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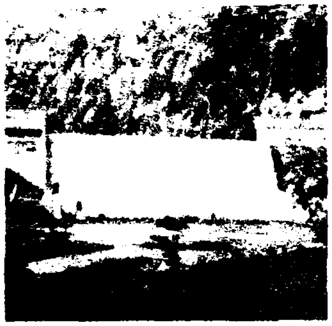

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-88-21

MARTINS FORK LAKE SEDIMENTATION STUDY

Hydraulic Model Investigation

by

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This report presents the analysis of the unexpectedly high rate of infill experienced at Martins Fork Lake, located in Harlan County, KY. The dam which impounds the lake is located in a drainage basin that has been actively strip-mined for a number of years. The study utilized the numerical model HL-1, "Sedimentation in Stream Networks," authored by Mr. W. A. Thomas. Existing conditions were verified by subjecting the initial lake geometry to historical inflows and reproducing actual deposition patterns and storage loss in the lake. Future conditions under several alternative inflowing water hydrographs, inflowing sediment loads, and land use conditions were analyzed. Results are discussed and recommendations made to mitigate future loss of flood-control storage.

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SUMMARY

This study was performed for the US Army Engineer District, Nashville. The Martins Fork Lake is located at mile 15.6 on the Martins Fork of the Cumberland River in southeast Kentucky. Significant surface strip mining of coal is conducted in the basin above the dam. In the first 6 years after closure of the dam in November 1978, the district measured lake infill rates varying from 0.37 acre-ft/square mile/year to 4.5 acre-ft/square mile/year. The average infill rate for the period May 1978 to June 1984 was 1.68 acre-ft/square mile/year. This significantly exceeded the design infill rate of 0.50. The district sought the involvement of the US Army Engineer Waterways Experiment Station (WES) to address this problem.

The study was designed to predict lake storage loss up to 50 years into the future under various assumptions of future conditions. Several remedial measures were also evaluated to mitigate loss of storage and recreational benefits. A one-dimensional computer model was developed to analyze the alternatives. The model used was the WES Stream Network Model (HL-1). This is a modified version of the HEC-6 code that allows simultaneous analysis of tributaries and the main stem of a stream network.

The HL-1 model was verified by reproducing depositional patterns and infill rates in the lake observed during the sediment range surveys in 1979, 1980, 1983, and 1984. Long-term (50-year) inflow hydrographs were developed since the homogeneous record was only 8 years in length. These hydrographs represented observed inflow rates, expected inflow rates, and worst case inflow rates. Water-discharge versus sediment-discharge relationships were developed from available data. These represented design conditions, observed conditions, and worst probable conditions of sediment inflow to the lake. Changes in total and flood-control storage were recorded for each test as were changes in lake depth.

Results of the alternatives tested revealed that for the assumed future conditions tested, the dam should provide most of the intended degree of flood control. The loss of flood-control storage varied from a low of 1.65 percent (Test 1) to a high of 13.8 percent (Test 10). Other alternatives (Tests 2-9) tested the sensitivity of the results by altering the future conditions. Several different inflowing hydrographs were tested in conjunction with several different sets of assumptions as to the amount of sediment that might be

transported into the lake. These resulted in losses of flood control storage that varied from 2.94 percent (Test 2) to 8.98 percent (Test 6). Under all alternatives analyzed, the lake will experience significant loss of depth and surface area due to infilling. Varying the operating rule curve for the lake (Test 8) reduced the infill rate expected under the current scheme of operation and mitigated the loss of depth in the lake by more evenly distributing the sediment deposition.

PREFACE

The work described in this report was performed from May 1987 to December 1987 for the US Army Engineer District, Nashville, and was funded under DA Form 2544 No. 87-0046.

Mr. W. D. Martin of the US Army Engineer Waterways Experiment Station (WES) was the Principal Investigator responsible for conducting the work and preparing this report. Mr. Martin worked under the supervision of Messrs. F. A. Herrmann, Jr., Chief, Hydraulics Laboratory (HL); R. A. Sager, Assistant Chief, HL; and W. H. McAnally, Jr., Chief, Estuaries Division. This report was edited by Mr. B. Odom, Information Technology Laboratory, under the Inter-Governmental Personnel Act.

Mrs. Peggy Hoffman, a technician in the HL Waterways Division (HR), performed the computer input and output tasks. Mr. W. A. Thomas, HR, provided valuable consultation and computer code modifications.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
feet per mile	0.1893935	metres per kilometre
gallons (US liquid)	3.785412	cubic decimetres
inches	2.54	centimetres
pounds (force) per square foot	14.5939	newtons per metre
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
square yards	0.8361274	square metres
tons (force)	8.896444	kilonewtons
yards	0.9144	metres

* To obtain Celsius (C) temperature readings from Farenheit (F) readings, use the following formula: C = (5/9)(F - 32).

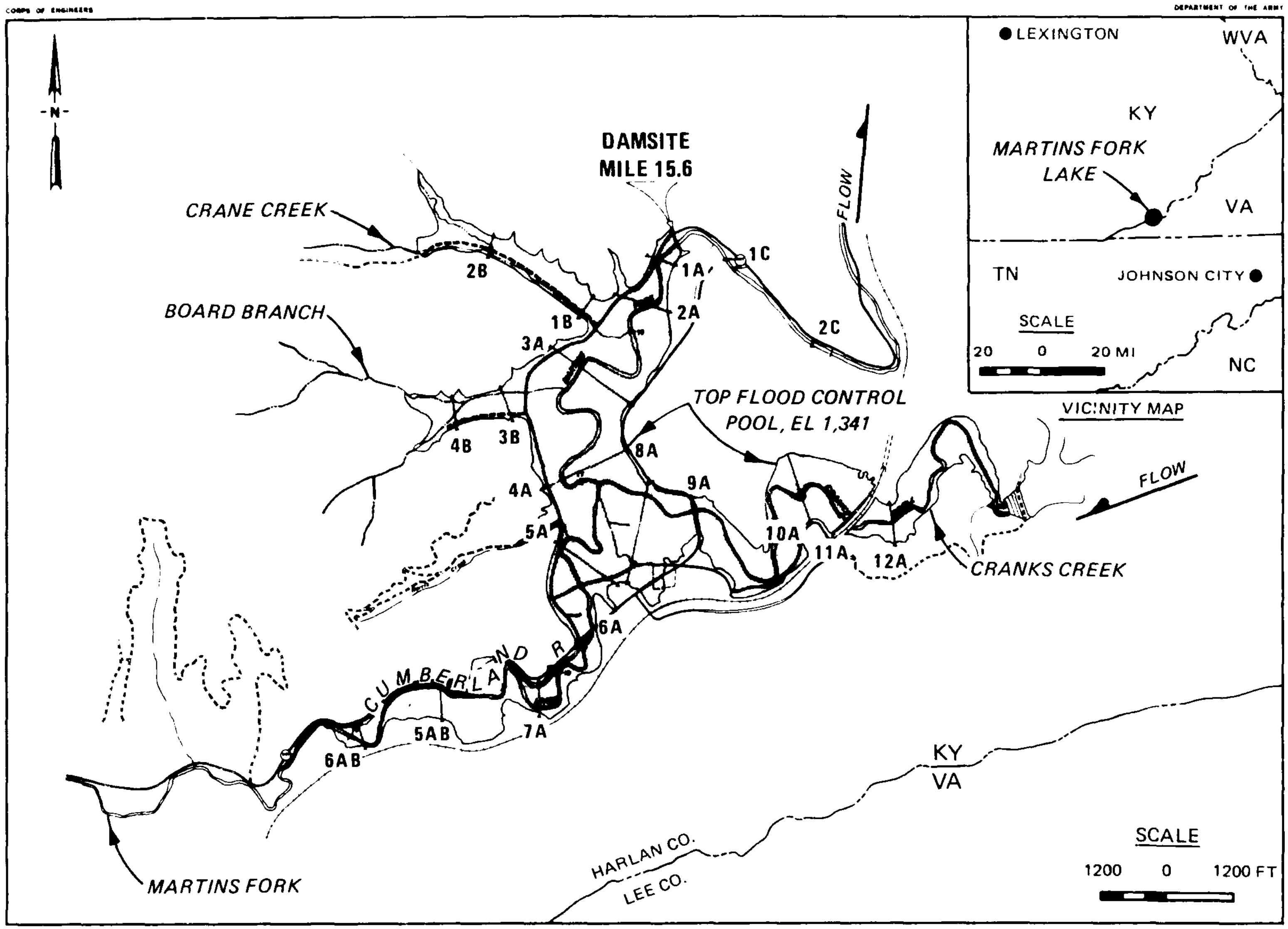

Figure 1. Martins Fork Lake, sedimentation ranges

MARTINS FORK LAKE SEDIMENTATION STUDY

PART I: INTRODUCTION

Authority

1. The Martins Fork dam and lake were authorized by the Flood Control Act of 27 October 1965 (PL 89-298, 89th Congress). This study was authorized by the US Army Engineer District, Nashville (ORN), on 10 April 1987.

Purpose

2. The purpose of this study is to evaluate sedimentation and associated impacts for Martins Fork Lake, KY, for the do-nothing alternative and several remedial measures which are intended to extend the effective life of the project.

Description of Project

Dam

3. Construction of the Martins Fork project was begun in December 1973, and the dam was closed in November 1978. The project was designed with the multiple purposes of flood control, water quality, and recreation. The dam is located at mile 15.6 on Martins Fork of the Cumberland River, Harlan County, KY (Figure 1). The dam is a straight concrete gravity structure. The top of the dam is located at el 1,360.* The emergency spillway is at el 1,341. There are three 4- by 4-ft** sluice gates with invert el of 1,272, 1,283, and 1,296. Pertinent data for the lake and dam are summarized in Appendix A.

Lake

4. The lake is regulated on a seasonal basis. The operation rule curve indicates that the water-surface elevation in the lake will be raised from el 1,300 to el 1,310 during the month of April. This elevation is maintained

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

** A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

until 1 October when the lake is drawn down to el 1,300 during the months of October and November. The lake stage is then maintained at el 1,300 until the following April. There are four inflow points in the reservoir. Crane Creek and Board Branch form two small arms of the reservoir. Cranks Creek and upper Martins Fork are the two main tributaries of the lake (Figure 1).

