TECHNICAL REPORT H-76-11

EFFECTS OF FLOOD FLOWS ON WATER QUALITY OF TIOGA-HAMMOND LAKES

Hydraulic Model Investigation

by

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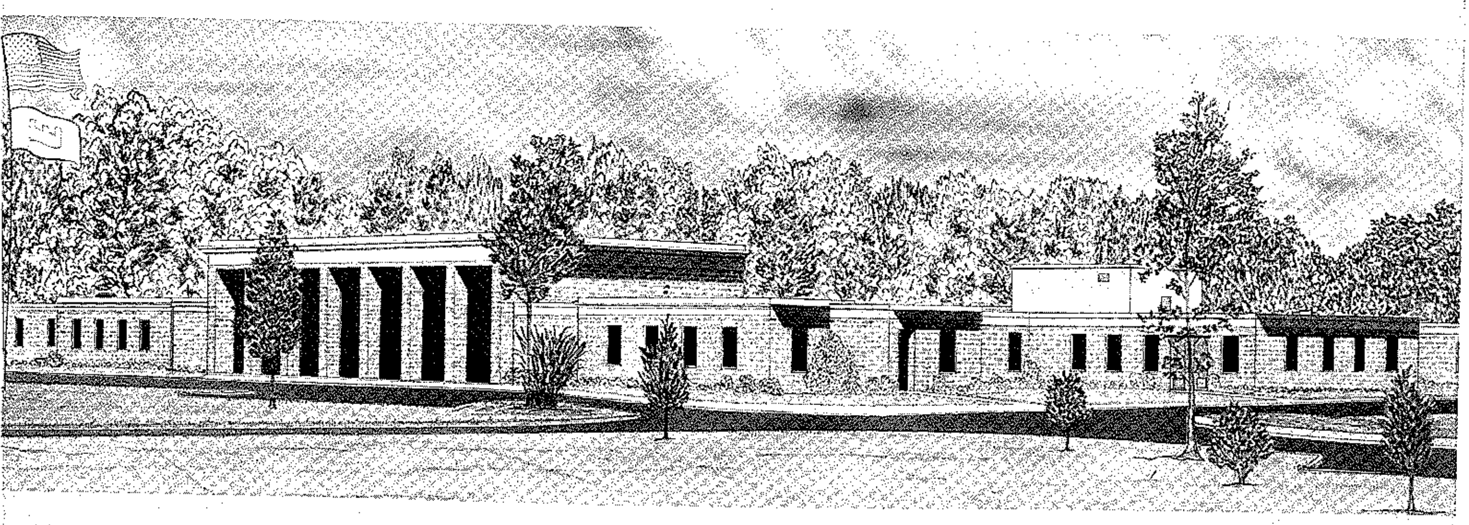

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The physical model investigation was conducted to estimate the dilution and dispersion of acidic and alkaline substances within Tioga-Hammond Lakes as a result of flood flows and to determine the concentration of these substances in the outflow during drawdown. The model, constructed to a distorted length scale ratio of 1:100 vertically and 1:2000 horizontally, consisted of Tioga and Hammond Lakes, the connecting channel of the dual reservoir system, Hammond outlet works, and the flood control intakes of Tioga outlet works. The model

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simulated density variations and stratifications expected to exist in the prototype due to temperature differences and reproduced the unsteady inflow and outflow hydrographs for various size floods. Concentrations of fluorescent dyes simulated the acidic and alkaline substances; water samples were collected and analyzed to determine the dilution and dispersion of the dyes throughout the lakes and in the outflow from the lakes. The expected concentrations of acidic and alkaline substances existing in the two lakes after flood inflows and drawdown and in the outflow during drawdown are presented for three flood conditions. The results provide information for estimating water quality for similar flood conditions within and downstream of the project and guidance for limiting adverse quality during drawdown.

PREFACE

The model investigation reported herein was authorized by the U. S. Army Engineer District, Baltimore, and conducted during the period March 1974-December 1975 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; J. L. Grace, Jr., Chief of the Structures Division; and J. P. Bohan, Chief of the Spillways and Channels Branch. Mr. M. S. Dortch conducted the model study and prepared this report. Messrs. F. L. Hebron and H. D. Price of the Instrumentation Services Division, WES, provided instrumentation support for the model study.

A conference was held at WES on 20-21 March 1975 to discuss various phases of the study. The meeting was attended by the following personnel: Messrs. E. E. Eiker and S. B. Powell of the Office, Chief of Engineers; Messrs. H. Kass and E. J. Marcinski of the Baltimore District; and Messrs. J. L. Grace, Jr., J. P. Bohan, and M. S. Dortch of WES.

