RESEARCH REPORT H-73-2

MATHEMATICAL SIMULATION OF THE TURBIDITY STRUCTURE WITHIN AN IMPOUNDMENT

Hydraulic Laboratory Investigation

by

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Hydraulics Laboratory
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The investigation reported herein was authorized by the U. S. Army Engineer District, Portland. The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, during the period June 1972 to September 1972, under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and T. E. Murphy, Chief of the Structures Branch. The analyses and developments were conducted by Messrs. D. G. Fontane and J. P. Bohan under the direct supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Channels Section. This report was prepared by Messrs. Fontane, Bohan, and Grace.

Director of WES during the conduct of the study and the preparation and publication of this report was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
acre-feet	1233.4817	cubic meters
feet per month	0.3048	meters per month
cubic feet per second	0.0283168	cubic meters per second

SUMMARY

The turbidity structure of an impoundment was simulated using a mathematical model capable of simulating physical and chemical characteristics of an impoundment. Turbidity was handled as a conservative chemical substance. The model was used to predict the thermal and turbidity structures of an existing impoundment and was verified with observed data. The model was then used to predict the turbidity structure of a proposed impoundment. The effectiveness of selective withdrawal and, in particular, of a low-level outlet in controlling the turbidity structure of an impoundment was demonstrated.

MATHEMATICAL SIMULATION OF THE TURBIDITY STRUCTURE WITHIN AN IMPOUNDMENT

Hydraulic Laboratory Investigation

PART I: INTRODUCTION

Background

1. Turbidity is an important water quality parameter which affects the physical, chemical, and biological characteristics of rivers, lakes, and impoundments and consequently affects the benefits to be realized relative to various specific and multipurpose interests. As defined by Rainwater and Thatcher,[1] turbidity is "the optical property of a suspension with reference to the extent to which penetration of light is inhibited by the presence of insoluble material." The insoluble material can consist of physical, chemical, and biological matter.

2. Turbidity problems generally occur in watersheds with unstable soil conditions. Periods of intense rainfall produce turbid runoffs, and a downstream impoundment traps the turbid flows. This phenomenon may cause impoundment releases to be turbid for an extended period of time. The problem can be particularly acute if the soils of the watershed are predominantly composed of fine particles, since settlement of such suspended materials will occur very slowly in an impoundment.

3. Turbidity problems have been the subject of studies of the Blue River[2] in Kansas, the Russian[3] and Eel River Basins[4] in northern California, and the Willamette River Basin[5] in Oregon. The study of the Hills Creek Reservoir in the Willamette River Basin, performed by Oregon State University and hereafter referred to as the "OSU study," was sponsored by the U. S. Army Engineer District, Portland.

4. After the December 1964 flood, a turbidity problem developed in Hills Creek Reservoir that has persisted to the present. One of the causative factors of the continuing turbidity problem at the Hills Creek Reservoir is the location of the outlets in relation to the total

depth of the reservoir. The penstock and regulating outlet are within 25 ft* of each other and are approximately at middepth of the reservoir, i.e., 80 and 105 ft above the bottom (fig. 1). This outlet placement

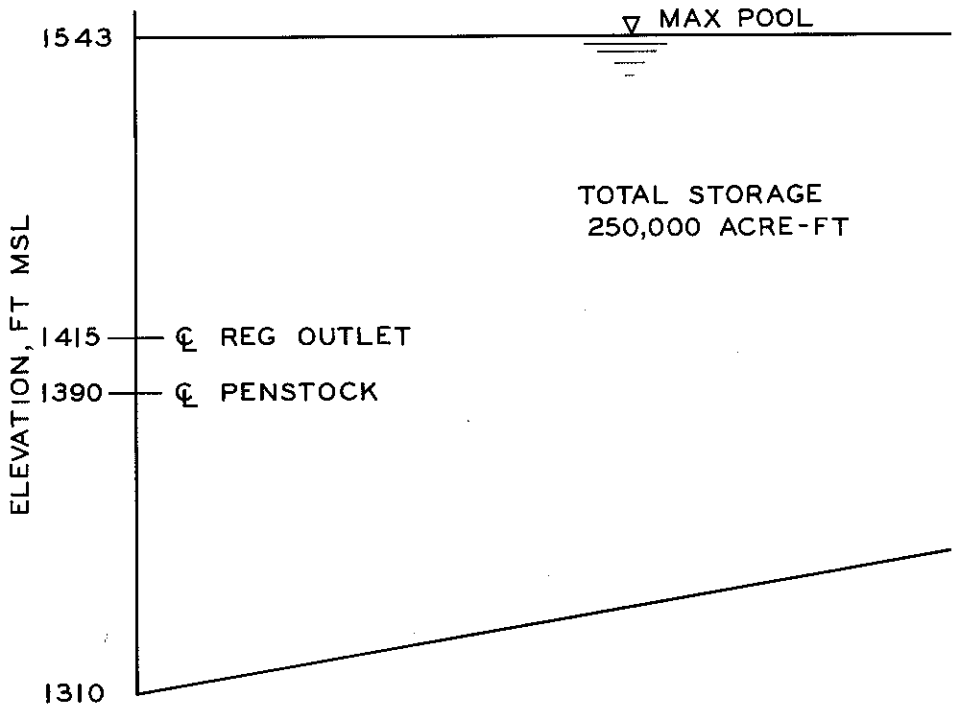

Fig. 1. Hills Creek Reservoir schematic

limits the amount of withdrawal from the lower levels of the pool, which are the levels of greatest turbidity. The concern within the Portland District office relative to the possibility of similar turbidity problems occurring at future reservoir sites, particularly at the proposed Lost Creek Reservoir in the Rogue River Basin, resulted in the conduct of the study reported herein.

Purpose of the Study

5. Methods were needed to analyze and evaluate the possibility

* A table of factors for converting British units of measurement to metric units is presented on page vii.

of turbidity becoming a problem at a proposed reservoir site and to quantify the ability of the proposed reservoir and regulating structures to handle such a problem. This study was therefore conducted to develop a mathematical model capable of predicting the turbidity structure within a reservoir as well as the turbidity of releases from that reservoir. The model was verified based on Hills Creek Reservoir data and was then used to analyze the proposed Lost Creek Reservoir and outlet works to evaluate the capabilities of selective withdrawal facilities and the plans of reservoir operation to control turbidity.