Basin

5. The basin is 26 miles in length and extends some 10 miles above the dam. The basin is 4 miles wide at the widest point. An earthfill dam on Cranks Creek controls 24.8 square miles of the drainage area above Martins Fork dam which totals 55.7 square miles. Martins Fork is a tributary of Clover Fork, which with Poor Fork forms the head waters of the Cumberland River (US Army Engineer District (USAED), Nashville, 1979). The three forks meet at the town of Harlan, KY. The dam on Martins Fork provides partial flood control to Harlan, KY. In 1977, the land use above the dam was as shown in Table 1.

Table 1

Land Use Above Martins Fork Dam Site, 1977

(USAED, Nashville, 1979)

	Acres	Percent of Total
Total drainage area	35,650	100
Water area	580	1.6
Agriculture	4,917	13.8
Woodland	28,047	78.7
Strip-mined areas	1,386	3.9
Miscellaneous (residential, roads, etc.)	720	2.0

Climatology

6. The climate of the Martins Fork watershed is a continental type affected by the mountainous nature of the terrain. Annual temperatures typically range from 0° to 100° F. The mean annual temperature is 58° F with January and July having the coldest (40° F) and warmest (77° F) average temperatures, respectively. The climate is characterized by high relative

humidity, low wind velocities, and frequent and rapid changes in the weather (USAED, Nashville, 1979).

Hydrology

7. The average annual precipitation is 49 in. with an average annual runoff of 29.52 in. Snow is frequent with 15 to 20 in. falling annually depending on the elevation. Major precipitation-producing storms are frontal in nature. The passage of the storm fronts frequently spawn thunderstorms that are responsible for locally heavy rainfall. Due to its steep topography and relatively short length, storms in the basin tend to produce rapid rise and fall of the stream elevation. Stream-gaging records have been kept on Martins Fork at a point just below the dam site since April 1971. The flood of record occurred in April 1977 before closure of the dam.

Historic Project Performance

8. The original design sediment inflow rate during the early design phase for the lake was 0.41 acre-ft/square mile of drainage area (USAED, Nashville, 1979). However, prior to closure of the dam, sediment began depositing behind the dam. This prompted more detailed analysis of the inflowing sediment rate. The district suspected that the actual inflow rate was greater than that allowed in the design of the project and began a monitoring program to quantify the problem that they faced. This earlier study was based on suspended sediment data collected by the district over a 1-year period (October 1976-September 1977). From this limited data set, a water discharge versus sediment discharge (Q versus Q_S) rating curve was developed. This curve, in conjunction with 7 years of historical water discharges taken on Martins Fork near Smith, KY, was used to calculate the annual sediment discharge. The Smith, KY, gage is located 0.3 mile below the dam site. As might be expected from a limited suspended sediment data set, the data represented a significant scatter of points. The sediment discharge was computed for an upper and lower envelope line and for the line of best fit. The computed values were 9.53, 1.67, and 5.20 acre-ft/square mile, respectively (USAED, Nashville, 1979). The design discharge was based on the reservoir on Cranks Creek trapping 100 percent of the sediment flowing into it. The 1976-1977 measurements

were taken at a point below the confluence of Cranks Creek and Martins Fork. During the sampling period, the Cranks Creek dam was being drained while work proceeded to provide additional outlet works at Cranks Creek dam. ORN personnel estimated that 70 percent of the sediment discharge measured came from Cranks Creek. Based on these observations and the measurements taken, 30 percent of the 1.67 acre-ft/square mile, or 0.50 acre-ft/square mile was selected to represent the new expected sediment inflow rate (USAED, Nashville, 1981).

9. Because of the uncertainty of the true sediment inflow rate, ORN decided to conduct follow-up sediment surveys of the Martins Fork Lake after closure in an attempt to better predict the inflowing sediment rate. These results were published as Supplements 1, 2, and 3 (USAED, Nashville, 1981, 1983, 1985) to Design Memorandum (DM) No. 9 (USAED, Nashville, 1979) that established the sediment ranges to be surveyed.

10. Supplement 1 (USAED, Nashville, 1981) established that 296 acre-ft of storage had been lost between May 1978 and July 1980. This equated to an inflow rate of 4.50 acre-ft/square mile/year. After adjusting this, based on an unauthorized operation of the Cranks Creek dam low level sluice gate, ORN revised the apparent measured inflow rate of 4.50 acre-ft/square mile/year to an inflow rate of 3.50 acre-ft/square mile/year. This was considerably above the 0.50 value established in DM No. 9 (USAED, Nashville, 1979).

11. Supplement 2 (USAED, Nashville, 1983) reported that 32 acre-ft of sediment were deposited between July 1980 and June 1983. This translated to 0.37 acre-ft/square mile/year. In order to resolve the difference between the Supplement 1 and Supplement 2 rates, a third resurvey was planned for June 1984 (USAED, Nashville, 1983).

12. Supplement 3 (USAED, Nashville, 1985) reported that 56 acre-ft were deposited between June 1983 and June 1984. This translated to 1.9 acre-ft/square mile/year which was considerably greater than the 0.50 value established in DM No. 9 (USAED, Nashville, 1979). Confronted with sediment inflow rates varying from 0.37 to 4.5 acre-ft/square mile/year, ORN sought US Army Engineer Waterways Experiment Station (WES) involvement in order to better understand the sedimentation rate and to provide a tool for reliable future prediction.

13. A modified version of the computer code HEC-6, "Scour and Deposition in Rivers and Reservoirs" (US Army Hydrologic Engineering Center 1977) was used in this study. The modified version is a WES code, "Sedimentation in Stream Networks," version 1.00 (HL-1). Unlike HEC-6, this code allows computations to simultaneously consider the interaction of several tributaries. Data requirements for the computer code were divided into three groups; (a) geometric, (b) sediment, and (c) hydrologic. A schematic of the model is shown in Figure 2.

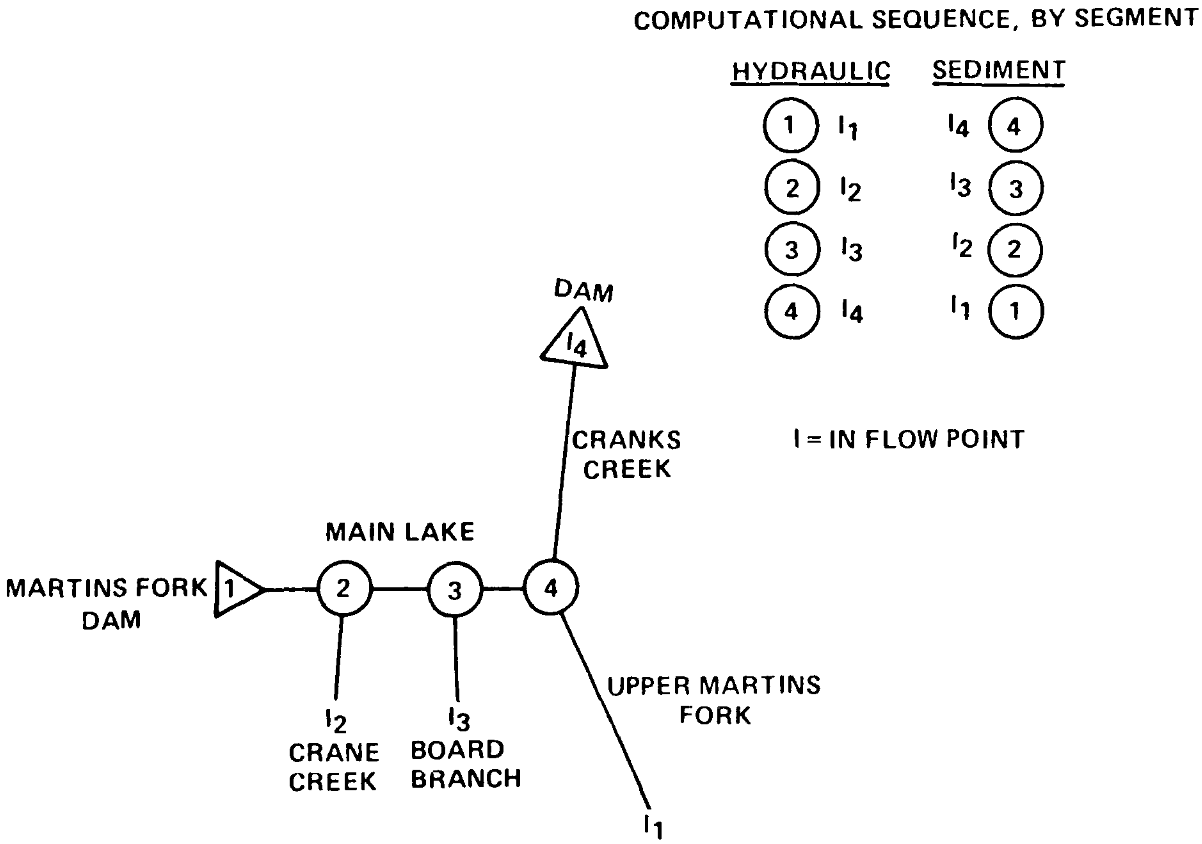

Figure 2. Schematic of the numerical model and computation sequence

Geometric Data

14. Geometric data required consisted of cross-section information for the base condition and for several of the resurveys conducted. The location of these cross sections is the same as the standard sediment ranges as shown

in Figure 1. Additional cross sections were generated by applying the ground slope to existing cross sections and interpolating them over the distance required. The base condition was taken to be that represented by the May 1978 survey. These data were provided by ORN in the form of computer files in the format required for the computer program "Geometric Elements from Cross Section Coordinates" (GEDA). The GEDA files were converted to HEC-6 format.

Roughness

15. Manning's n values were selected for each stem of the network. The values selected are shown in Table 2.

Table 2

Manning's n Values

Network	n Value
Martins Fork main stem	0.040
Crane Creek	0.045
Board Branch	0.050
Cranks Creek	0.045

Overbank n values were all 0.10. Prototype storage values for use in verification of the model were taken from DM No. 9 (USAED, Nashville, 1979) and the three supplements as reported on Eng Form 1787.

Modifications

16. It was also necessary to extend the model boundaries farther up the two main lake tributaries. A weighted stream slope was calculated for the main stem based on the slope and reach lengths for the last six sections on this reach. This resulted in a stream slope of 15.94 ft/mile. This slope was applied to generate five extrapolated sections on the main stem over a 10,050-ft reach. From quadrangle maps, a slope of 6.94 ft/mile was used to generate four sections on Cranks Creek over a 3,150-ft reach. On the two minor tributaries, the last cross section was extended at zero slope to the end of the cove formed by the lake. These adjustments were necessary to reproduce the prototype volume in the model.

Sediment

General

17. The sediment data required for input to the computer program consisted of data describing the bed material, the size fractions present in the inflowing sediment load, and the water discharge versus sediment discharge relationship.

