ℓ average during 30 consecutive discharge days. It appears that some of the regulations pertaining to spillway discharge rates need to be revised. A 25-year, 24-hour precipitation event will usually have a higher peak runoff rate than a 100-year, 6-hour event. A 25-year, 6-hour event, however, will produce peak rates lower than those already provided for by the 10-year, 24-hour design event. In fact, the peak rates from the 10-year, 24-hour event will be very similar to the peak rates produced from a 100-year, 6-hour event on many watersheds.

In addition to providing guidelines on how to quantify the watershed hydrologic parameters that might occur on surface mine areas, predictive equations are presented for estimating peak effluent sediment concentrations and basin trap efficiency. Care should be taken in using these equations as all the data were generated by the DEPOSITS model (Ward, Haan and Barfield, 1977a). The model does not adequately account for basins in which there is considerable turbulence, short circuiting or resuspension of deposited sediment. The coefficient of determination for all the equations that are presented is greater than 0.9 but, unless great care is taken in estimating the parameters used in each equation, poor estimates of actual basin performance may be obtained.

simulation model. The DEPOSITS model has been tested in simulation studies on several actual basins and appears to give a good estimate of basin performance. It also gave a good estimate of the performance of Callahan Reservoir during a 60-day period in 1973. A new version of the model allows for variation in the particle size distribution with runoff rate, and in this paper criteria are presented which account for basins with a permanent pool and also considers base flow conditions following a design storm event.

INTRODUCTION

Although the new surface mine legislation imposes many new restrictions on mining operators, perhaps the most controversial and difficult provision to comply with is contained in section 715.17 (e) of Public Law 95-87. In part this section says:

> Sedimentation ponds must provide at least a 24-hour detention time and a surface area of at least 1 square foot for each 50 gallons per day of inflow for runoff entering the pond(s) that results from a 10-year, 24-hour precipitation event. ... An additional sediment storage volume must be provided equal to 0.2 acre-feet for each acre of disturbed area within the upstream drainage area... Spillway systems shall be provided to safely discharge the peak runoff from a precipitation event with a 25-year recurrence interval, or larger event as specified by the regulatory authority ... An appropriate combination of principal and emergency spillways shall be provided to safely discharge the runoff resulting from a 100-year, 6-hour precipitation event, or larger event as specified by the regulatory authority. ... All ponds shall be removed ... unless the regulatory authority approves retention of the ponds ...

The terminology used in this section is not clearly defined and sizing of the basin, determination of peak flow rates, detention times, and estimation of runoff volumes is open to many interpretations.

THE DESIGN OF SEDIMENT BASINS[1]

A. D. Ward,[2] C. T. Haan[3] and B. J. Barfield[3]

ABSTRACT

Passage of Public Law 95-87 has placed several new restrictions on the design of surface mine sediment basins. It created much controversy as to the required sizing of the sediment basins, and adequate design methods are not available for estimating basin performance and effluent sediment concentrations. This paper presents guidelines as to how the hydrologic parameters affecting sediment basin design may be quantified and contains predictive equations for estimating basin trap efficiency and peak effluent sediment concentrations. Multiple regression analysis techniques were employed with data generated by the WASH hydrograph computer program and by the DEPOSITS

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PAPER NO ________

THE DESIGN OF SEDIMENT BASINS

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For presentation at the 1978 Summer Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Utah State University
Logan, Utah
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SUMMARY:

Public Law 95-87 has placed several new restrictions on the surface mining industry. This paper addresses procedures that can be used to meet the requirements concerning sediment detention basins as set forth in the new law.

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

ADDENDUM A

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. TIOS	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE EVALUATION OF PERFORMANCE CAPABILITY OF SURFACE MINE SEDIMENT BASINS		5. REPORT DATE August 3, 1979 TIOS 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles E. Ettinger, Joseph E. Lichty		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Skelly and Loy 2601 North Front Street Harrisburg, Pennsylvania 17110		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-2677
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 6/20-8/3/79 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This document presents findings of a study to determine the effectiveness of surface mine sedimentation basins in sediment removal during the occurrence of a variety of rare storm events. Through the use of simulation techniques, a series of six sedimentation basins were studied to determine their performance during the experience of three discrete precipitation events, the 2-year, 5-year, and 10-year twenty four hour storms. This report details findings, conclusions, and recommendations relative to a surface mine sediment basin's ability to meet the current effluent guidelines for suspended solids removal.