PART II: ANALYSES AND DEVELOPMENTS

The Mathematical Model

6. The model utilized for this study was an adaptation of the mathematical model developed by Clay and Fruh.[6] The basic model was adapted for U. S. Army Engineer Waterways Experiment Station (WES) use on a GE-400 computer.

7. The model developed by Clay and Fruh was capable of simulating thermal and conservative chemical characteristics of a reservoir. Temperature was considered by Clay and Fruh as the major mechanism controlling inflow placement and convective mixing. This concept was modified for the study reported herein so that density based on both temperature and turbidity could be considered the mechanism controlling inflow placement, withdrawal of outflows, and convective mixing.

8. Turbidity was handled as a conservative chemical substance. An examination of the turbidity profiles observed in Hills Creek Reservoir indicated that some settling of suspended solids occurred. However, it was difficult to isolate this separate effect from the available and gross data, which included the effects of dilution and dispersion as affected by inflow, outflow, convection, diffusion, and stratification. If the unknown effects of density stratification on the settling action of suspended colloidal particles of the size indicated in Hills Creek Reservoir were neglected, it is doubtful that the suspended material would settle at a rate greater than 0.1 to 13.0 ft per month. In view of this relatively negligible rate of settling and since the greatest degree of turbidity would be obtained by ignoring settlement, the assumption was made that suspended material entering the reservoir would remain in suspension.

Model Verification

9. As a basis for verifying the model, Hills Creek Reservoir was assumed isothermal on 1 March 1971. An initial turbidity profile was

assumed based on an analysis of the observed turbidity profiles. From inflow data furnished by the Portland District and the OSU study,[5] the relationship between turbidity concentration (T , mg/ℓ) and rate of inflow to Hills Creek Reservoir (Q , cfs) was determined as

$$T = 0.000008\ Q^{1.88} \tag{1}$$

This type of relationship is similar to those developed by Brown and Ritter[3,4] for the Russian and Eel River Basins.

10. Hills Creek Reservoir was simulated for the period March through December 1971. Initial attempts of model verification showed poor agreement between predicted and observed profiles for both temperature and turbidity at the elevations of the outlets. One observation of the OSU study[5] had been that releases indicated a withdrawal zone above the level of the outlets. This development was attributed to the approach geometry of the intake structure. An analysis of the Hills Creek Reservoir profiles, details of the approach channel, local topography, and structural geometry yielded the assumption that the area controlling withdrawal was that of the approach channel between elevations 1430 and 1468 ft msl (fig. 2). Using this assumed effective withdrawal

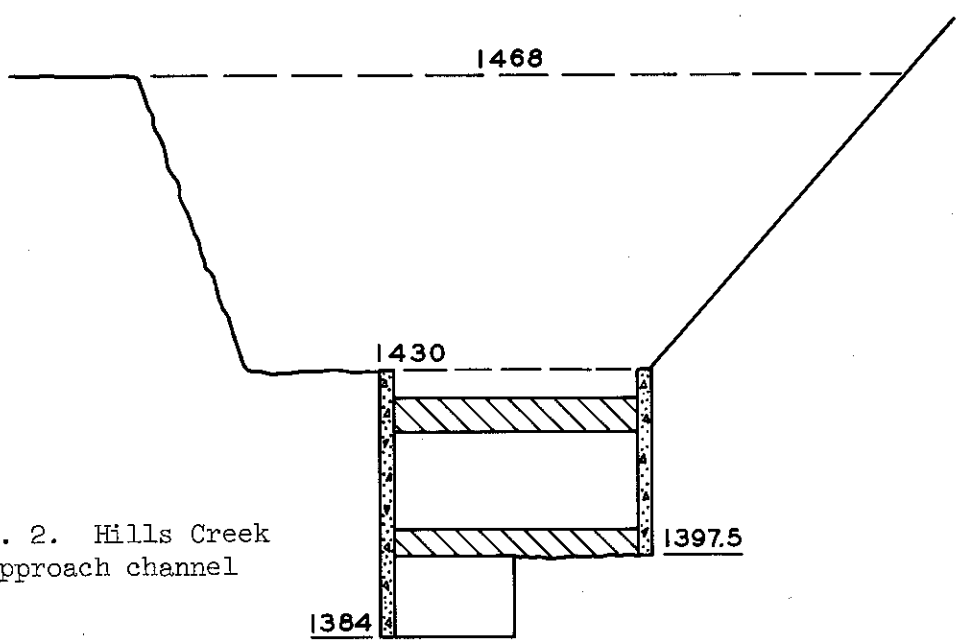

Fig. 2. Hills Creek approach channel

area, reasonable agreement between the predicted and observed temperature and turbidity profiles was obtained (plate 1, table 1).

11. To determine the effects of a storm occurring in January 1971 on pool turbidity conditions in March, Hills Creek Reservoir was simulated for the period 1 January to 1 March. Various simulations were made using different initial temperatures and turbidity conditions. Simulations were also made with the January storm artificially removed by altering the reservoir inflow hydrograph. An analysis of these results (plate 2) indicated that the turbidity profile existing in the reservoir on 1 March was almost entirely a function of the storm inflow turbidity. The turbidity profiles predicted for 1 March differed considerably from the profile assumed in the initial model verification, since the predicted profiles indicated higher concentrations in the upper level of the pool. It was assumed that the highly turbid storm flows, which occur during the winter when the lake is almost isothermal, would plunge to the reservoir bottom. However, this assumption would not necessarily be valid if the inflow temperature was significantly higher than that of the reservoir. It was also felt that the turbidity concentration of the inflow would be significantly reduced due to mixing that would occur upon entry into the reservoir. These assumptions were believed warranted based on the observations of Lake Mendocino made by Brown and Ritter[4] and on the initial results of inflow studies being conducted at WES. Therefore, storm flows for the two major storm days (17 and 18 January) were mathematically "forced" to plunge to the bottom of the reservoir, and the turbidity concentrations for those days were reduced 50 percent. The profile obtained for 1 March from this simulation showed good agreement with the assumed 1 March profile (plate 3).