Bed material

18. ORN provided sediment samples of the bed material in the reservoir and on the two main tributaries. The location of these samples is shown in Figure 3. These were analyzed by WES personnel. As expected, the samples taken from the reservoir bed were primarily fine sand, silts, and clays. The Stream Network Model (HL-1) requires a description of the bed material present initially at each cross section by grain size fraction. Since there were no data available that described the bed prior to closure of the dam, the existing samples were analyzed, and a representative composite grain size distribution curve was developed. This was used at each cross section throughout the model to simulate the bed as it existed at the time the dam was closed. This composite curve is shown in Figure 4.

Size fractions

19. The HL-1 requires that the inflowing total sediment load be broken down by size fraction. The US Geological Survey (USGS) collects daily suspended sediment samples on Martins Fork above the lake. These data were available for the period June 1985 through April 1987. The location of this gage is shown in Figure 3. Limited detailed data were available for a range of flows. The grain size curves of the suspended sediment for three inflow rates are shown in Figure 5. These curves were used as the basis for breaking down total inflowing sediment load by size fraction. Curve 1 was not used. Curve 2 was used for Martins Fork main stem and Cranks Creek. Curve 3 was used for Crane Creek and Board Branch.

Inflowing sediment

20. The USGS inflowing sediment data for water discharges greater than 5 cfs were plotted to help determine the Q versus Q_s relationship for Martins Fork. The plotted raw data is shown in Figure 6. This data set was considered inadequate in and of itself due to the lack of the important high flow points. To augment and extend this data set, inflowing sediment loads

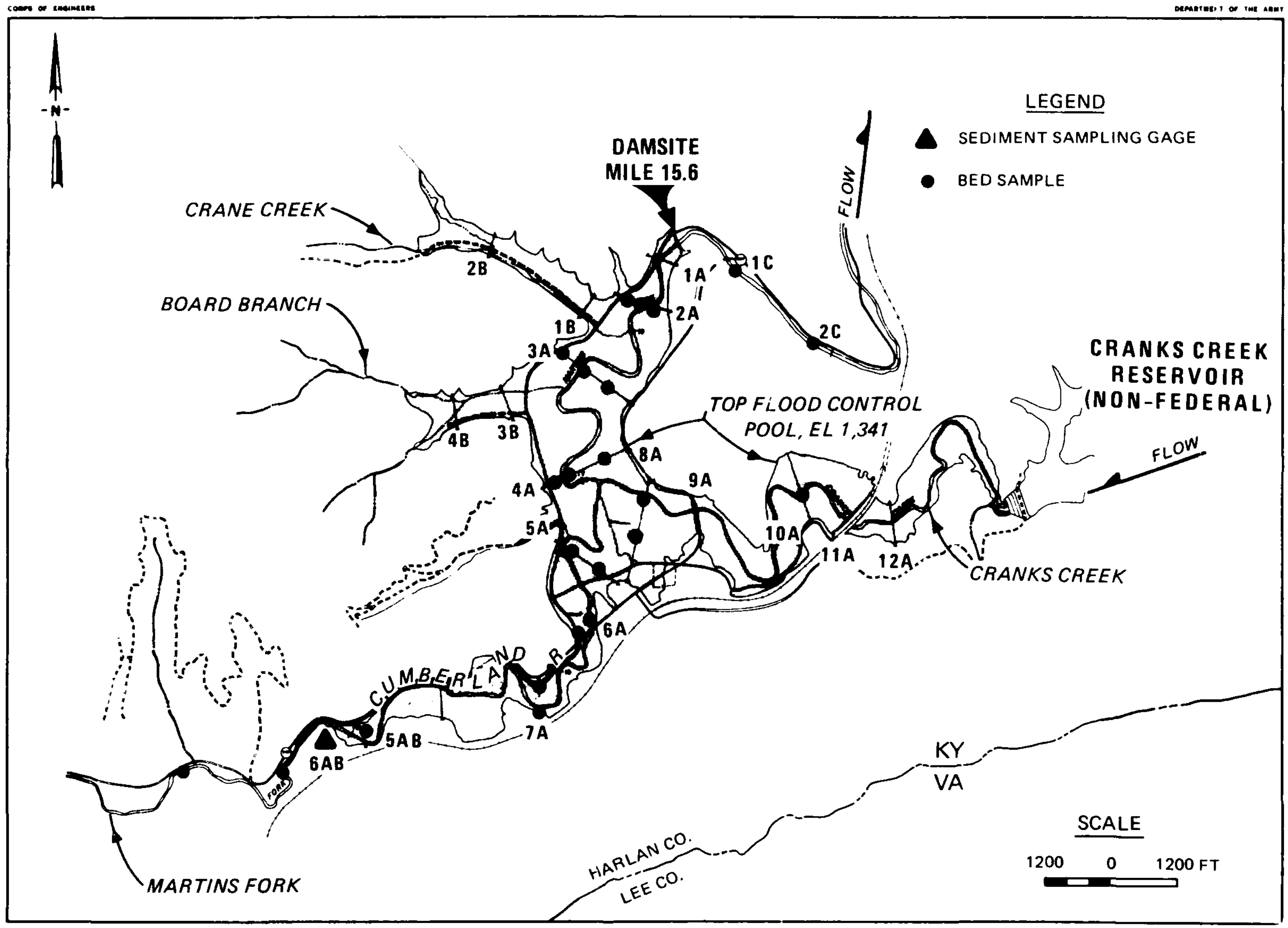

Figure 3. Martins Fork Lake, location of bed samples

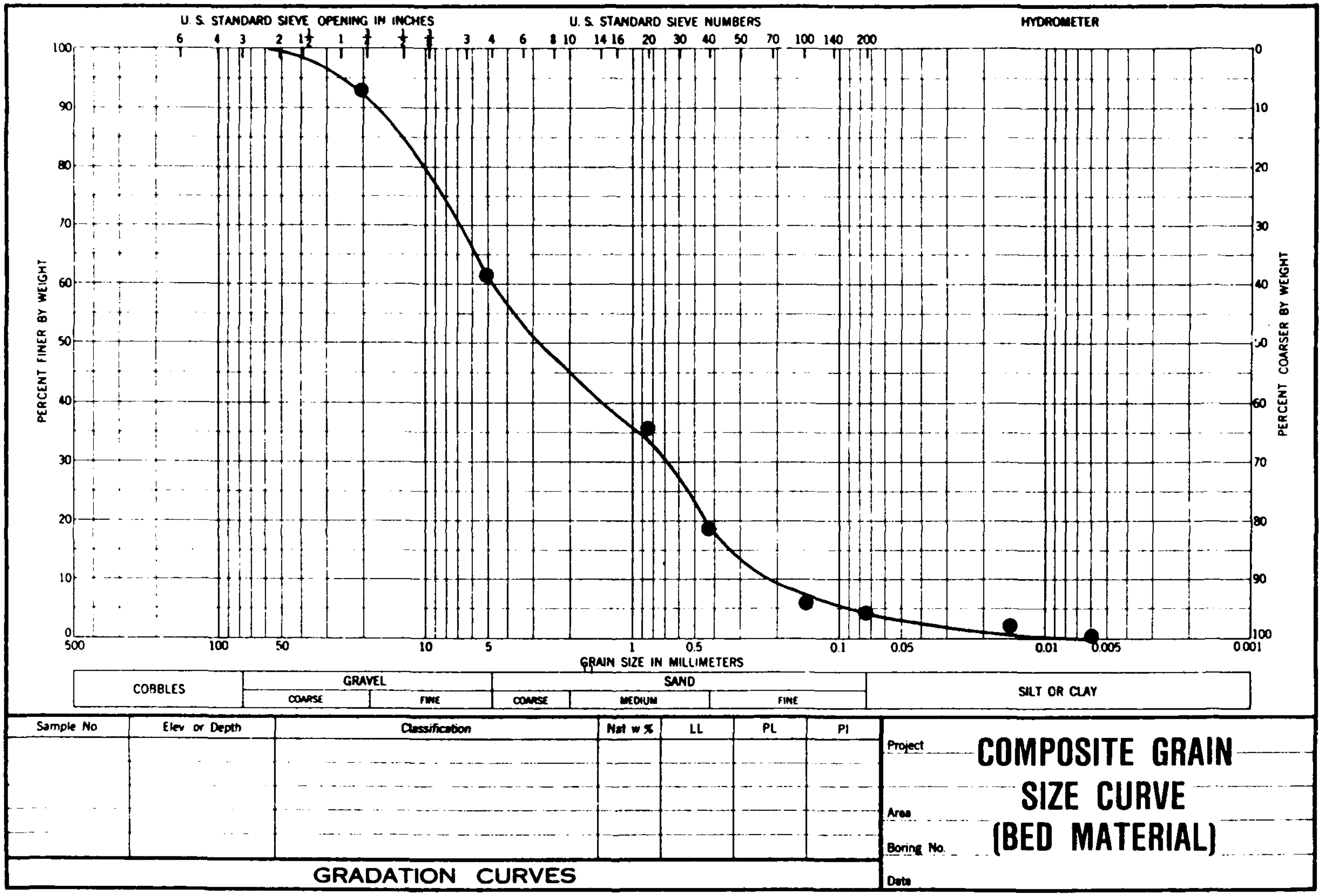

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Figure 4. Martins Fork Lake, composite grain size curve (bed material)