This report was submitted in partial fulfillment of Contract No. 68-03-2677 by Skelly and Loy under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 20, 1979 to July 27, 1979, and work was completed as of August 3, 1979.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sedimentation Ponds		

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

TABLE A-22. (continued)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	2.92	ACRE-FT
STORM VOLUME DISCHARGED	=	1.11	ACRE-FT
POND VOLUME AT PEAK STAGE	=	3.93	ACRE-FT
PEAK STAGE	=	12.24	FT
PEAK INFLOW RATE	=	41.47	CFS
PEAK DISCHARGE RATE	=	0.39	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	53648.1	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	2374.3	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1506.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	665.5	MG/L
BASIN TRAP EFFICIENCY	=	97.66	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	95.71	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	41.54	HRS
DETENTION TIME INCLUDING STORED FLOW	=	85.73	HRS
SEDIMENT LOAD	=	97.00	TONS

TABLE A-22. SEDIMENT POND KY-1B (10 yr. storm)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	2.92	ACRE-FT
STORM VOLUME DISCHARGED	=	1.40	ACRE-FT
POND VOLUME AT PEAK STAGE	=	3.57	ACRE-FT
PEAK STAGE	=	11.39	FT
PEAK INFLOW RATE	=	41.47	CFS
PEAK DISCHARGE RATE	=	0.83	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	53648.1	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	3331.1	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	2013.9	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1006.6	MG/L
BASIN TRAP EFFICIENCY	=	96.04	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	77.01	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	23.98	HRS
DETENTION TIME INCLUDING STORED FLOW	=	70.08	HRS
SEDIMENT LOAD	=	97.00	TONS

TABLE A-21. SEDIMENT POND KY-1B (5 yr. storm)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	2.20	ACRE-FT
STORM VOLUME DISCHARGED	=	0.70	ACRE-FT
POND VOLUME AT PEAK STAGE	=	2.95	ACRE-FT
PEAK STAGE	=	9.92	FT
PEAK INFLOW RATE	=	31.39	CFS
PEAK DISCHARGE RATE	=	0.81	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	51915.4	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	2602.2	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1564.5	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	519.2	MG/L
BASIN TRAP EFFICIENCY	=	97.91	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	91.71	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	21.40	HRS
DETENTION TIME INCLUDING STORED FLOW	=	84.59	HRS
SEDIMENT LOAD	=	71.00	TONS

TABLE A-20. (continued)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	3.62	ACRE-FT
STORM VOLUME DISCHARGED	=	2.12	ACRE-FT
POND VOLUME AT PEAK STAGE	=	4.53	ACRE-FT
PEAK STAGE	=	13.19	FT
PEAK INFLOW RATE	=	44.66	CFS
PEAK DISCHARGE RATE	=	0.49	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	10430.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	559.7	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	323.5	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	194.8	MG/L
BASIN TRAP EFFICIENCY	=	95.75	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	69.57	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	41.13	HRS
DETENTION TIME INCLUDING STORED FLOW	=	59.80	HRS
SEDIMENT LOAD	=	22.00	TONS

TABLE A-20. SEDIMENT POND KY-1A (10 yr. storm)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	3.62	ACRE-FT
STORM VOLUME DISCHARGED	=	2.12	ACRE-FT
POND VOLUME AT PEAK STAGE	=	4.28	ACRE-FT
PEAK STAGE	=	12.68	FT
PEAK INFLOW RATE	=	44.66	CFS
PEAK DISCHARGE RATE	=	0.74	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	10430.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	646.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	390.5	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	235.1	MG/L
BASIN TRAP EFFICIENCY	=	94.88	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	44.49	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.27	HRS
DETENTION TIME INCLUDING STORED FLOW	=	38.22	HRS
SEDIMENT LOAD	=	22.00	TONS

TABLE A-19. SEDIMENT POND KY-1A (5 yr. storm)