Simulation of Lost Creek Reservoir

12. Using information furnished by the Portland District, Lost Creek Reservoir was simulated for the period March through December for each of three study years. An average year (1950), a low-water year (1955), and a high-temperature year (1958) were studied. The initial

turbidity profile (plate 3) and the turbidity of inflows were assumed to be the same as those used for the 1971 Hills Creek Reservoir simulation. The reservoir operation scheme was based on meeting a release temperature objective. The simulations yielded lower turbidity concentrations for the Lost Creek Reservoir than those predicted for the Hills Creek Reservoir (table 2). An analysis of the results indicated, however, that a revised plan of reservoir operation might be even more effective in reducing turbidity concentrations.

13. The major storms in this region generally occur in December, January, and February. During these three months, the reservoir is nearly isothermal. Since Lost Creek Reservoir will have selective withdrawal capability (fig. 3), turbid water could be released as soon as

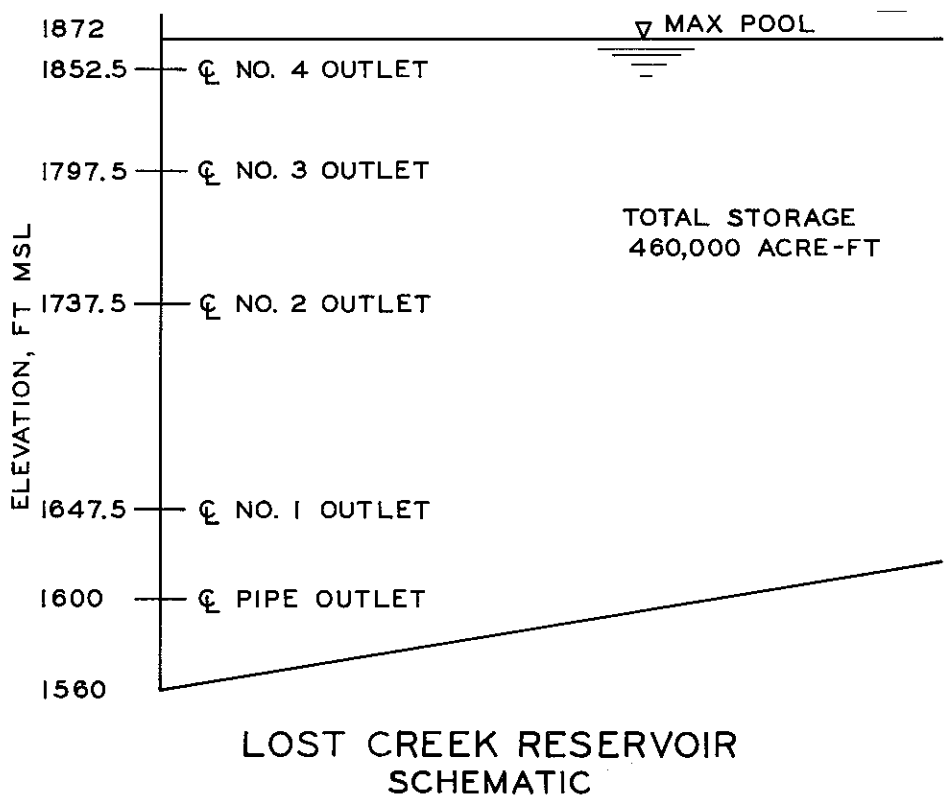

Fig. 3. Lost Creek Reservoir schematic

possible following a storm. This capability should reduce the amount of turbidity in the reservoir while having only minor effects on the temperature objective. In this study, the Lost Creek Reservoir was simulated for the average year (1950) with the initial low-level

outlet (No. 1 outlet, elevation 1647.5) being operated for the month of March. The results (table 3) showed a significant turbidity reduction with a minor difference in temperatures for the period April through September when compared with the simulation based on the operation for a release temperature objective.

14. Based on the above results, additional simulations were made to determine if selective withdrawal in December, January, and February could significantly reduce pool and release turbidities during the summer months. Another objective of these studies was to evaluate the effectiveness of an additional low-level pipe outlet (fig. 3, elevation 1600). From data for the Rogue River furnished by the Portland District, the relationship between turbidity concentration (T , mg/ℓ) and inflow quantity (Q , cfs) was determined to be

$$T = 0.035869217\ Q^{0.72},\ Q < 3800 \text{ cfs} \qquad (2)$$

$$T = 0.000000065\ Q^{2.32},\ Q \geq 3800 \text{ cfs} \qquad (3)$$

The relationship shown by equation 3 is again consistent with the observations of Brown and Ritter.[3,4] The average turbidity per unit volume was calculated for each day of simulation. This value was used to determine the effectiveness of various reservoir operation schemes.

15. Lost Creek Reservoir was simulated from December through March for each of the study years. The same assumptions made for the Hills Creek Reservoir, with regard to plunging turbid storm flows and reduction of storm turbidity concentrations, were made for Lost Creek Reservoir. For each study year, three schemes of reservoir operation were analyzed. Reservoir operations were based on a temperature objective only, a turbidity objective using the initial low-level outlet (No. 1), and a turbidity objective using the proposed low-level pipe outlet. In each of the three study years, the use of the low-level pipe outlet yielded the greatest turbidity reduction (the least amount of turbidity remaining in the reservoir) by March (table 4). In 1955, for example, by using the pipe outlet, the average turbidity per unit

volume in the reservoir was reduced nearly 76 percent from the average turbidity per unit volume immediately following a December storm.

The Computer Program

16. The computer program used for the study (called WESTEX) was developed at WES in time-sharing and batch modes for the GE-400 computer. The program is a category C program as defined by Engineer Regulation 1110-1-10.[7] The model requires daily input and will accept either monthly average or actual daily values. Examples of program input and output are presented in tables 5 and 6, respectively.

PART III: DISCUSSION

17. Observations regarding turbidity in Hills Creek Reservoir and its tributaries indicated that the concentration of suspended material introduced into an impoundment can be correlated with the rate of inflow and that the settling rate of suspended material is negligible. The observations and predictions regarding the turbidity and temperature of downstream releases confirmed the results of several specific WES model studies, which illustrated that the local geometry and topography adjacent to an intake structure may have a significant effect upon its selective withdrawal characteristics.

18. The significance of relatively small density differences between inflow and water within a reservoir was demonstrated and confirms the need for ongoing WES research to develop techniques for describing and predicting the characteristics of density currents entering a stratified reservoir.