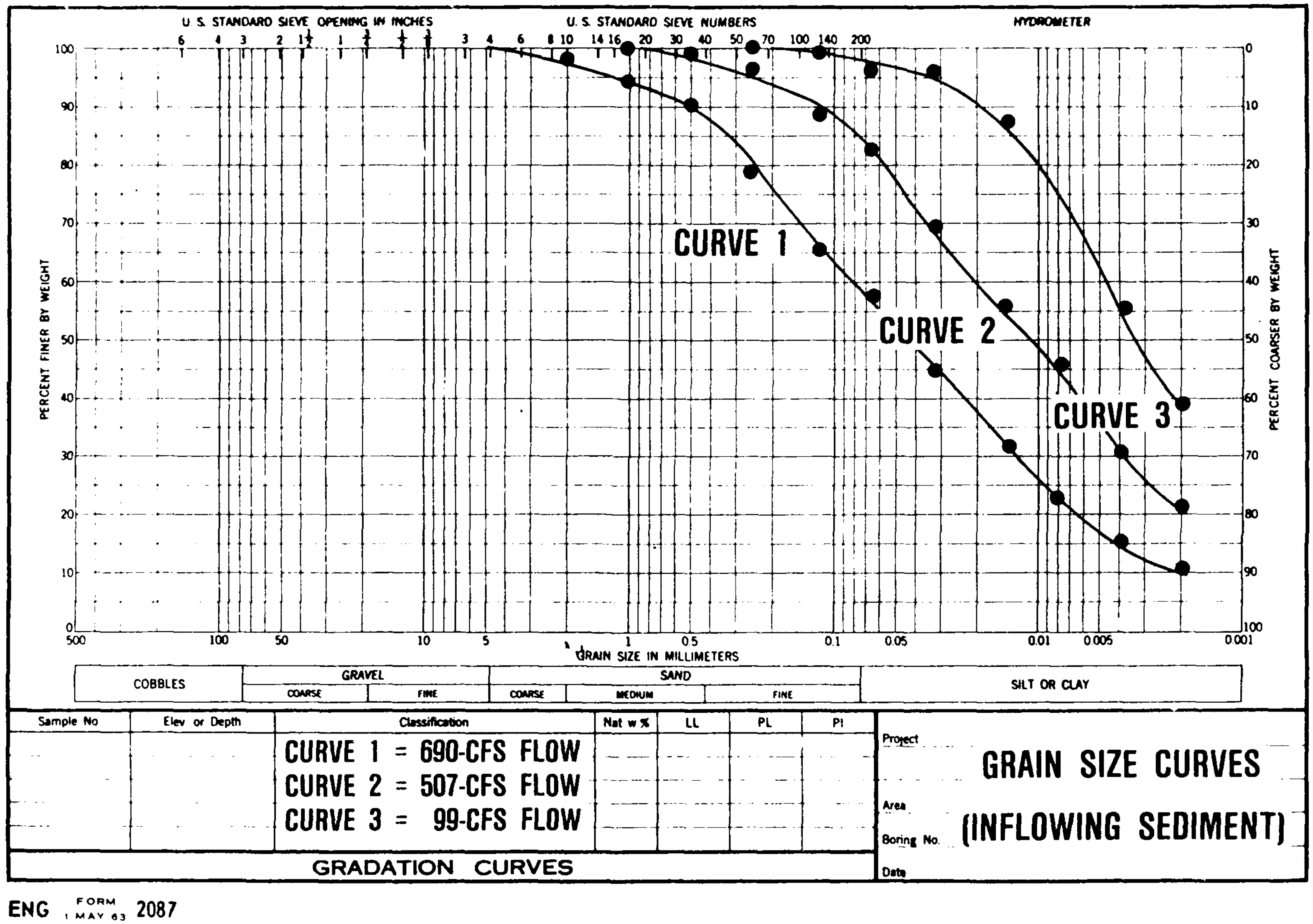

Figure 5. Martins Fork Lake, grain size curves (inflowing sediment)

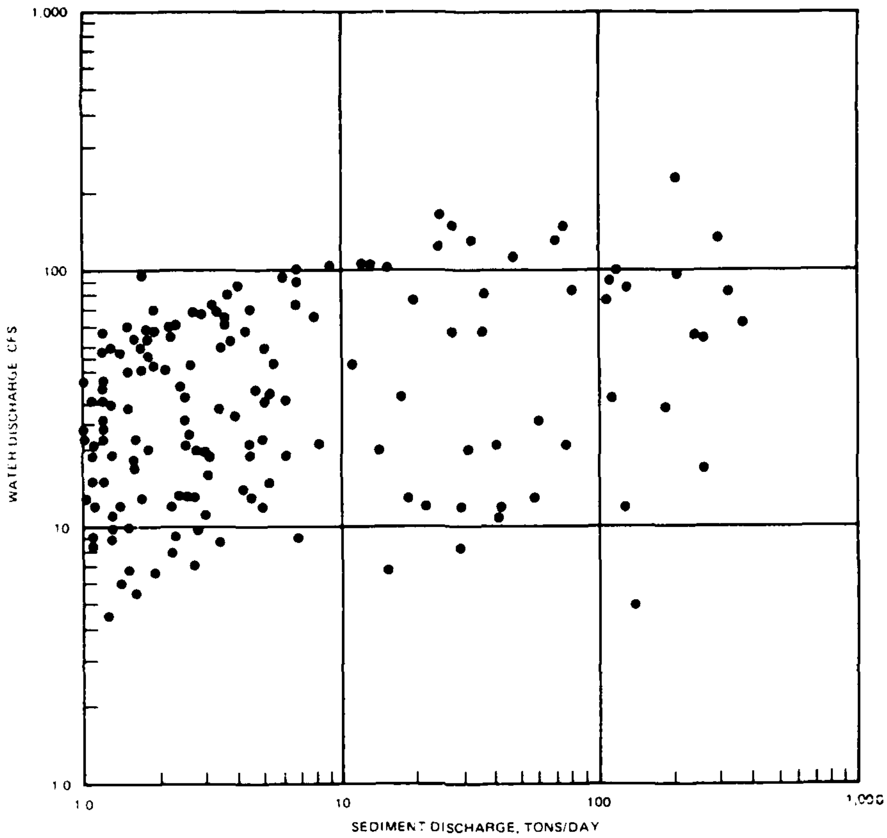

Figure 6. Martins Fork Lake, inflowing sediment data points

were calculated. Random flows up to the highest flow in the historical record were run with the model in a fixed bed mode. This allowed the hydraulics to be calculated furnishing velocities, water discharges, and slopes. The transport equation selected was the Memphis District equation. This equation is a version of Ilo's equation (Ilo 1975) that was modified by the author and Guy W. Forney, Jr., US Army Engineer District, Memphis, in 1976. The form of the equation is given below.

$$Q_s = \frac{1}{4} Q \, (V*V) \, \frac{S}{d_{65}}$$

where

Q_s = sediment discharge, tons/day

Q = water discharge, cfs

V = average velocity, fps

S = slope, ft/ft

d_{65} = grain size of bed material for which 65 percent is finer by weight, ft

To fully represent lake conditions, the hydraulics were generated for lake el of 1,300 and 1,310. The inflowing sediment load was then calculated for a range of flows for each condition using a d_{65} of 0.09 mm determined from studying bed samples obtained by ORN. From these calculations, a composite Q versus Q_s curve was developed based on a weighted average of the time the lake was at each elevation according to the operating rule curve. Utilization of this curve will be discussed later in the verification section of this report. The curves developed are shown in Figure 7 along with selected prototype data points for high flows which transported at least 100 tons/day of sediment.

Hydrologic Data

General

21. Hydrologic data for input into the program consists of water discharge rates, starting water-surface elevations, water temperatures, and durations of the discharges.

Discharges

22. Inflows to the lake were provided by ORN for the period January 1979-June 1987. These were calculated based on known dam releases, known lake stages, and known changes in storage. The inflows were used to generate the hydrographs for the verification and production computer runs. The historical hydrograph was analyzed and reduced to a discharge histogram that preserved the water/sediment relationship. This allowed economical computer analysis without affecting the final results. Basically, flows greater than 100 cfs were represented as daily discharges. Flows less than 100 cfs were represented by variable durations up to 31 days for periods of extremely low flows.

23. ORN also provided the flood of record discharges as recorded at the gaging station located 0.3 mile below the dam site. This flood occurred from 6 a.m. on 3 April 1977 to 12 midnight on 17 April 1977. This storm was added to several of the histograms. ORN reported the event to be approximately the 50-year storm. In order to fully evaluate this extreme event, it was represented by 6-hr or 0.25-day flow durations.

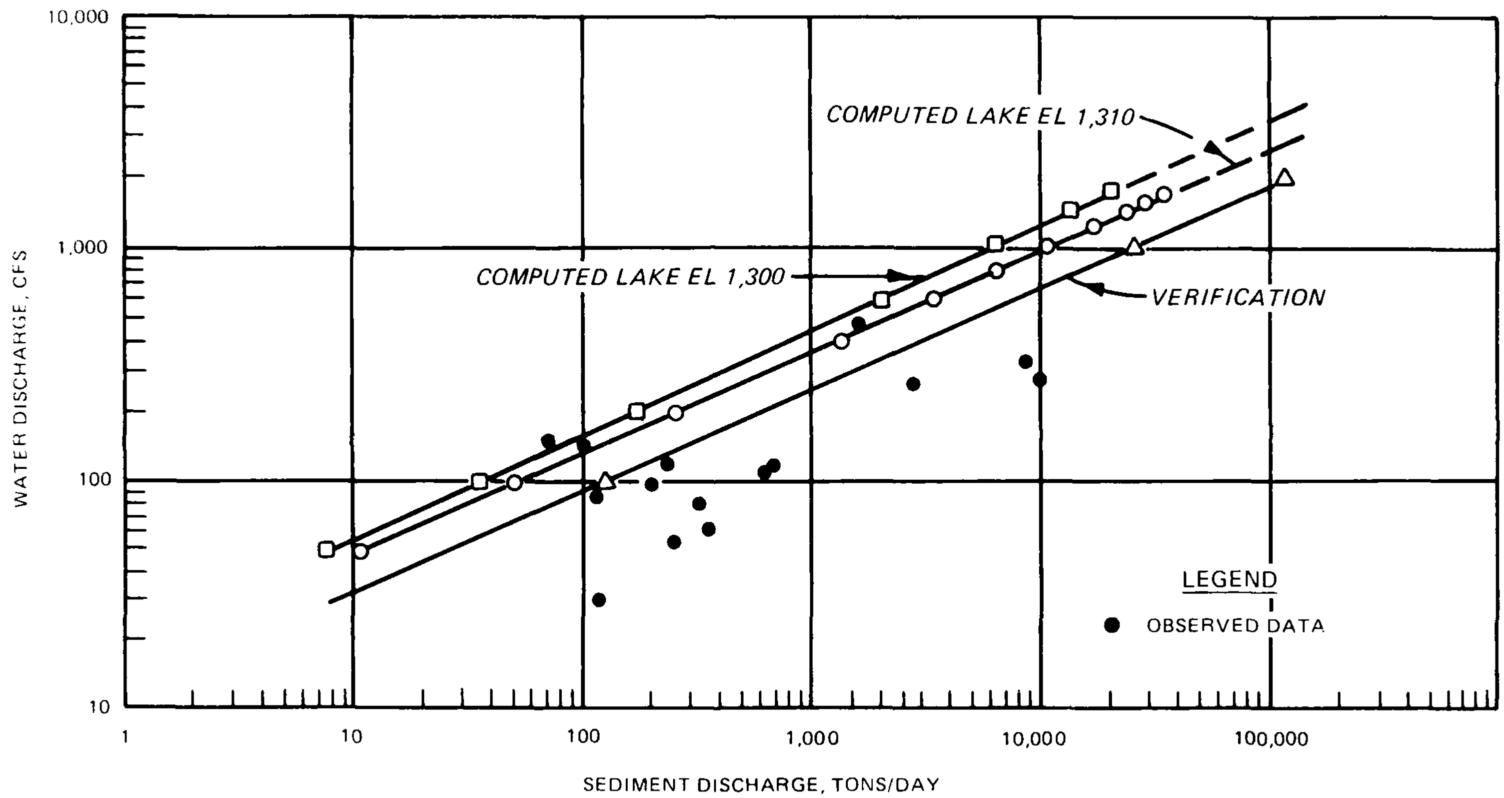

Figure 7. Martins Fork Lake, inflowing sediment relationships

24. The ORN historical inflows represent net inflow to the lake without respect to origin. Therefore, it was necessary to distribute the flows among the various tributaries. ORN had limited field measurements taken during the period September 1984-April 1986. These measured the flow contribution of Cranks Creek. The percent contribution from Cranks Creek varied widely from a low of 31 percent to a high of 75 percent. The average of the 16 measurements indicated that 43.3 percent of the flow was contributed by Cranks Creek.