PERMANENT POOL CAPACITY	=	1.50	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	2.41	ACRE-FT
STORM VOLUME DISCHARGED	=	0.92	ACRE-FT
POND VOLUME AT PEAK STAGE	=	3.09	ACRE-FT
PEAK STAGE	=	10.20	FT
PEAK INFLOW RATE	=	27.51	CFS
PEAK DISCHARGE RATE	=	0.74	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	10760.5	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	590.0	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	470.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	186.6	MG/L
BASIN TRAP EFFICIENCY	=	95.79	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	33.30	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	16.19	HRS
DETENTION TIME INCLUDING STORED FLOW	=	28.93	HRS
SEDIMENT LOAD	=	14.00	TONS

TABLE A-18. (continued)

PERMANENT POOL CAPACITY	=	1.94	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	3.62	ACRE-FT
STORM VOLUME DISCHARGED	=	1.60	ACRE-FT
POND VOLUME AT PEAK STAGE	=	4.96	ACRE-FT
PEAK STAGE	=	12.80	FT
PEAK INFLOW RATE	=	51.64	CFS
PEAK DISCHARGE RATE	=	0.48	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	165327.4	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	7377.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	4955.8	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	2321.9	MG/L
BASIN TRAP EFFICIENCY	=	97.09	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	92.26	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	42.57	HRS
DETENTION TIME INCLUDING STORED FLOW	=	81.85	HRS
SEDIMENT LOAD	=	372.00	TONS

TABLE A-18. SEDIMENT POND WV-4B (10 yr. storm)

PERMANENT POOL CAPACITY	=	1.94	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	3.62	ACRE-FT
STORM VOLUME DISCHARGED	=	1.68	ACRE-FT
POND VOLUME AT PEAK STAGE	=	4.73	ACRE-FT
PEAK STAGE	=	12.52	FT
PEAK INFLOW RATE	=	51.64	CFS
PEAK DISCHARGE RATE	=	0.72	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	165327.4	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	8980.6	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	5880.4	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	2818.8	MG/L
BASIN TRAP EFFICIENCY	=	96.40	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	78.61	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	28.93	HRS
DETENTION TIME INCLUDING STORED FLOW	=	71.23	HRS
SEDIMENT LOAD	=	372.00	TONS

TABLE A-17. SEDIMENT POND WV-4B (5 yr. storm)

PERMANENT POOL CAPACITY	=	1.94	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	2.72	ACRE-FT
STORM VOLUME DISCHARGED	=	0.77	ACRE-FT
POND VOLUME AT PEAK STAGE	=	3.86	ACRE-FT
PEAK STAGE	=	11.43	FT
PEAK INFLOW RATE	=	38.77	CFS
PEAK DISCHARGE RATE	=	0.72	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	159768.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	8474.4	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	5127.0	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1525.1	MG/L
BASIN TRAP EFFICIENCY	=	98.01	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	72.90	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	21.63	HRS
DETENTION TIME INCLUDING STORED FLOW	=	67.51	HRS
SEDIMENT LOAD	=	270.00	TONS

TABLE A-16. (continued)

PERMANENT POOL CAPACITY	=	1.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	17.89	ACRE-FT
STORM VOLUME DISCHARGED	=	15.94	ACRE-FT
POND VOLUME AT PEAK STAGE	=	15.83	ACRE-FT
PEAK STAGE	=	13.47	FT
PEAK INFLOW RATE	=	94.75	CFS
PEAK DISCHARGE RATE	=	3.87	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	17118.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1336.7	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	503.4	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	451.8	MG/L
BASIN TRAP EFFICIENCY	=	93.47	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	31.96	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	25.69	HRS
DETENTION TIME INCLUDING STORED FLOW	=	31.32	HRS
SEDIMENT LOAD	=	167.00	TONS

TABLE A-16. SEDIMENT POND WV-4A (10 yr. storm)

PERMANENT POOL CAPACITY	=	1.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	17.89	ACRE-FT
STORM VOLUME DISCHARGED	=	15.77	ACRE-FT
POND VOLUME AT PEAK STAGE	=	17.09	ACRE-FT
PEAK STAGE	=	13.90	FT
PEAK INFLOW RATE	=	94.75	CFS
PEAK DISCHARGE RATE	=	2.58	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	17118.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1174.4	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	435.8	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	390.7	MG/L
BASIN TRAP EFFICIENCY	=	94.41	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	49.62	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	39.50	HRS
DETENTION TIME INCLUDING STORED FLOW	=	47.61	HRS
SEDIMENT LOAD	=	167.00	TONS