Directors of WES during the testing program and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acres	4046.856	square metres
acre-feet	1233.482	cubic metres
cubic feet per second	0.02831685	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

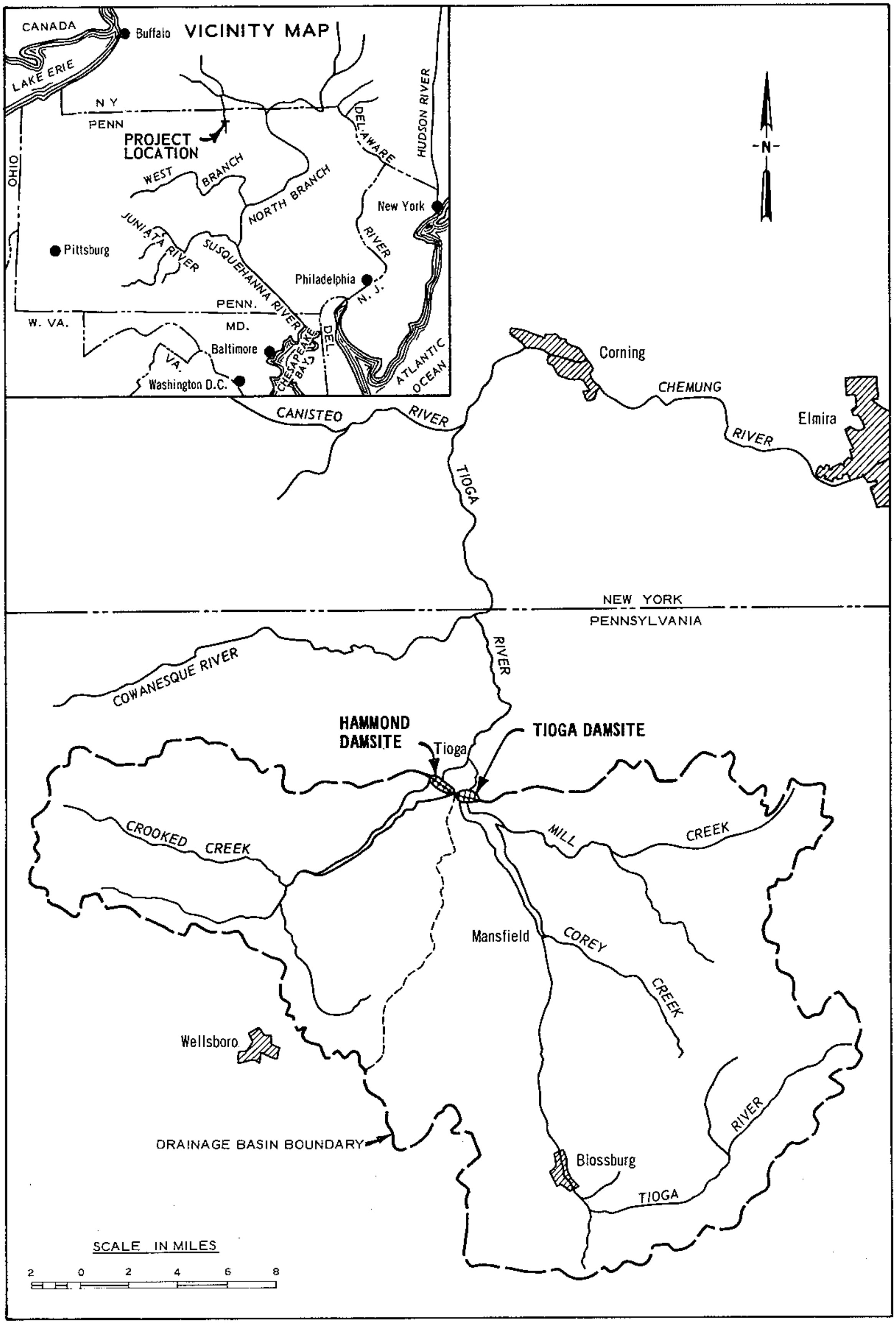

Figure 1. Location map

EFFECTS OF FLOOD FLOWS ON WATER QUALITY OF TIOGA-HAMMOND LAKES

Hydraulic Model Investigation

PART I: INTRODUCTION

Project Description

1. The Tioga-Hammond Lakes project is on the Tioga River and Crooked Creek in north central Pennsylvania about 8 miles* south of the Pennsylvania-New York State boundary (Figure 1, page 6). The proposed lakes will provide flood control and recreation. The Tioga damsite is on the Tioga River about 1.7 miles upstream from its confluence with Crooked Creek. The Hammond damsite is on Crooked Creek about 3.3 miles upstream from its confluence with the Tioga River. Both dams are immediately south of the borough of Tioga.

2. The project features include Tioga embankment, Hammond embankment, a concrete uncontrolled spillway (ogee type), Tioga outlet works, Hammond outlet works, Crooked Creek outlet works, and a channel connecting Tioga and Hammond Lakes. The general plan of the project is shown in Plate 1. Pertinent data for the dual reservoir system are presented in the following tabulation.