25. By planimetering the drainage areas of the four tributaries to the lake (Crane Creek, Board Branch, Cranks Creek, and Upper Martins Fork), the relative percent of the basin above the dam was determined. These are shown in Table 3.

Table 3

Tributary Drainage Areas and Flow Contribution

Tributary	Percent Basin Area	Recommended Flow, %
Crane Creek	3	3
Board Branch	2	2
Cranks Creek	44.5	44.5
Martins Fork	50.5	50.5

This method resulted in 44.5 percent of the flow being contributed by Cranks Creek. This compares favorably with the 43.3 percent average from field observations. It also provides a reasonable basis for assigning flows to the minor tributaries.

Water-surface elevations

26. Water-surface elevations were available from ORN as daily lake stages. These were associated directly with the discharges in the histogram when daily durations were used. When longer durations were used, the stages were averaged over the period. Since the flood of record occurred prior to closure of the dam, lake stages were not directly available for association with these flows. In order to generate the stages, the storm was routed through the reservoir. Critical assumptions were that the beginning lake stage was at el 1,300, that the sluices were operated according to the operating rule curve, and that the initial storage table (December 1978) was

appropriate. The inflow was taken as the recorded discharge. The outflow was computed from sluice stage/discharge rating curves. The difference in inflow/outflow values was converted to a change in storage. The change in storage was added/subtracted from the storage in the lake, and a new lake elevation was determined from the stage/storage table for the lake.

Water temperature

27. Water temperature is utilized to compute the fall velocities for the sediment particles. Water temperatures were unavailable for the daily period of record. However, water-temperature data were available for water years 1976-1977 and 1977-1978. Air temperature records were available for a much longer period at Baxter, KY. These data were used to compute average monthly water temperature for use in the Martins Fork study. The ratio of monthly average air to water temperature was calculated based on the 1976-1978 detailed data. These ratios were then averaged to obtain one value for each month. The average monthly water temperature was then calculated by dividing the long-term average air temperature by the average air/water ratio.

Durations

28. As stated above, flow durations of 1 day were used for flows in excess of 100 cfs. Lower flows were averaged and represented by longer durations. The exact duration assigned to the lower flows varied and was based on flow magnitudes, how rapidly the lake stage varied, and the position of the next spike in the hydrograph. Even low flows may lead to model instability if the flow duration is too long. To address this, the maximum duration was set at 31 days to prevent computational instability in the model.

PART III: METHODS USED

29. The testing procedure consisted of three steps: (a) model start up, (b) verification, and (c) testing of alternatives. The actual test runs are made only after verification is complete and are referred to as production runs.

Start-Up

30. The start-up procedure consists of coding the main stem geometry and running random flows with the model in a fixed-bed mode or rigid boundary mode. In this mode, no sediment is transported, and the model is evaluated for reasonableness of hydraulic results only. The next step is to add sediment to the model and to establish that the model is transporting sediment in a reasonable manner. Both of these steps are accomplished with the dam removed and only evaluate flow in the predam channel and overbanks. For this stage of the testing, the active bed limits are set within the original channel. The active bed is the portion of the model in which sediment is exchanged with the water flowing through the model. A sediment transport equation is also selected. Yang's method and the modified Laursen method (Madden 1985)* were evaluated, and the Laursen method was selected to perform the internal transport calculations for the noncohesive materials. The clay and silt size materials are transported or deposited by the program computations based on a critical value for bed shear. This value was set at 0.02 lb/sq ft. Steps 1 and 2 above are next repeated with the tributaries added to the model. The dam is then added, and the behavior of the model checked. During this stage, no fine tuning of the model parameters is done. Rather, the general features of the geometry and sediment portions of the model are checked for reasonableness.

Verification

31. The verification procedure is an iterative process whereby the

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* E. P. Madden. 1985. "Modified Laursen Method for Estimating Bed Material Sediment Load" (unpublished notes).

model is set up and run with beginning conditions (geometry, sediment, and historical flows), the same as those in the prototype. The model results are compared to another prototype data set at a point in the future. In this case the time zero or beginning condition was selected as January 1979. This was selected as the beginning point since ORN had complete flow records from this point in time, and the lake was completely filled. Historic flows and lake stages were used from January 1979 through June 1984. The intermediate prototype surveys of July 1980, June 1983, and June 1984 were used to measure model verification. In the verification procedure, if the model is not representing conditions observed in the prototype, the model input variables are studied for reasonableness and adjusted to better represent what conditions are (or were) in the prototype. In the case of the Martins Fork model, the initial trial distribution of grain size fractions in the inflowing sediment load was not reproducing observed deposition patterns in the model. The size fraction distribution was adjusted, based on more detailed data available from the USGS as shown in Figure 5. Table 4 summarizes the deposition pattern verification results. The model was also not reproducing the initial storage volume accurately. Upon examination, it was found that the error was in the upper end of the stage storage curve and that the model required extension up the tributaries as described in paragraph 16. Table 5 summarizes the volumetric verification.

32. The inflowing sediment load, developed as described in paragraph 20 above, was found to reproduce an infill rate of 0.47 acre-ft/square mile/year. This value fell between the original design sediment inflow rate of 0.41 and the adjusted design rate of 0.50 acre-ft/square mile/year and was considered to accurately represent conditions expected prior to closure of the dam. Therefore, this curve was designated as the design $Q - Q_s$ relationship and was used to represent the inflowing sediment load relationship for Tests 1, 2, and 5.

33. At this point, the model was accurately reproducing the design infill rate but was below the observed rate. In the prototype, an infill rate of 1.68 acre-ft/square mile/year was observed between May 1978 and June 1984. Further analysis of the suspended sediment data indicated that the composite $Q - Q_s$ curve could be increased by a factor of three and still fall in a reasonable range of the observed data (verification Figure 7). Therefore, the total load was multiplied by three, and the model rerun. This resulted in an

Table 4

Depositional Pattern Verification

Section No.	Comparison Sediment Range	Prototype Bed Change, ft	Model Bed Change, ft
		Martins Fork	
0.01	1	0.50	0.43
0.02	1	0.50	0.43
0.03	2	0.50	0.41
0.20	3	0.50	0.38
1.10	1A	0.50	0.16
2.10	2A	0.50	0.22
3.10	3A	0.50	0.24
4.10	4A	0.50	0.37
5.10	5A	1.50	0.97
6.10	6A	3.75	3.50
7.10	7A	0.75	0.53
8.00	5AB	0.40	-0.15
9.00	6AB	0.20	-0.06
10.00	--	--	0.14
11.00	--	--	0.06
12.00	--	--	0.14
13.00	--	--	0.15
14.00	--	--	0.43
		Crane Creek	
1.02	1B	0.20	0.07
1.20	--	--	0.15
2.20	2B	0.00	-0.14
2.30	--	--	0.04
		Board Branch	
3.02	3B	0.20	0.07
3.20	--	--	0.09
4.20	4B	0.80	-0.15
4.30	--	--	0.02
		Cranks Creek	
8.01	8A	0.50	0.36
8.10	--	--	0.46
9.10	9A	0.50	0.44
10.10	10A	1.50	1.31
11.10	11A	1.75	2.47
12.10	12A	0.50	0.67
12.15	--	--	1.12
12.20	--	--	1.35
12.30	--	--	1.53
12.40	--	--	3.62

Table 5

Volumetric Verification, Model Versus Prototype

Elevation ft NGVD	Volume, acre-ft							
	January 1979		July 1980		June 1983		June 1984	
	Model	Prototype	Model	Prototype	Model	Prototype	Model	Prototype
1,265	--	--	--	--	--	--	--	--
1,270	4	22	4	17	4	5	4	5
1,275	19	85	18	32	17	28	16	27
1,280	132	253	127	117	124	142	122	138
1,285	506	648	488	491	477	498	468	484
1,290	1,295	1,356	1,262	1,142	1,240	1,188	1,227	1,165
1,295	2,305	2,413	2,261	2,168	2,231	2,169	2,213	2,137
1,300	3,473	3,674	3,417	3,408	3,376	3,380	3,353	3,345
1,305	4,866	5,133	4,789	4,855	4,732	4,814	4,701	4,778
1,310	6,413	6,758	6,327	6,483	6,265	6,456	6,228	6,420
1,315	8,217	8,561	8,122	8,281	8,050	8,306	7,999	8,266
1,320	10,256	10,561	10,162	10,268	10,088	10,351	10,030	10,304
1,325	12,455	12,760	12,361	12,474	12,288	12,561	12,224	12,511
1,330	14,809	15,168	14,715	14,879	14,642	14,933	14,573	14,877
1,335	17,345	17,768	17,251	17,471	17,106	17,475	17,108	17,417
1,340	20,045	20,545	19,950	20,255	19,877	20,291	19,808	20,224
1,341	20,614	21,120	20,519	20,824	20,445	20,874	20,377	20,807

inf[illegible] of 1.40 acre-ft/square mile/year which reasonably reproduced the obs[illegible] rate of 1.68. At this point the model was reproducing observed sediment deposition patterns, volumetric changes, and infill rates and was deemed verified.