TABLE A-15. SEDIMENT POND WV-4A (5 yr. storm)

PERMANENT POOL CAPACITY	=	1.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	10.77	ACRE-FT
STORM VOLUME DISCHARGED	=	8.83	ACRE-FT
POND VOLUME AT PEAK STAGE	=	8.97	ACRE-FT
PEAK STAGE	=	11.12	FT
PEAK INFLOW RATE	=	42.29	CFS
PEAK DISCHARGE RATE	=	3.87	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	15103.8	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1236.1	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	507.7	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	420.9	MG/L
BASIN TRAP EFFICIENCY	=	93.52	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	24.47	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	15.46	HRS
DETENTION TIME INCLUDING STORED FLOW	=	23.31	HRS
SEDIMENT LOAD	=	94.00	TONS

TABLE A-14. (continued)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	11.56	ACRE-FT
STORM VOLUME DISCHARGED	=	5.13	ACRE-FT
POND VOLUME AT PEAK STAGE	=	15.93	ACRE-FT
PEAK STAGE	=	22.17	FT
PEAK INFLOW RATE	=	153.03	CFS
PEAK DISCHARGE RATE	=	1.58	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	76208.4	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	4591.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	3032.0	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1398.6	MG/L
BASIN TRAP EFFICIENCY	=	96.07	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	78.76	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	40.59	HRS
DETENTION TIME INCLUDING STORED FLOW	=	68.87	HRS
SEDIMENT LOAD	=	539.00	TONS

TABLE A-14. SEDIMENT POND WV-3B (10 yr. storm)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	11.56	ACRE-FT
STORM VOLUME DISCHARGED	=	5.13	ACRE-FT
POND VOLUME AT PEAK STAGE	=	15.18	ACRE-FT
PEAK STAGE	=	21.65	FT
PEAK INFLOW RATE	=	153.03	CFS
PEAK DISCHARGE RATE	=	2.38	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	76208.4	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	5259.1	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	3600.7	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1660.8	MG/L
BASIN TRAP EFFICIENCY	=	95.34	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	52.83	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.32	HRS
DETENTION TIME INCLUDING STORED FLOW	=	46.35	HRS
SEDIMENT LOAD	=	539.00	TONS

TABLE A-13. SEDIMENT POND WV-3B (5 yr. storm)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	8.72	ACRE-FT
STORM VOLUME DISCHARGED	=	2.30	ACRE-FT
POND VOLUME AT PEAK STAGE	=	12.44	ACRE-FT
PEAK STAGE	=	19.62	FT
PEAK INFLOW RATE	=	115.43	CFS
PEAK DISCHARGE RATE	=	2.38	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	73273.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	4980.0	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	3127.0	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	865.5	MG/L
BASIN TRAP EFFICIENCY	=	97.51	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	42.52	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	19.05	HRS
DETENTION TIME INCLUDING STORED FLOW	=	38.54	HRS
SEDIMENT LOAD	=	392.00	TONS

TABLE A-12. (continued)

PERMANENT POOL CAPACITY	=	6.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	13.00	ACRE-FT
STORM VOLUME DISCHARGED	=	2.88	ACRE-FT
POND VOLUME AT PEAK STAGE	=	17.76	ACRE-FT
PEAK STAGE	=	14.02	FT
PEAK INFLOW RATE	=	119.08	CFS
PEAK DISCHARGE RATE	=	1.48	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	41310.3	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1362.1	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1051.2	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	340.8	MG/L
BASIN TRAP EFFICIENCY	=	98.66	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	108.49	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	45.77	HRS
DETENTION TIME INCLUDING STORED FLOW	=	99.90	HRS
SEDIMENT LOAD	=	306.00	TONS

TABLE A-12. SEDIMENT POND WV-3A (10 yr. storm)

PERMANENT POOL CAPACITY	=	6.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	13.00	ACRE-FT
STORM VOLUME DISCHARGED	=	6.42	ACRE-FT
POND VOLUME AT PEAK STAGE	=	15.62	ACRE-FT
PEAK STAGE	=	13.30	FT
PEAK INFLOW RATE	=	119.08	CFS
PEAK DISCHARGE RATE	=	4.01	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	41310.3	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	2301.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1456.9	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	753.4	MG/L
BASIN TRAP EFFICIENCY	=	95.84	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	78.90	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.28	HRS
DETENTION TIME INCLUDING STORED FLOW	=	70.81	HRS
SEDIMENT LOAD	=	306.00	TONS