Elevations**	Tioga	Hammond
Top of dam	1170.0	1169.0
Spillway crest	--	1131.0
Riverbed at dam	1031.0	1053.0
Normal summer pool	1081.0	1086.0
Normal winter pool	1060.0	1075.0
Connecting channel weir crest	1101.0	
Outlet works gate seats	1035.0	1058.0
		1064.5 (Crooked Creek)

(Continued)

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to mean sea level.

Elevations	Tioga	Hammond
Plunge pool floor	--	1053.5

Reservoir length (miles)		
Length at spillway crest (el 1131.0)	9.9	7.8

Reservoir storage (acre-ft)		
Winter conservation lake	2,200	2,800
Summer conservation lake	12,000	10,000
Flood control	59,800	60,200

Reservoir surface area (acres)		
Spillway crest (el 1131.0)	1,600	1,770
Spillway design flood (Tioga - el 1164.8) (Hammond - el 1163.5)	3,120	2,800

3. The connecting channel will be sufficiently large to permit operation of the two reservoirs as one flood control project. Hammond outlet works is intended to control flow through the connecting channel. The plan for Hammond outlet works is shown in Plate 2. Whenever either lake's pool exceeds the connecting channel weir crest (el 1101), water will be allowed to discharge over the weir into the lake with the lower pool. When both pools are below el 1101, only flow from Hammond Lake to Tioga Lake will be allowed through the gate structure of Hammond outlet works. This scheme of operation for the gate structure is intended to allow release of Hammond Lake water and to prevent the acidic water of Tioga Lake from entering and polluting Hammond Lake during normal flow conditions. Tioga River water is acidic due to coal mine drainage, and it will not support fish life. For normal flow, the pH of the Tioga River ranges from about 4.0 to 6.3, with an average pH closer to 4.0. This low pH is caused by sulfuric acid (H_2SO_4) concentrations as high as 50 mg/ℓ. Concentrations this high could possibly exist in Tioga Lake. The water of Crooked Creek is alkaline, and should provide a favorable environment for fish. The pH of Crooked Creek ranges from 7.8 to 8.2

with concentrations of calcium carbonate ($CaCO_3$) as high as 50 mg/ℓ.

4. Tioga outlet works (Plate 3), located in the left abutment of the Tioga embankment, will provide controlled selective withdrawal and flood releases from Tioga Lake. Crooked Creek outlet works will provide flow into Crooked Creek downstream of the Hammond dam. This will allow the alkaline water from Hammond Lake, entering the Tioga River by way of Crooked Creek, to mix with and help neutralize the acidic water released from Tioga Lake during low flow periods.

5. Control features and discharge capacities for the three outlet works are presented below.

	Outlet Works		
Control	Tioga	Hammond	Crooked Creek
Service gates	Two 7 ft by 21 ft	Two 8 ft-4 in. by 11 ft-6 in.	One 3 ft by 3 ft
Selective withdrawal ports	Four 3 ft by 6 ft	None	None
Conduit design discharge, cfs	15,860	8150	225

Purpose and Scope Of Study

6. During normal flow periods, Hammond outlet works will prevent Tioga Lake from contaminating Hammond Lake, and water released from Crooked Creek outlet works will help raise the pH of releases from Tioga Lake by flow augmentation. However, mixing may occur between the lakes during flood flows, and drawdown procedures could cause large quantities of poor quality water (low pH) to be released from the project. This could result in deterioration of the water quality in Hammond Lake and downstream of the dual reservoir system.

7. The study reported herein was conducted to investigate the dilution and dispersion of acidic and alkaline substances during floods. A physical model was used to simulate flood inflows and outflows and to determine the dispersive effects of these flows. The study included (a) description of the internal (stratified) flows in the lakes during

floods, (b) determination of stratification changes resulting from flood inflows and outflows, and (c) determination of acidic and alkaline substance concentrations existing in the two lakes after flood inflows and drawdown and in the outflow during drawdown.

PART II: THE MODEL

Approach and Description

8. A physical modeling approach was used for the study because of the highly dynamic nature of the flows that occur during floods. Due to the high flow rates and short duration of inflows and outflows, existing mathematical models were considered inadequate for describing the hydrodynamic phenomena.

9. The model (Figure 2), constructed to a distorted length scale ratio of 1:100 vertically and 1:2000 horizontally, consisted of Tioga and Hammond Lakes, the connecting channel, Hammond outlet works, and the flood control intakes of Tioga outlet works. Crooked Creek outlet works and the selective withdrawal facilities of Tioga outlet works were not included in the model because the low flow capabilities of these structures were not within the interest of this study.