Alternatives Analyzed

General

34. The verified model was used to perform the tests on the various alternatives evaluated. These tests, or production runs, evaluated conditions

50 years into the future from January 1979. The verified geometric and sediment conditions were subjected to a 50-year hydrograph, and conditions were evaluated at 10-year intervals. The discharge hydrographs, the $Q - Q_s$ relationships, and the reservoir rule curve were varied to simulate various future scenarios as described below. The alternatives tested and model conditions for each are summarized in Table 6.

Hydrographs

35. Three production hydrographs were used in testing the alternatives. One consisted of the observed lake inflows and lake stages for the period January 1979-December 1986. This period was reproduced and stacked to create a 50-year hydrograph. This hydrograph was termed historical since it was developed from the historical record.

36. The period 1979-1986 inflows were analyzed by comparing these flows to the longer period available at the USGS gage below the dam site where 15 years of record were available. This analysis indicated that the long-term average runoff was 29.52 in./year. The runoff for the period 1979-1986 averaged 24.32 in./year. Therefore, during the 1979-1986 period, the average runoff was 18 percent below normal. Using this record to generate the production hydrograph would result in a long-term deficiency in sediment transported. Based on this, a synthetic 50-year hydrograph was constructed that more closely reproduced the 15-year average runoff. To do this, 2 years were selected whose average runoff, when averaged together, represented the long-term runoff. The 2 years selected were water years 1982 and 1984. Together they yielded a slightly below average runoff (28.43 in./year) but included detailed data on the storm of May 1984 which produced the record inflow since closure of the dam. The 15-year period of record was then analyzed to determine the historic pattern of years that fell above (wet) and below (dry) the 15-year average. The years 1982 and 1984 were then arranged in this order and repeated to construct a 50-year hydrograph. This hydrograph was termed synthetic. The pertinent data in the above procedure is presented in Table 7. Figure 8 shows the synthetic hydrograph arrangement and its correspondence with the chronological years.

37. At the request of ORN, the synthetic hydrograph was modified by adding the April 1977 storm (storm of record). Necessary input parameters for this storm, which occurred prior to closure of the dam, were developed as described in paragraph 26. This storm was estimated by ORN to have a return

Table 6

Alternatives Tested and Model Conditions

Test No.	Hydrograph	$Q - Q_s$ Relation	Comment
1	Historical	Design	1,2
2	Synthetic	Design	2,3
3	Historical	Observed	1,4
4	Synthetic	Observed	3,4
5	Modified synthetic	Design	2,5
6	↓	Observed	4,5
7	↓	↓	4,5,6
8	↓	↓	4,5,7
9	↓	↓	4,5,8
10	↓	Modified	5,9

Comments

1. Historical hydrograph consists of observed 1979-1986 flows repeated to generate 50 years of record.

2. Design water/sediment discharge ($Q - Q_s$) relationship reproduces the lake design infill rate of 0.5 acre-ft/square mile/year of drainage area.

3. Synthetic hydrograph consisted of the water years 1982 and 1984 arranged in the historical pattern of wet and dry years to generate 50 years of record. These 2 years more nearly represent the long-term rainfall runoff volume than the limited observed flows represented in the historical hydrograph.

4. Observed $Q - Q_s$ relationship reproduces the infill rate observed to date at Martins Fork Lake approximately 1.7 acre-ft/square mile/year of drainage area.

5. Modified synthetic hydrograph is the same as the synthetic hydrograph except that the storm of record (April 1977) has been added at the beginning and the end of the 50-year hydrograph.

6. This test is the base test for a series of tests that evaluate the modification of the lake operating rule curve. This one simulates operation by the current rule curve (el 1,300 winter, el 1,310 summer).

7. This test evaluates a -10 ft shift in the rule curve during the winter months to el 1,290.

8. This test evaluates a constant lake el of 1,310.

9. This test provides a greater inflow rate of sediment based on increased strip mining in the Martins Fork basin.

Table 7

Synthetic Hydrograph Development

Water Year	Mean Q cfs	Max Q cfs	Min Q cfs	Runoff in.	Historic Designation	Selected Synthetic Year
1972	147	1,390	3	35.93	Wet	
1973	174	3,710	9	42.25	↓	
1974	200	3,730	8	48.72	↓	
1975	164	3,380	1	39.86	↓	
1976	105	2,360	1	25.51	Dry	
1977	92	5,100	4	22.51	Dry	
1978	137	1,270	2	33.43	Wet	
1979	143	841	0	34.73	Wet	
1980	107	687	6	26.13	Dry	
1981	58	818	9	14.12	Dry	
1982	126	679	8	30.73	Wet	30.73
1983	119	543	10	28.97	Dry	
1984	107	1,010	9	26.13	↓	26.13
1985	73	334	8	17.79	↓	
1986	65	568	9	15.93	↓	
						28.43
			average	29.52		

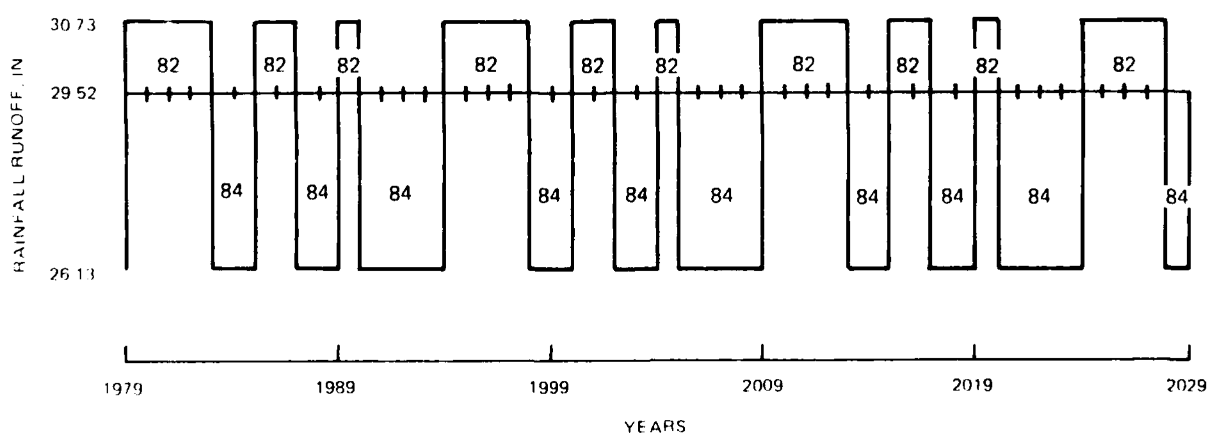

Figure 8. Martins Fork Lake, synthetic inflow hydrograph arrangement

interval of 50 years. To simulate the worst possible case, this storm was added to the beginning and end of the synthetic hydrograph. The resulting hydrograph was designated the modified synthetic hydrograph.

$Q - Q_s$ relationships

38. The relationships developed, as described in paragraph 20, and modified, as described in paragraph 32, were used in the production runs. The $Q - Q_s$ relationship that approximated the design infill rate of 0.50 acre-ft/square mile/year was designated as the design relationship.

39. The $Q - Q_s$ relationship that verified the observed infill rate of 1.68 acre-ft/square mile/year during the period May 1978-June 1984 was designated as the observed relationship.

40. The observed relationship was further modified to represent changed land use in the Martins Fork basin. This modification assumed all strippable lands would be developed.

41. The procedure for determining the increased contribution to the inflowing sediment load from future strip mining was based on the following assumptions:

- a. Acres stripped prior to 1978 = 1,390 (USAED, Nashville, 1979).
- b. Acres stripped 1980-1986 = 955.5 (Burchfield 1986).
- c. Remaining strippable acreage = 545 (From ORN).
- d. "c" above would be accompanied by 273 acres of haul roads.
- e. Sediment yield from undisturbed lands = 0.0123 acre-ft/square mile (Vanoni 1977).
- f. Lands in "c" above would only increase inflow from Upper Martins Fork.

42. The acres stripped prior to 1986 equated to 3.67 square miles. When the additional acres were added, this equated to 4.94 square miles. The sediment yield from undisturbed acres was taken to be 0.0123 acre-ft/square mile. This value was obtained from a study of the Cane Branch watershed in southern Kentucky (Vanoni 1977). Based on the observed annual yield of 1.68 acre-ft/square mile during the period 1979-1984 and 30.9 square miles of drainage area, the total average annual sediment yield observed was 51.91 acre-ft. The 0.0123 value was applied to the 27.23 square miles of undisturbed drainage area, and an unknown value was applied to the disturbed area of 3.67 square miles. The sum of these values was equated to the average annual yield of 51.91 acre-ft. The unknown value was thus determined to be

14.05 acre-ft/square mile/year and represented the yield from disturbed acreage. This value agrees reasonably with figures published from the Cane Branch watershed in southern Kentucky which determined that the yield from disturbed acreage was 13.23 acre-ft/square mile/year (Vanoni 1977). The 14.05 value was then applied to the total potential disturbed area of 4.94 square miles and added to 0.0123 times the remaining undisturbed area of 25.96 square miles resulting in a new annual sediment yield of 69.73 acre-ft for the upper Martins Fork basin. This value, when divided by the 30.9 square miles drainage area, gives a new sediment yield of 2.26 acre-ft/square mile/year. The HL-1 verification model was based on a yield value of 1.40. To incorporate the new yield value into HL-1, the 2.26 was divided by 1.40 to yield a multiplier of 1.61. This was applied uniformly to the inflowing sediment load. It is recognized, as with all forecasts of future conditions, that this procedure is open to debate. However, it is based on the best available data and is conservative in that it assumes no chronological decrease due to natural healing of the strip benches and haul roads. It should therefore truly represent the worst case alternative.

Rule curve

43. The existing operating rule curve for the Martins Fork Lake is shown in Figure 9. One of the alternatives considered was to alter this curve to determine the impacts on the infill rate/pattern. To this end, the HL-1 was run first with the lake stage varied according to the existing rule curve. This was necessary in order to establish a base condition for this series of tests. Two additional tests were run. One varied the rule curve by lowering the winter pool to el 1,290. The other evaluated leaving the lake at el 1,310 year around.