TABLE A-11. SEDIMENT POND WV-3A (5 yr. storm)

PERMANENT POOL CAPACITY	=	6.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	9.02	ACRE-FT
STORM VOLUME DISCHARGED	=	2.50	ACRE-FT
POND VOLUME AT PEAK STAGE	=	12.73	ACRE-FT
PEAK STAGE	=	12.34	FT
PEAK INFLOW RATE	=	77.65	CFS
PEAK DISCHARGE RATE	=	2.76	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	41316.5	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1588.2	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1191.8	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	351.0	MG/L
BASIN TRAP EFFICIENCY	=	97.99	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	99.16	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.32	HRS
DETENTION TIME INCLUDING STORED FLOW	=	90.69	HRS
SEDIMENT LOAD	=	202.00	TONS

TABLE A-10. (continued)

PERMANENT POOL CAPACITY	=	4.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	7.97	ACRE-FT
STORM VOLUME DISCHARGED	=	3.59	ACRE-FT
POND VOLUME AT PEAK STAGE	=	11.00	ACRE-FT
PEAK STAGE	=	18.64	FT
PEAK INFLOW RATE	=	87.17	CFS
PEAK DISCHARGE RATE	=	1.13	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	64062.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	3342.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	2429.4	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1119.5	MG/L
BASIN TRAP EFFICIENCY	=	96.15	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	81.24	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	39.70	HRS
DETENTION TIME INCLUDING STORED FLOW	=	71.34	HRS
SEDIMENT LOAD	=	308.00	TONS

TABLE A-10. SEDIMENT POND WV-2B (10 yr. storm)

PERMANENT POOL CAPACITY	=	4.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	7.97	ACRE-FT
STORM VOLUME DISCHARGED	=	3.59	ACRE-FT
POND VOLUME AT PEAK STAGE	=	10.46	ACRE-FT
PEAK STAGE	=	18.23	FT
PEAK INFLOW RATE	=	87.17	CFS
PEAK DISCHARGE RATE	=	1.70	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	64062.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	3897.7	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	2934.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1352.4	MG/L
BASIN TRAP EFFICIENCY	=	95.34	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	54.37	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	25.70	HRS
DETENTION TIME INCLUDING STORED FLOW	=	47.90	HRS
SEDIMENT LOAD	=	308.00	TONS

TABLE A-9. SEDIMENT POND WV-2B (5 yr. storm)

PERMANENT POOL CAPACITY	=	4.37	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	6.01	ACRE-FT
STORM VOLUME DISCHARGED	=	1.64	ACRE-FT
POND VOLUME AT PEAK STAGE	=	8.59	ACRE-FT
PEAK STAGE	=	16.53	FT
PEAK INFLOW RATE	=	64.91	CFS
PEAK DISCHARGE RATE	=	1.70	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	62541.9	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	3638.3	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	2453.3	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	687.6	MG/L
BASIN TRAP EFFICIENCY	=	97.55	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	43.94	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	18.71	HRS
DETENTION TIME INCLUDING STORED FLOW	=	39.87	HRS
SEDIMENT LOAD	=	223.00	TONS

TABLE A-8. (continued)

PERMANENT POOL CAPACITY	=	4.48	ACRE-FT	
DEAD STORAGE	=	0.0	ACRE-FT	
STORM RUNOFF VOLUME	=	23.90	ACRE-FT	
STORM VOLUME DISCHARGED	=	19.39	ACRE-FT	
POND VOLUME AT PEAK STAGE	=	24.54	ACRE-FT	
PEAK STAGE	=	15.77	FT	
PEAK INFLOW RATE	=	117.46	CFS	
PEAK DISCHARGE RATE	=	3.43	CFS	
PEAK INFLOW SEDIMENT CONCENTRATION	=	6184.6	MG/L	(boxed)
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	397.9	MG/L	(boxed)
STORM AVERAGE EFFLUENT CONCENTRATION	=	172.6	MG/L	
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	141.8	MG/L	
BASIN TRAP EFFICIENCY	=	94.65	%	
DETENTION TIME OF FLOW WITH SEDIMENT	=	52.14	HRS	
DETENTION TIME FROM HYDROGRAPH CENTERS	=	38.57	HRS	(boxed)
DETENTION TIME INCLUDING STORED FLOW	=	47.48	HRS	
SEDIMENT LOAD	=	85.00	TONS	