19. The OSU study[5] indicated that essentially all of the turbidity entering Hills Creek Reservoir was contributed during one or more major winter storms. All of the turbidity input by the storm was usually not removed in that given year, and the reservoir could experience a cumulative carryover of turbidity. Simulations with the mathematical model confirmed the above conclusion as well as the experience that the occurrence of a single major storm every three to five years could create a long-term turbidity problem in a reservoir lacking selective withdrawal facilities.

20. The effectiveness of selective withdrawal facilities and a coordinated plan of operation as a means of controlling water quality was demonstrated as well as the need for various multilevel outlets, including a low-level outlet near the bottom of an impoundment.

21. The importance of defining the objectives desired and of further analyses to develop plans, designs, and coordinated operating procedures for all pertinent water quality parameters rather than for a single water quality parameter was also indicated by this study. The results also indicated that an adequate design of an impoundment,

its regulating structures, and a coordinated reservoir operation can be developed for achieving the desired objectives. The existence of methodology for analyzing, budgeting, and evaluating both physical and conservative chemical characteristics indicated the potential for simulating biological characteristics which are of importance and concern relative to the overall environment. The evaluation of water quality parameters should include an analysis over a number of consecutive years to determine if any carryover effect will occur.

22. The importance of a mathematical model capable of analyzing with various increments or steps in time depending upon the water quality parameter of interest has been demonstrated. Certainly, periods of major storms should be analyzed on a daily basis, whereas monthly analyses may be sufficient for the remaining periods and parameters. Certain parameters subject to biodegradation may require hourly analyses. It is believed that actual operations should be conducted on the basis of appropriate and timely monitoring of the quality within an impoundment and both the immediate and long-term objectives for which the project is intended.

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Table 1

Comparison of Predicted and Observed Outflow Temperatures, Hills Creek Reservoir

Date	Temperature, °C		
	Predicted	Observed	Diff
1 Mar 1971	5.0	4.7	+0.3
30 Mar 1971	5.4	6.1	-0.7
29 Apr 1971	6.7	6.4	+0.3
28 May 1971	8.4	9.2	-0.8
27 Jun 1971	9.9	8.9	+1.0
26 Jul 1971	11.7	9.2	+2.5
25 Aug 1971	14.7	11.1	+3.6
24 Sep 1971	16.1	14.2	+1.9
23 Oct 1971	15.0	13.3	+1.7
22 Nov 1971	9.4	9.4	0.0
21 Dec 1971	5.5	6.1	-0.6

Note: Mean absolute error = 1.22 °C.
Standard deviation of the absolute error = 1.05 °C.

Table 2

Turbidity Conditions and Temperatures for Inflow and Outflow

Date	Inflow Quantity acre-ft	Inflow Temperature °C	Inflow Turbidity mg/ℓ	Outflow Quantity acre-ft	Outflow Temperature °C	Outflow Turbidity mg/ℓ
Hills Creek Reservoir Simulation						
1 Mar 1971	4217	5.1	17.1	2515	5.0	118.1
30 Mar 1971	4217	5.1	17.1	2515	5.4	43.3
29 Apr 1971	3340	7.5	8.8	2792	6.7	25.3
28 May 1971	4435	8.9	16.2	2911	8.4	19.2
27 Jun 1971	3350	9.9	9.0	3128	9.9	15.5
26 Jul 1971	1640	13.9	2.4	1623	11.7	13.7
25 Aug 1971	840	17.1	0.6	1980	14.7	11.5
24 Sep 1971	850	10.7	0.6	2673	16.1	11.7
23 Oct 1971	851	6.9	0.7	2911	15.0	15.4
22 Nov 1971	2990	7.1	15.6	2990	9.4	18.1
21 Dec 1971	4237	4.5	18.6	5702	5.5	110.8
Lost Creek Reservoir Simulation						
1 Mar 1950	5706	5.3	17.1	3829	4.0	72.9
30 Mar 1950	5706	5.3	17.1	3829	5.3	22.9
29 Apr 1950	5833	6.9	8.8	3899	6.6	16.9
28 May 1950	6875	8.8	16.2	6877	10.5	15.1
27 Jun 1950	5952	10.8	9.0	6431	10.6	13.9
26 Jul 1950	3253	13.5	2.4	4913	10.1	20.6
25 Aug 1950	2519	13.7	0.6	4459	11.4	31.0
24 Sep 1950	2311	11.4	0.6	3099	11.6	27.0
23 Oct 1950	3794	7.9	0.7	4491	10.6	6.4
22 Nov 1950	5493	5.9	15.6	5502	8.7	10.6
21 Dec 1950	8235	5.2	18.6	8175	5.5	18.6
1 Mar 1955	2966	5.2	17.1	1400	4.0	48.9
30 Mar 1955	2966	5.2	17.1	1400	5.3	23.6
29 Apr 1955	3760	5.6	8.8	1527	5.8	19.2
28 May 1955	5740	8.5	16.2	4562	10.2	16.4
27 Jun 1955	5427	11.2	9.0	5912	10.3	15.6
26 Jul 1955	2651	11.9	2.4	4330	9.7	22.5
25 Aug 1955	2049	13.4	0.6	4196	11.6	16.6
24 Sep 1955	1952	10.7	0.6	2934	11.8	12.7
23 Oct 1955	2093	8.2	0.7	2727	10.7	9.6
22 Nov 1955	3249	5.0	15.6	3249	9.2	15.1
21 Dec 1955	9425	4.7	18.6	9425	5.3	19.8
1 Mar 1958	5106	5.2	17.1	3027	6.5	27.7
30 Mar 1958	5106	5.2	17.1	3027	6.5	25.3
29 Apr 1958	5449	6.8	8.8	3469	7.1	17.2
28 May 1958	7298	10.6	16.2	7296	11.6	16.8
27 Jun 1958	5675	11.5	9.0	6172	10.9	17.2
26 Jul 1958	3334	14.3	2.4	5017	10.5	27.2
25 Aug 1958	2693	14.7	0.6	4633	11.0	35.0
24 Sep 1958	2489	10.8	0.6	3677	12.4	10.6
23 Oct 1958	2356	9.1	0.7	2994	10.8	7.7
22 Nov 1958	3487	5.8	15.6	3486	7.7	16.3
21 Dec 1958	3322	5.0	18.6	3324	11.4	7.8