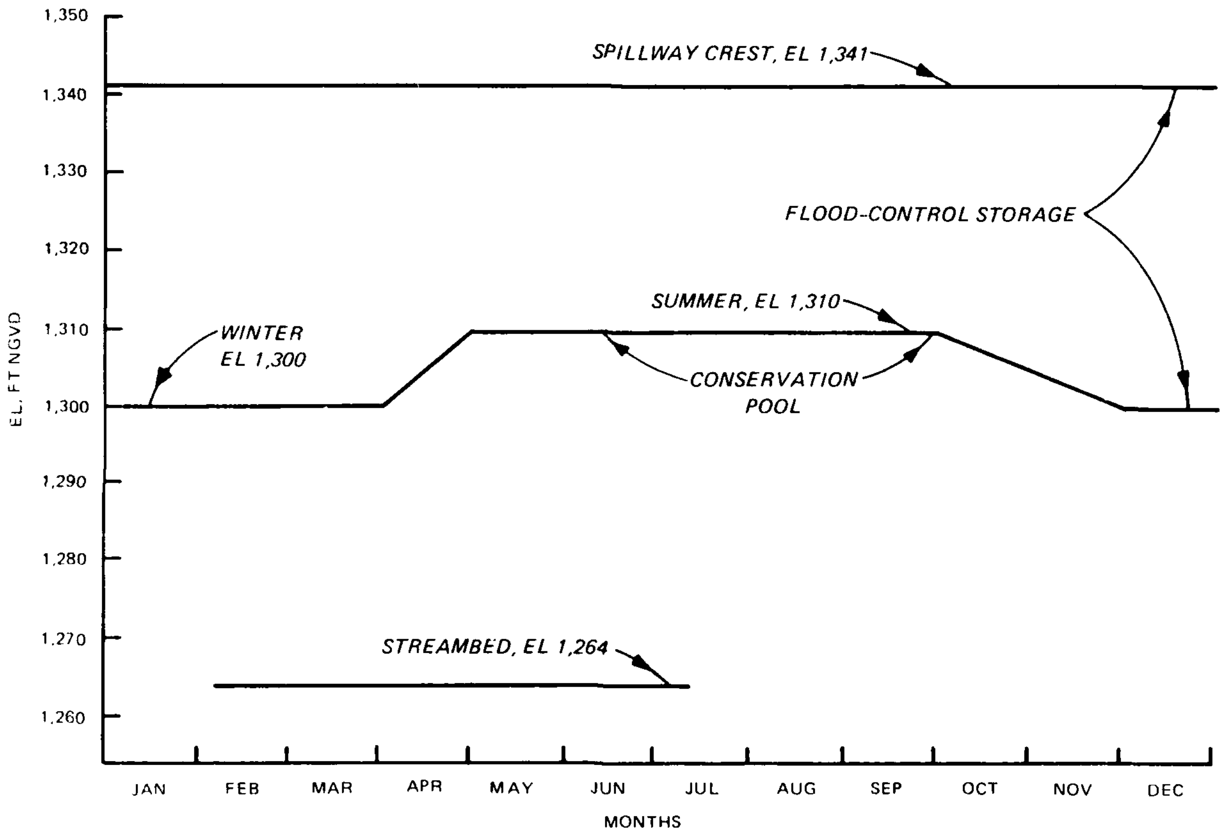

Figure 9. Martins Fork Lake, operating rule curve

PART IV: RESULTS

44. The alternatives tested can be arranged in four groups as shown in Table 8.

Table 8

Variables Evaluated

Tests	Variable Evaluated
1,2,5	Discharge hydrographs versus design $Q - Q_s$
3,4,6	Discharge hydrographs versus observed $Q - Q_s$
7,8,9	Rule curve
6,10	Land use/sediment yield change

The tests were designed to evaluate the effects of varying parameters on future conditions in the lake. The parameters varied depended on the underlying assumption as pertained to future conditions. These are summarized in Table 9. The results of these tests are discussed in detail below.

Table 9

Tests and Future Assumptions

Test	Assumption
3,4,6	Do-nothing alternative
1,2,5	Construct and maintain efficient sediment control structures
7,8,9	Vary operating rule curve
10	High coal prices, maximum strip-mining effort

Do-Nothing Alternative

Storage

45. Tests 3, 4, and 6 assumed an inflowing sediment rate equivalent to

that observed at the lake during the period 1979-1984. This rate was 1.40 acre-ft/square mile/year. The only variable was the hydrograph used for each test. These are summarized in Table 6. The results of the storage evaluation are presented in Table 10.

Table 10

Storage Effects after 50 years, Tests 3, 4, and 6

Test	Total Lost acre-ft	Total Lost %	Flood Control Lost acre-ft	Flood Control Lost %	Infill Rate acre-ft/ square mile/year
3	1,671	8.11	815	4.75	1.08
4	2,433	11.80	1,388	8.10	1.58
6	2,674	12.97	1,540	8.98	1.73

Water depth

46. The depths are reported at 10-year intervals. These results are summarized in Table 11. No results are reported for the minor tributaries of the lake (Crane Creek, Board Branch) since less than 1 ft of general deposition is predicted in these portions of the lake.

Control Sediment

Storage

47. Tests 1, 2, and 5 assumed an inflowing sediment load equivalent to the modified design rate of 0.50 acre-ft/square mile/year. This test series evaluates lake conditions with effective sediment control methods in place in the basin that limit the inflowing sediment rate to the design rate. This was evaluated against several hydrographs. Test variables are summarized in Table 6. The results of the storage evaluation are presented in Table 12.

Water depth

48. Loss of water depth for these tests is shown at selected locations in Table 13. The depths are reported at 10-year intervals. Since Test 5 was clearly worse than Tests 1 and 2, results for Test 5 were not recorded. The minor tributaries did not experience significant deposition in these tests and are not shown.

Table 11

Lake Depths, Over Time, Selected Locations

Tests 3, 4, and 6

Test	Section No.	Depth, ft with lake at el 1,300					
		Initial Year	Year +10	Year +20	Year +30	Year +40	Year +50
3	Martins Fork	35.8	35.1	34.4	33.7	33.0	32.3
	3.1	26.8	26.4	26.0	25.6	25.2	24.8
	5.1	19.7	18.0	15.9	13.5	10.9	8.3
	6.1	12.7	6.9	4.5	2.7	1.9	2.2
	7.1	0.6	0.1	0.2	--	--	0.0
	Cranks Creek						
	8.01	23.7	23.1	22.5	21.7	21.0	20.1
	9.1	20.4	19.3	17.0	14.2	10.5	5.9
	10.1	9.5	6.8	5.1	2.8	1.5	1.6
	12.1	1.5	0.5	--	--	--	--
4	Martins Fork	35.8	35.0	34.2	33.3	32.5	31.5
	3.1	26.8	26.4	25.9	25.3	24.8	24.2
	5.1	19.7	17.9	15.6	12.1	8.5	4.6
	6.1	12.7	6.5	1.3	0.7	0.7	1.6
	7.1	0.6	--	--	--	--	--
	Cranks Creek						
	8.01	23.7	23.0	22.3	21.4	20.3	19.0
	9.1	20.4	19.7	18.4	13.5	7.7	2.3
	10.1	9.5	6.8	2.1	1.3	1.0	--
	12.1	1.5	--	--	--	--	--
6	Martins Fork	35.8	34.8	33.9	33.0	32.2	31.0
	3.1	26.8	26.2	25.7	25.2	24.6	23.8
	5.1	19.7	17.5	14.9	11.4	7.8	3.3
	6.1	12.7	5.4	1.2	0.4	0.0	2.2
	7.1	0.6	--	--	--	--	--
	Cranks Creek						
	8.01	23.7	22.8	22.0	21.1	20.0	18.4
	9.1	20.4	19.5	18.0	13.3	7.6	2.7
	10.1	9.5	6.5	1.9	1.3	0.9	--
	12.1	1.5	--	--	--	--	--

Table 12

Storage Effects after 50 years, Tests 1, 2, and 5

Test	Total Lost acre-ft	Total Lost %	Flood Control Lost acre-ft	Flood Control Lost %	Infill Rate acre-ft/ square mile/year
1	577	2.80	282	1.65	0.37
2	858	4.16	504	2.94	0.56
5	1,039	5.04	604	3.52	0.67

Table 13

Lake Depths, Over Time, Selected Locations, Tests 1 and 2

		Depth,ft with lake at el 1,300					
Test	Section No.	Initial Year	Year +10	Year +20	Year +30	Year +40	Year +50
1	Martins Fork	35.8	35.6	35.3	35.1	34.9	34.7
	3.1	26.8	26.7	26.5	26.4	26.3	26.2
	5.1	19.7	19.2	18.7	18.1	17.5	16.8
	6.1	12.7	10.6	8.7	6.9	5.7	5.1
	7.1	0.6	0.5	0.5	0.3	0.2	0.2
	Cranks Creek						
	8.01	23.7	23.5	23.3	23.1	22.9	22.7
	9.1	20.4	20.1	19.9	19.5	19.0	17.9
	10.1	9.5	8.5	7.6	6.8	6.1	6.3
	12.1	1.5	1.3	1.0	0.7	0.5	0.3
2	Martins Fork	35.8	35.5	35.3	35.0	34.8	34.5
	3.1	26.8	26.7	26.5	26.3	26.2	26.0
	5.1	19.7	19.1	18.5	17.8	17.1	16.4
	6.1	12.7	10.5	8.4	6.3	4.3	2.4
	7.1	0.6	0.2	--	--	--	--
	Cranks Creek						
	8.01	23.7	23.5	23.3	23.0	22.8	22.5
	9.1	20.4	20.2	19.9	19.7	19.3	18.9
	10.1	9.5	8.9	7.9	6.6	5.0	3.2
	12.1	1.5	1.1	0.6	0.0	--	--

Rule Curve

Storage

49. Tests 7, 8, and 9 assumed the observed inflowing sediment rate. The modified synthetic hydrograph was used for all tests. The variable evaluated was the operating rule curve for the lake. These are summarized in Table 6. The results of the storage evaluation are presented in Table 14.

Table 14

Storage Effects after 50 years, Tests 7, 8, and 9

	Total Lost		Flood Control Lost		Infill Rate acre-ft/
Test	acre-ft	%	acre-ft	%	square mile/year
7	2,111	10.24	591	3.44	1.37
8	1,859	9.02	466	2.72	1.20
9	2,184	10.60	879	5.11	1.41

Water depth

50. The loss of water depth is shown in Table 15 at selected locations at 10-year intervals. Since Test 9 was clearly worse that Tests 7 and 8, the results for Test 9 were not recorded. The minor tributaries are not included since they experienced no significant depostion.

Maximum Strip

Storage

51. Test 10 evaluates the most extreme case. The modified synthetic hydrograph simulates the highest expected inflows. The inflowing sediment represents that expected if all of the strippable coal resources were mined in the upper Martins Fork basin. The inflowing sediment rate was 2.26 acre-ft/square mile/year. The results of the storage evaluation are presented in Table 16.