TABLE A-8. SEDIMENT POND WV-2A (10 yr. storm)

PERMANENT POOL CAPACITY	=	4.48	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	23.90	ACRE-FT
STORM VOLUME DISCHARGED	=	19.39	ACRE-FT
POND VOLUME AT PEAK STAGE	=	22.83	ACRE-FT
PEAK STAGE	=	15.45	FT
PEAK INFLOW RATE	=	117.46	CFS
PEAK DISCHARGE RATE	=	5.15	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	6184.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	456.4	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	202.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	166.5	MG/L
BASIN TRAP EFFICIENCY	=	93.72	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	33.56	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	24.73	HRS
DETENTION TIME INCLUDING STORED FLOW	=	30.86	HRS
SEDIMENT LOAD	=	85.00	TONS

TABLE A-7. SEDIMENT POND WV-2A (5 yr. storm)

PERMANENT POOL CAPACITY	=	4.48	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	14.90	ACRE-FT
STORM VOLUME DISCHARGED	=	10.40	ACRE-FT
POND VOLUME AT PEAK STAGE	=	14.01	ACRE-FT
PEAK STAGE	=	12.80	FT
PEAK INFLOW RATE	=	58.51	CFS
PEAK DISCHARGE RATE	=	5.15	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	5702.7	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	427.8	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	212.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	151.4	MG/L
BASIN TRAP EFFICIENCY	=	93.99	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	22.80	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	13.91	HRS
DETENTION TIME INCLUDING STORED FLOW	=	20.05	HRS
SEDIMENT LOAD	=	50.00	TONS

TABLE A-6. (continued)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	11.23	ACRE-FT
STORM VOLUME DISCHARGED	=	4.81	ACRE-FT
POND VOLUME AT PEAK STAGE	=	15.68	ACRE-FT
PEAK STAGE	=	22.02	FT
PEAK INFLOW RATE	=	148.66	CFS
PEAK DISCHARGE RATE	=	1.54	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	125316.0	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	6777.7	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	4465.2	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1978.6	MG/L
BASIN TRAP EFFICIENCY	=	96.61	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	79.73	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	40.56	HRS
DETENTION TIME INCLUDING STORED FLOW	=	69.86	HRS
SEDIMENT LOAD	=	861.00	TONS

TABLE A-6. SEDIMENT POND WV-1B (10 yr. storm)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	11.23	ACRE-FT
STORM VOLUME DISCHARGED	=	4.81	ACRE-FT
POND VOLUME AT PEAK STAGE	=	14.96	ACRE-FT
PEAK STAGE	=	21.48	FT
PEAK INFLOW RATE	=	148.66	CFS
PEAK DISCHARGE RATE	=	2.31	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	125316.0	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	7994.5	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	5398.3	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	2392.6	MG/L
BASIN TRAP EFFICIENCY	=	95.90	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	51.51	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.29	HRS
DETENTION TIME INCLUDING STORED FLOW	=	45.05	HRS
SEDIMENT LOAD	=	861.00	TONS

TABLE A-5. SEDIMENT POND WV-1B (5 yr. storm)

PERMANENT POOL CAPACITY	=	6.42	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	8.47	ACRE-FT
STORM VOLUME DISCHARGED	=	2.05	ACRE-FT
POND VOLUME AT PEAK STAGE	=	12.30	ACRE-FT
PEAK STAGE	=	19.52	FT
PEAK INFLOW RATE	=	112.13	CFS
PEAK DISCHARGE RATE	=	2.31	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	100058.5	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	6696.4	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	4013.9	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	1015.8	MG/L
BASIN TRAP EFFICIENCY	=	97.85	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	44.11	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	19.18	HRS
DETENTION TIME INCLUDING STORED FLOW	=	40.30	HRS
SEDIMENT LOAD	=	520.00	TONS

TABLE A-4. (continued)