Table 3

Results of Lost Creek Reservoir Simulation

Operation	Date	Inflow Quantity acre-ft	Inflow Temperature °C	Inflow Turbidity mg/ℓ	Outflow Quantity acre-ft	Outflow Temperature °C	Outflow Turbidity mg/ℓ
Temperature objective (No. 3 ports in March)	1 Mar 1950	5706	5.3	17.1	3829	4.0	72.9
	30 Mar 1950	5706	5.3	17.1	3829	5.3	22.9
	29 Apr 1950	5833	6.9	8.8	3899	6.6	16.9
	28 May 1950	6875	8.8	16.2	6877	10.5	15.1
	27 Jun 1950	5952	10.8	9.0	6431	10.6	13.9
	26 Jul 1950	3253	13.5	2.4	4913	10.1	20.6
	25 Aug 1950	2519	13.7	0.6	4459	11.4	31.0
	24 Sep 1950	2311	11.4	0.6	3099	11.6	27.0
Temperature and turbidity objective (No. 1 ports in March)	1 Mar 1950	5706	5.3	17.1	3829	4.0	91.2
	30 Mar 1950	5706	5.3	17.1	3829	4.1	92.8
	29 Apr 1950	5833	6.9	8.8	3899	6.7	15.3
	28 May 1950	6875	8.8	16.2	6877	10.5	15.0
	27 Jun 1950	5952	10.8	9.0	6431	10.7	13.0
	26 Jul 1950	3253	13.5	2.4	4913	10.2	15.4
	25 Aug 1950	2519	13.7	0.6	4459	11.4	21.3
	24 Sep 1950	2311	11.4	0.6	3099	11.6	17.9

Table 4

Comparison of Average Turbidities per Unit Volume

Lost Creek Reservoir

Type of Reservoir Operation Scheme	Average Turbidity per Unit Volume, mg/ℓ		% Reduction (22 Dec 1954 to 15 Mar 1955)	Average Turbidity per Unit Volume, mg/ℓ	
	22 Dec 1954	15 Mar 1955		1 Mar 1950	1 Mar 1958
Based on temperature objective only	142.3	82.8	41.8	25.1	29.1
Based on turbidity objective using No. 1 outlet	131.4	38.0	71.1	17.6	27.6
Based on turbidity objective using proposed pipe outlet	128.1	31.3	75.6	15.9	26.7

FOREWORD

The investigation reported herein was authorized by the U. S. Army Engineer District, Portland. The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, during the period June 1972 to September 1972, under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and T. E. Murphy, Chief of the Structures Branch. The analyses and developments were conducted by Messrs. D. G. Fontane and J. P. Bohan under the direct supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Channels Section. This report was prepared by Messrs. Fontane, Bohan, and Grace.

Director of WES during the conduct of the study and the preparation and publication of this report was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

Table 5

Computer Input for Mathematical Simulation of the Turbidity Structure in an Impoundment