Water quality

52. The loss of water depth at selected locations at 10-year intervals is shown in Table 17. The minor tributaries are not included. Even this

Table 15

Lake Depths, Over Time, Selected Locations, Tests 7, and 8

Test	Section No.	Depth, ft with lake at el 1,300 Initial Year	Year +10	Year +20	Year +30	Year +40	Year +50
7	Martins Fork	35.8	35.5	33.3	32.0	30.8	29.2
	3.1	26.8	26.0	25.2	24.4	23.2	21.5
	5.1	19.7	16.0	11.6	7.5	5.2	4.0
	6.1	12.7	6.1	5.0	4.0	3.0	2.1
	7.1	0.6	0.4	0.9	1.5	1.3	1.2
	Cranks Creek						
	8.01	23.7	22.1	20.5	18.1	6.5	5.0
	9.1	20.4	14.9	8.9	7.1	6.0	4.4
	10.1	9.5	5.1	3.1	1.6	1.2	0.2
	12.1	1.5	1.3	0.9	0.3	--	--
8	Martins Fork	35.8	34.1	32.5	30.9	28.5	25.0
	3.1	26.8	25.5	24.0	22.4	20.6	16.8
	5.1	19.7	15.8	15.0	13.6	13.0	11.0
	6.1	12.7	11.5	10.8	11.0	10.4	9.0
	7.1	0.6	0.4	0.6	0.5	0.6	0.4
	Cranks Creek						
	8.01	23.7	15.3	14.4	13.7	14.0	13.6
	9.1	20.4	14.8	13.1	11.6	11.4	10.9
	10.1	9.5	11.4	10.7	9.8	9.4	8.3
	12.1	1.5	1.2	0.8	0.0	--	--

Table 16

Storage Effects after 50 years, Test 10

Test	Total Lost acre-ft	Total Lost %	Flood Control Lost acre-ft	Flood Control Lost %	Infill Rate acre-ft/ square mile/year
10	3,996	19.39	2,365	13.80	2.59

Table 17

Lake Depths, Over Time, Selected Locations, Test 10

		Depth, ft with lake at el 1,300					
Test	Section No.	Initial Year	Year +10	Year +20	Year +30	Year +40	Year +50
10	Martins Fork	35.8	34.1	32.7	31.2	31.2	29.0
	3.1	26.8	25.8	25.0	24.0	22.8	21.1
	5.1	19.7	15.9	11.9	7.5	2.8	--
	6.1	12.7	1.8	--	--	--	--
	7.1	0.6	--	--	--	--	--
	Cranks Creek						
	8.01	23.7	22.2	20.7	18.9	16.2	5.4
	9.1	20.4	18.7	12.4	2.9	1.1	1.0
	10.1	9.5	3.3	1.1	--	--	--
	12.1	1.5	--	--	--	--	--

extreme event only produced maximum depostion in the minor tributaries of slightly more than 1 ft.

Trap Efficiency

53. The trap efficiency is defined as the sediment inflow less the sediment outflow divided by the inflow. The HL-1 calculates the trap efficiency by sediment classification. Trap efficiency was not calculated for Tests 5 and 9. The results are tabulated in Table 18.

Table 18

Trap Efficiency after 50 years by Sediment Classification

Test	Sand	Silt	Clay
1	1.0	0.58	0.05
2	1.0	0.55	0.04
3	1.0	0.58	0.05
4	1.0	0.54	0.04
5	--	--	--
6	1.0	0.49	0.04
7	1.0	0.47	0.03
8	1.0	0.42	0.02
9	--	--	--
10	1.0	0.49	0.03

PART V: CONCLUSIONS

54. From the resurveys of the lake sedimentation ranges performed by ORN, it is apparent that Martins Fork is experiencing high rates of sediment inflow. The design rate of 0.50 acre-ft/square mile/year has definitely been exceeded. The rate observed for the period May 1978-June 1984 was 1.68 acre-ft/square mile/year. Calculations based on figures obtained from a similar watershed in southern Kentucky (Vanoni 1977) yield a value of 1.58 acre-ft/square mile/year. Compared to this value, Martins Fork is experiencing an infill rate that is not unusual for basins in which strip-mining activities are being conducted.

55. The drainage basin above the Cranks Creek dam remains a mystery. There is strip mining in this area, but the extent and potential future expansion have not been quantified. If the district decides to pursue further studies on Martins Fork, establishing a continuous sediment sampling station on Cranks Creek would be helpful in determining the importance of this tributary to the total sediment budget of the basin. The conclusions drawn from the tests are discussed below by future assumption.

Do-Nothing Alternative

Storage

56. These tests assume no remedial actions are taken. Three hydrographs representing historical, expected, and worst case conditions were tested. These results are presented in Table 10. The lake will continue to perform its flood control purpose. The worst case indicated a loss of about 9 percent of the flood control storage after 50 years. Total storage lost for this case (Test 6) was about 13 percent. However, storage lost below el 1,300 does not affect flood control storage which is that storage which exists between el 1,300 and 1,341.

Water depth

57. Results (Table 11) indicate that after 50 years the lake will be considerably reduced in size. Serious infilling will extend downstream to section 5.1 on the main stem and upstream to section 9.1 on Cranks Creek. It is likely that mud flats will develop in these areas.

Control Sediment

Storage

58. These tests assume that the inflowing sediment is controlled to limit the infill rate to that originally used for design. Results are shown in Table 12. The control could be established either by sediment traps at the source, that is, the strip-mining areas, or by a large sediment trap located on Martins Fork above the normal pool elevation. The latter would be more desirable. This alternative would allow trapped sediment to be removed by economical means such as surface removal by earth moving equipment. Also, new mining operations would be covered without special structures being constructed.

59. The lake will continue to function for flood control under this assumption. The worst case indicates a loss of 3.5 percent of the flood control storage and 10.6 percent of the total storage after 50 years (Table 12).

Water depth

60. Results (Table 13) indicate that after 50 years the lake will be more shallow but not much smaller. The lake should not extend beyond section 7.1 on the main stem and section 12.1 on Cranks Creek.

Rule Curve

Storage

61. These tests assume that the rule curve can be changed from the present operation. Leaving the lake at el 1,310 year-round would increase the infill rate by 3 percent over the current rule curve. Loss of flood control storage would increase by 50 percent.

62. Lowering the lake stage by 10 ft during the winter months would decrease the infill rate by 12 percent over the present operation. Loss of flood control storage would be decreased by 21 percent. Complete results are shown in Table 14.

Water depth

63. This alternative would spread the deposition more uniformly through the lake. The upper ends of the lake would experience less deposition compared to the current rule curve while more deposition would occur in the vicinity of the dam. The generalized deposition at the dam would indicate

that the low level sluice would be covered by some 3 ft of sediment. However, the local turbulence and high velocities in the vicinity of the gate should prevent it being affected if it is used periodically for routine releases. Results are shown in Table 15.

Maximum Strip

Storage

64. Under this assumption, the lake will experience an infill rate of 2.59 acre-ft/square mile/year. This will result in a loss of 13.8 percent of the flood control storage and 19.4 percent of the total storage. This represents the worst possible case for the basin short of a failure of the Cranks Creek dam. Even under this extreme condition, the lake should essentially still provide substantial flood control benefits.

Water depth

65. This assumption gave the worst water depth results (Table 17). The lake would not extend much beyond section 3.1 on the main stem and section 9.1 on Cranks Creek. Large mud flats would exist above these locations on Martins Fork and Cranks Creek.

PART VI: RECOMMENDATIONS

66. Based on the results and conclusions drawn from this study, the following recommendations are made to the district:

a. The district should consider altering the rule curve for the lake. Comparison of Tests 7 and 8 indicate that this could very well be a viable and economical way of prolonging the flood control purposes of the Martins Fork project. The WES Hydraulics Laboratory can conduct futher, more detailed analysis of this alternative in conjunction with ORN to optimize the rule curve.

b. The district should consider the economics of maintaining the lake if each of the purposes of the project is to be preserved. The expense of constructing and maintaining at least one sediment trap on Martins Fork above the lake needs to be compared to the expense of dredging deposited material from the lake at 20-year intervals. By 1998, some 1,100 acre-ft of deposition is expected in the lake if no action is taken. This equates to 1.8 million cu yd of material. The sediment trap would have the advantage of limiting the maintenance area and allowing more economical methods of removal of the material.

c. If long-term degradation of water depth is not of paramount importance, the district can still count on the lake providing significant flood control benefits under any future alternative analyzed.

d. If further studies are deemed necessary, the district should consider establishing a second continuous sediment sampling gage on Cranks Creek below the dam in order to quantify the relative sediment contribution of this portion of the basin. This gage should be operated continuously for the first year. Thereafter, sampling can be suspended during the dry months of the year, June through October.

e. If no further studies are planned for the basin, the continuous sediment sampling gage on Martins Fork can be discontinued. If it is left in place, sampling can be suspended during the dry months of June through October.

f. The resurveys of the sediment ranges need not be conducted as frequently as have been done in the past. Three- to five-year intervals would be sufficient to monitor deposition in the lake.

g. The strip-mining activities in the upper Martins Fork basin and perhaps those in the Cranks Creek watershed are apparently the major sources of sediment that is being deposited in the lake. Given the economic importance of coal mining to this region and the remaining coal reserves in the basin, this condition is likely to continue for many years. Efforts should continue to ensure that the coal mining interests are attempting to limit the sediment that escapes from their mining sites and haul roads. Based on observed inflow rates in the lake, remedial measures taken to date seem to be basically ineffective.

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APPENDIX A: CUMBERLAND RIVER BASIN, KY, MARTINS FORK LAKE, PERTINENT DATA

General

Authorization	Flood Control Act of 27 October 1965 (PL 89-298, 89th Congress
Purpose	Flood Control, water quality, and recreation
Location	Martins Fork, Cumberland River mile 15.6
Drainage Area	55.7 square miles
Type of Dam	Concrete gravity
Length of Dam	504 ft
Height of Dam	97 ft
Spillway	Uncontrolled concrete ogee, 200 ft in length

Elevations, ft NGVD

Top of dam	1,360
Flood control pool	1,341
Normal pool	1,310
Conservation pool	1,300
Outlet sluices, 3, 4 by 4 ft	1,272
	1,283
	1,296

Reservoir area, acres (as built)

Flood control pool	578
Normal pool	340
Conservation pool	274

Reservoir storage, acre-ft (as built)

Flood control pool	21,120
Normal pool	6,758
Conservation pool	3,674

Maximum outflow, cu ft/sec

Flood of record, April 1977	9,000
Standard project flood	15,600
Spillway design flood	57,000