PERMANENT POOL CAPACITY	=	6.33	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	21.59	ACRE-FT
STORM VOLUME DISCHARGED	=	12.32	ACRE-FT
POND VOLUME AT PEAK STAGE	=	24.75	ACRE-FT
PEAK STAGE	=	15.95	FT
PEAK INFLOW RATE	=	99.93	CFS
PEAK DISCHARGE RATE	=	3.10	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	22634.9	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1280.9	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	732.9	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	491.8	MG/L
BASIN TRAP EFFICIENCY	=	95.83	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	80.19	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	40.76	HRS
DETENTION TIME INCLUDING STORED FLOW	=	71.96	HRS
SEDIMENT LOAD	=	294.00	TONS

TABLE A-4. SEDIMENT POND WV-1A (10 yr. storm)

PERMANENT POOL CAPACITY	=	6.33	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	21.59	ACRE-FT
STORM VOLUME DISCHARGED	=	15.00	ACRE-FT
POND VOLUME AT PEAK STAGE	=	22.05	ACRE-FT
PEAK STAGE	=	15.34	FT
PEAK INFLOW RATE	=	99.93	CFS
PEAK DISCHARGE RATE	=	6.34	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	22634.9	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1595.8	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	824.6	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	587.9	MG/L
BASIN TRAP EFFICIENCY	=	94.28	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	57.58	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	26.08	HRS
DETENTION TIME INCLUDING STORED FLOW	=	52.20	HRS
SEDIMENT LOAD	=	294.00	TONS

TABLE A-3. SEDIMENT POND WV-1A (5 yr. storm)

PERMANENT POOL CAPACITY	=	6.33	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	13.86	ACRE-FT
STORM VOLUME DISCHARGED	=	7.32	ACRE-FT
POND VOLUME AT PEAK STAGE	=	16.31	ACRE-FT
PEAK STAGE	=	13.57	FT
PEAK INFLOW RATE	=	53.99	CFS
PEAK DISCHARGE RATE	=	4.45	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	21002.8	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1239.3	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	740.7	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	405.9	MG/L
BASIN TRAP EFFICIENCY	=	95.91	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	74.95	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	25.72	HRS
DETENTION TIME INCLUDING STORED FLOW	=	67.10	HRS
SEDIMENT LOAD	=	180.00	TONS

TABLE A-2. (continued)

PERMANENT POOL CAPACITY	=	2.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	5.16	ACRE-FT
STORM VOLUME DISCHARGED	=	1.98	ACRE-FT
POND VOLUME AT PEAK STAGE	=	7.13	ACRE-FT
PEAK STAGE	=	6.78	FT
PEAK INFLOW RATE	=	61.69	CFS
PEAK DISCHARGE RATE	=	0.78	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	54295.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	1811.6	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1151.1	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	481.9	MG/L
BASIN TRAP EFFICIENCY	=	98.18	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	94.08	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	38.43	HRS
DETENTION TIME INCLUDING STORED FLOW	=	84.26	HRS
SEDIMENT LOAD	=	170.00	TONS

TABLE A-2. SEDIMENT POND PA-1 (10 yr. storm)

PERMANENT POOL CAPACITY	=	2.93	ACRE-FT
DEAD STORAGE	=	0.0	ACRE-FT
STORM RUNOFF VOLUME	=	5.16	ACRE-FT
STORM VOLUME DISCHARGED	=	2.22	ACRE-FT
POND VOLUME AT PEAK STAGE	=	6.68	ACRE-FT
PEAK STAGE	=	6.38	FT
PEAK INFLOW RATE	=	61.69	CFS
PEAK DISCHARGE RATE	=	1.31	CFS
PEAK INFLOW SEDIMENT CONCENTRATION	=	54295.6	MG/L
PEAK EFFLUENT SEDIMENT CONCENTRATION	=	2312.3	MG/L
STORM AVERAGE EFFLUENT CONCENTRATION	=	1424.8	MG/L
AVERAGE EFFLUENT SEDIMENT CONCENTRATION	=	635.7	MG/L
BASIN TRAP EFFICIENCY	=	97.48	%
DETENTION TIME OF FLOW WITH SEDIMENT	=	82.27	HRS
DETENTION TIME FROM HYDROGRAPH CENTERS	=	25.04	HRS
DETENTION TIME INCLUDING STORED FLOW	=	75.07	HRS
SEDIMENT LOAD	=	170.00	TONS