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620C THE FOLLOWING DATA IS THE INPUT REQUIRED FOR A TEN MONTH
630C THERMAL AND TURBIDITY SIMULATION.
640C RESERVOIR GEOMETRY AND SIMULATION ALTERNATIVES.
650 DATA DELZ/10./,DELT/1.0/,NSTEP/10/
660 DATA NP/4/,DEPTH/272./,ZSPILL/320./,B/1795./,ELVB/1560./
670 DATA PAREA/4*360./,PHGT/87.5,177.5,237.5,292.5/
680 DATA VOL/.5,.5,2.,2.,2.,4.,4.,6.,7.,7.,9.,9.,11.,11.,13.,13.,
690&13.,16.,18.5,18.5,19.,22.,22.,25.,25.,26.,28.,28.,31.,32.,
700&33.,36.,0.,0.,0./
710 DATA WIDTH/360.,785.,1035.,1130.,1183.,1205.,1233.,1254.,1289.,
720&1318.,1354.,1385.,1435.,1506.,1610.,1725.,2020.,2400.,2665.,
730&2780.,2972.,3223.,3532.,3801.,4140.,4255.,4382.,4520.,4658.,
740&4800.,4940.,5080./
750C DIFFUSION, NET HEAT EXCHANGE, AND EVAPORATION DATA.
760 DATA EMAXMO/12*2000./,EMINMO/12*10./
770 DATA ENGMO/91.,189.,243.,209.,200.,140.,55.,-49.,-81.,37.,
780&29.,63./
790 DATA EVAPMO/.0,1.52,2.59,3.09,4.77,5.71,3.65,1.8,.0,.0,.0,.0/
800C INFLOW QUANTITIES, TEMPERATURE, AND TURBIDITY.
810 DATA INFLMO/5.706,5.833,6.875,5.952,3.253,2.519,2.311,3.794,
820&5.493,8.235,3.552,3.942/
830 DATA INTMO/5.31,6.91,8.83,10.76,13.51,13.67,11.44,7.94,5.91,
840&5.23,5.,5./
850 DATA TURB/17.1,8.8,16.2,9.0,2.4,.6,.6,.7,15.6,18.6,106.2,
860&8.5/
870C PORT OPERATION AND OUTFLOW DATA.
880 DATA NOPNMO/1,1,1,2,2,2,2,2,2,1,1,1/
890 DATA IPRTMO(1,1)/1/,IPRTMO(2,1)/3/,IPRTMO(3,1)/4/,IPRTMO(4,1)
900&/3/,IPRTMO(4,2)/4/,IPRTMO(5,1)/2/,IPRTMO(5,2)/3/,IPRTMO(6,1)
910&/1/,IPRTMO(6,2)/2/,IPRTMO(7,1)/1/,IPRTMO(7,2)/2/,IPRTMO(8,1)
920&/2/,IPRTMO(8,2)/3/,IPRTMO(9,1)/2/,IPRTMO(9,2)/3/,IPRTMO(10,1)
930&/3/,IPRTMO(11,1)/3/,IPRTMO(12,1)/3/
940 DATA ISPLMO/12*4/
950 DATA OTFLMO(1,1)/3.829/,OTFLMO(2,1)/3.899/,OTFLMO(3,1)/6.877/,
960&OTFLMO(4,1)/5.057/,OTFLMO(4,2)/1.374/,OTFLMO(5,1)/3.309/,
970&OTFLMO(5,2)/1.604/,OTFLMO(6,1)/.741/,OTFLMO(6,2)/3.718/,OTFLMO
980&(7,1)/.525/,OTFLMO(7,2)/2.574/,OTFLMO(8,1)/3.78/,OTFLMO(8,2)
990&/.711/,OTFLMO(9,1)/.287/,OTFLMO(9,2)/5.215/,OTFLMO(10,1)/8.17
1000&5/,OTFLMO(11,1)/3.564/,OTFLMO(12,1)/2.073/
1010C TEMPERATURE AND TURBIDITY INITIAL CONDITIONS.
1020 DATA TINT/4.5,4.5,4.5,4.5,4.5,4.5,4.5,4.5,4.5,4.5,4.5,5.,5.,5.,
1030&5.,5.,5.,5.,5.5,5.5,5.5,5.5,6.1,6.1,6.7,7.8,9*8.3/
1040 DATA NCHEM/2/,SP/1.3/,TOC/4.0/,CHEMO2/32*0.0/,CHEMO1/349.,340.,
1050&327.,310.,290.,270.,247.,225.,194.,167.,146.,127.,116.,104.,90.,
1060&77.,65.,55.,46.,38.,32.,28.,26.,9*24.7/
1070C END OF DATA.
```

Table 6

Computer Output for Mathematical Simulation of the Turbidity Structure in an Impoundment

DAY NUMBER 1

DEPTH = 272.67 FEET.

INFLOW = 5706. ACRE FEET.

TEMPERATURE IN = 5.3 DEG C.

TURBIDITY IN = 17.1 MG/L

OUTFLOW = 3829. ACRE FEET, COMPOSED OF

3829. ACRE FEET FROM GATE NO. 1 AT 11.0 FEET ABOVE BOTTOM.

WITHDRAWAL = 3829.00

TEMPERATURE OUT = 4.5 DEG C.

TURBIDITY OUT = 245.7 MG/L

EVAPORATION = 0. ACRE FEET.

IMPOUNDMENT PROFILES

Y (FT)	WITHDRAWAL (AC FT)	TEMP (DEG C)	TURBIDITY (MG/L)	ELEVATION (FT)
272.7	0.00	8.57	24.7	1832.7
265.0	0.00	8.46	24.7	1825.0
255.0	0.00	7.65	24.7	1815.0
245.0	0.00	6.80	24.8	1805.0
235.0	0.00	6.24	25.1	1795.0
225.0	0.00	6.02	26.5	1785.0
215.0	0.00	5.60	30.4	1775.0
205.0	0.00	5.52	31.2	1765.0
195.0	0.00	5.49	36.7	1755.0
185.0	0.00	5.45	39.2	1745.0
175.0	0.00	5.11	54.6	1735.0
165.0	0.00	5.01	59.4	1725.0
155.0	0.00	5.00	71.8	1715.0
145.0	0.00	5.00	86.1	1705.0
135.0	0.00	5.00	99.0	1695.0
125.0	0.87	5.00	111.7	1685.0
115.0	8.58	5.00	122.3	1675.0
105.0	427.07	4.71	143.2	1665.0
95.0	416.42	4.50	155.2	1655.0
85.0	410.07	4.50	177.5	1645.0
75.0	399.81	4.50	211.7	1635.0
65.0	393.70	4.50	235.0	1625.0
55.0	385.23	4.50	259.7	1615.0
45.0	378.52	4.50	276.1	1605.0
35.0	361.78	4.50	299.8	1595.0
25.0	331.47	4.50	321.5	1585.0
15.0	251.42	4.50	331.7	1575.0
5.0	64.06	4.50	347.8	1565.0

TOTAL THERMAL ENERGY = 2.021 MILLION DEG C ACRE FEET.

(Continued)

Table 6 (Concluded)

NDAY = 1

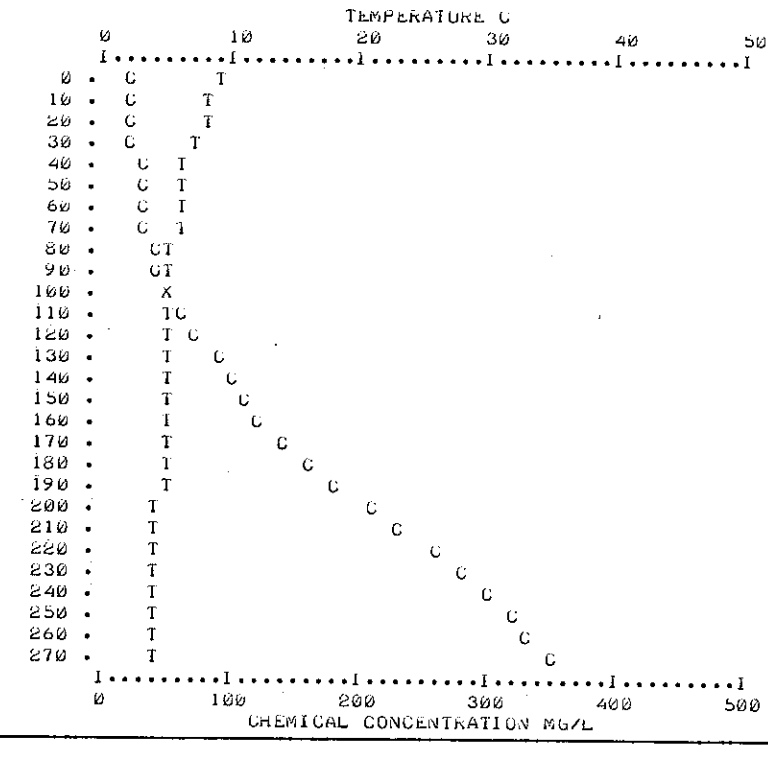
DENSITY PROFILES

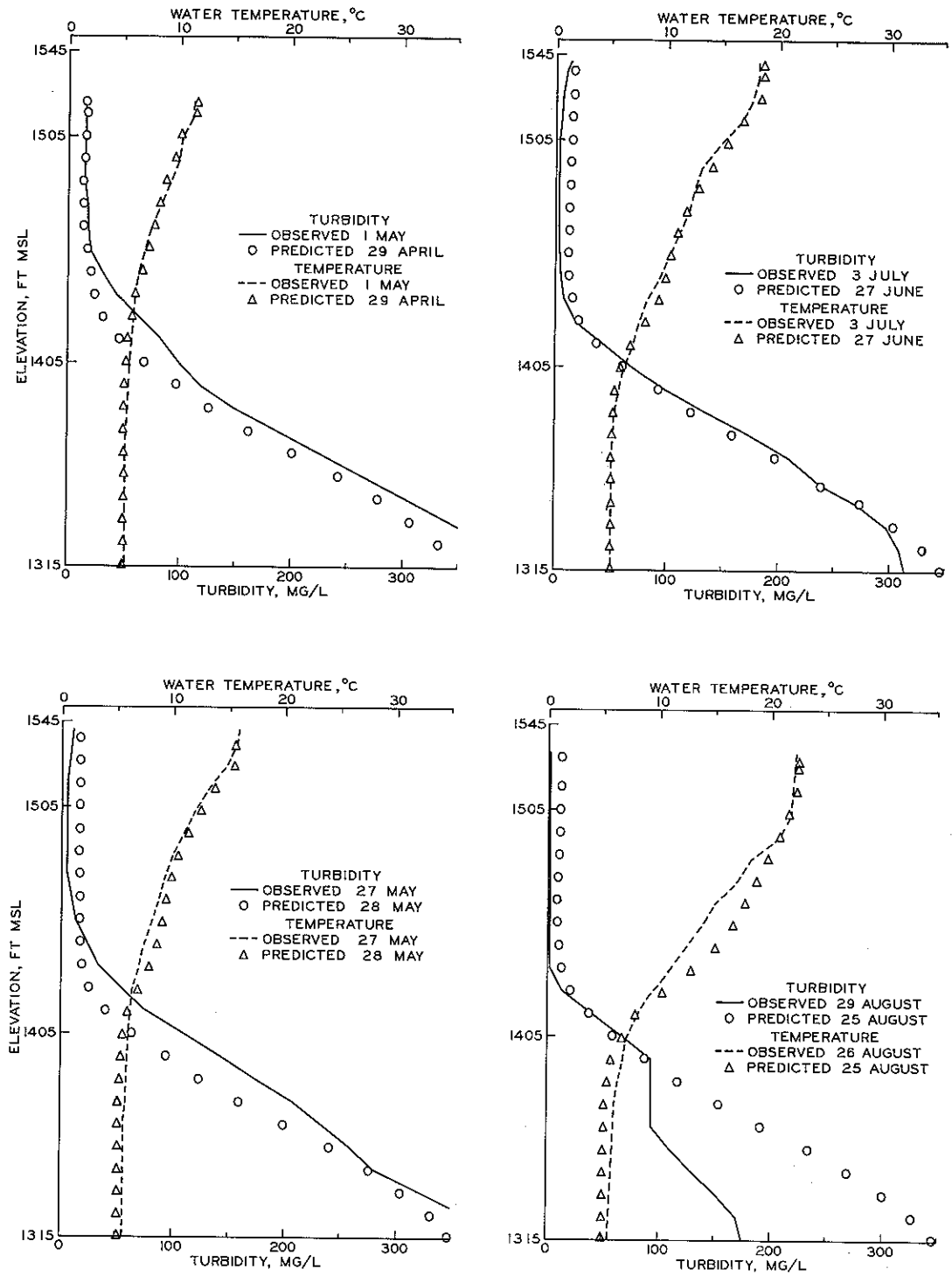
Y	TEMP + CHEM	TEMP
272.7	0.9998396442	0.9998396385
265.0	0.9998484457	0.9998484400
255.0	0.9999041761	0.9999041704
245.0	0.9999439513	0.9999439456
235.0	0.9999628901	0.9999628843
225.0	0.9999685472	0.9999685410
215.0	0.9999815927	0.9999815855
205.0	0.9999815927	0.9999815855
195.0	0.9999822770	0.9999822682
185.0	0.9999833283	0.9999833192
175.0	0.9999917575	0.9999917438
165.0	0.9999917575	0.9999917438
155.0	0.9999919020	0.9999918842
145.0	0.9999919050	0.9999918842
135.0	0.9999919082	0.9999918842
125.0	0.9999919110	0.9999918842
115.0	0.9999919713	0.9999919420
105.0	0.9999979242	0.9999978884
95.0	0.9999979242	0.9999978884
85.0	0.9999979498	0.9999979051
75.0	0.9999979570	0.9999979051
65.0	0.9999979620	0.9999979051
55.0	0.9999979674	0.9999979051
45.0	0.9999979720	0.9999979051
35.0	0.9999979766	0.9999979051
25.0	0.9999979805	0.9999979051
15.0	0.9999979835	0.9999979051
5.0	0.9999979856	0.9999979051

DAY = 1

T IS TEMPERATURE IN DEGREES CENTIGRADE
C IS CHEMICAL CONCENTRATION IN MG/L

VERTICAL AXIS IS DEPTH BELOW THE SURFACE IN FEET



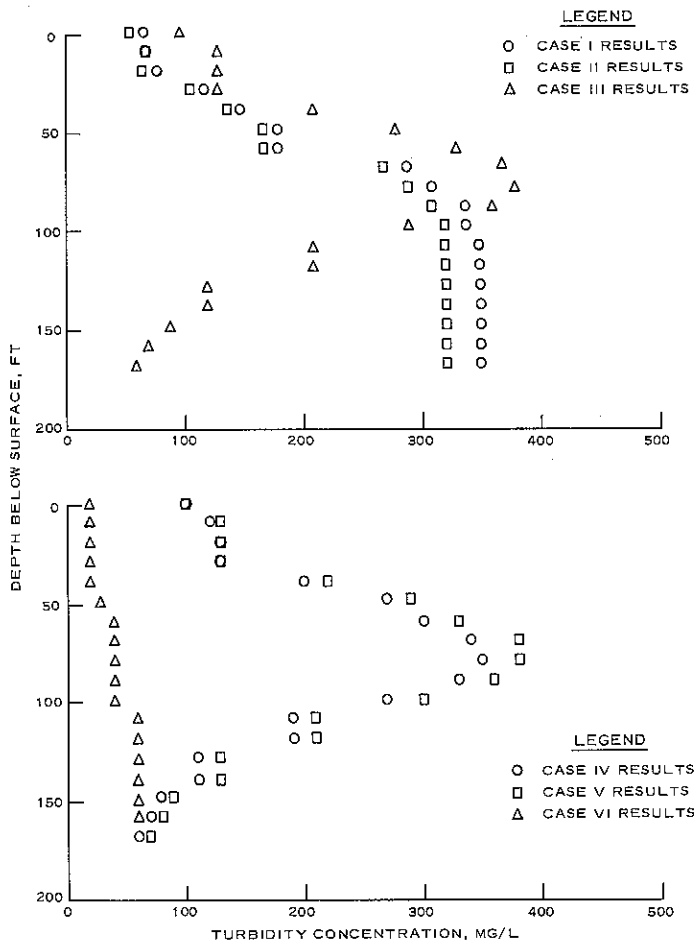


HILLS CREEK RESERVOIR, 1971

OBSERVED AND PREDICTED TEMPERATURE AND TURBIDITY PROFILES

PLATE 1

PLATE 2



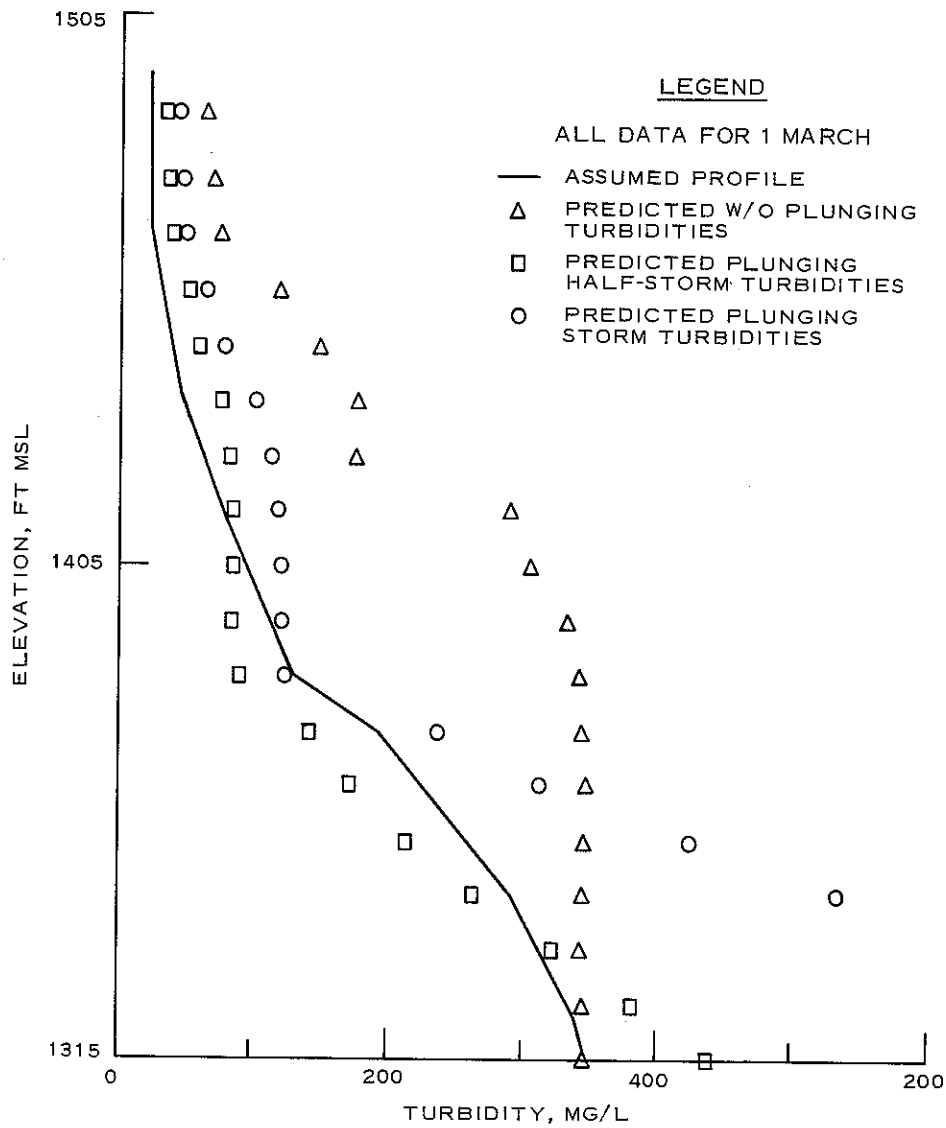
LEGEND

JANUARY AND FEBRUARY 1971

CASE I	INITIAL CONDITIONS ARE THOSE OF DECEMBER 1971.
CASE II	INITIAL CONDITIONS ARE TEMPERATURE EQUAL TO THAT OF DECEMBER 1971 AND ZERO MG/L OF TURBIDITY IN THE RESERVOIR.
CASE III	INITIAL CONDITIONS ARE TEMPERATURE EQUAL TO 6° C ISOTHERMAL AND TURBIDITY EQUAL TO THAT OF DECEMBER 1971.
CASE IV	INITIAL CONDITIONS ARE TEMPERATURE EQUAL TO 6° C ISOTHERMAL AND ZERO MG/L OF TURBIDITY IN THE RESERVOIR.
CASE V	INITIAL CONDITIONS ARE TEMPERATURE EQUAL TO 6° C ISOTHERMAL AND 100 MG/L OF TURBIDITY IN THE RESERVOIR.
CASE VI	INITIAL CONDITIONS ARE THOSE OF DECEMBER 1971. JANUARY STORM "REMOVED".

HILLS CREEK RESERVOIR

PREDICTED 1 MARCH PROFILES



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17 AND 18 JANUARY 1971

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13. ABSTRACT

The turbidity structure of an impoundment was simulated using a mathematical model capable of simulating physical and chemical characteristics of an impoundment. Turbidity was handled as a conservative chemical substance. The model was used to predict the thermal and turbidity structures of an existing impoundment and was verified with observed data. The model was then used to predict the turbidity structure of a proposed impoundment. The effectiveness of selective withdrawal and, in particular, of a low-level outlet in controlling the turbidity structure of an impoundment was demonstrated.

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