10. With the vertically distorted model, turbulent flow was preserved while the simulation of the entire dual reservoir system maintained the same fundamental character of prototype flow. Use of an undistorted model would have required a model of such large dimensions and discharge capacity that the cost would have been impractical. By vertical scale exaggeration, the model size was reduced and hydraulic similitude was preserved.

11. The model was constructed of transparent plastic; through the use of various dyes, the currents in the vertical and longitudinal directions could be observed. The lake models reproduced the general alignment of the two impoundments and the relations between depth-station, elevation-volume, elevation-width at various stations, and the elevation-surface area. The sides of the model flume were stepped vertically (Figure 3) so that the design requirements could be satisfied without visual distortion through the flume. Although the topography was not reproduced exactly, sufficient geometric similarity was preserved for the simulation and evaluation of the effects of geometry on the hydrodynamics of stratified flow within the lakes.

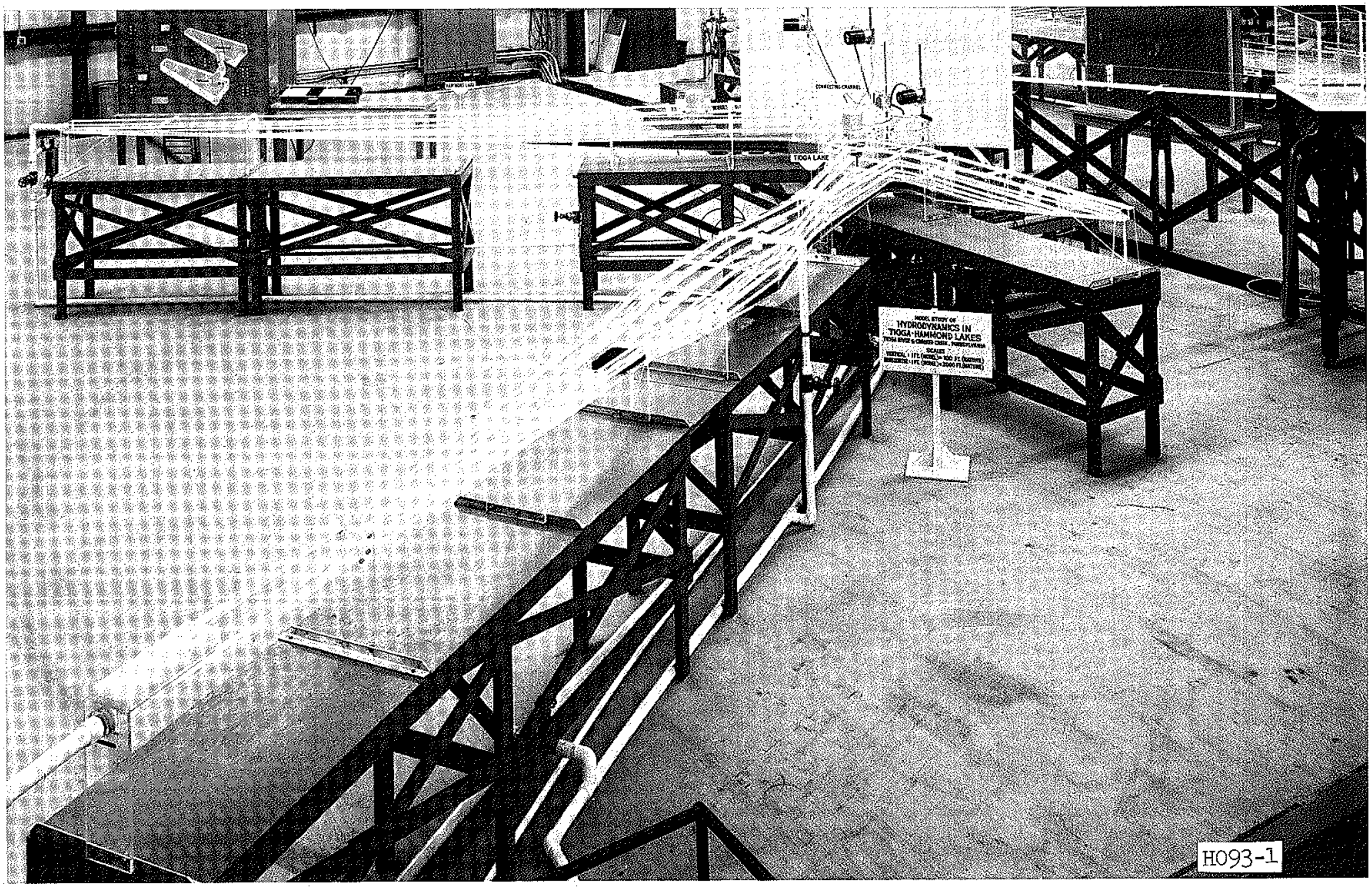

Figure 2. Hydrodynamic model of Tioga-Hammond Lakes

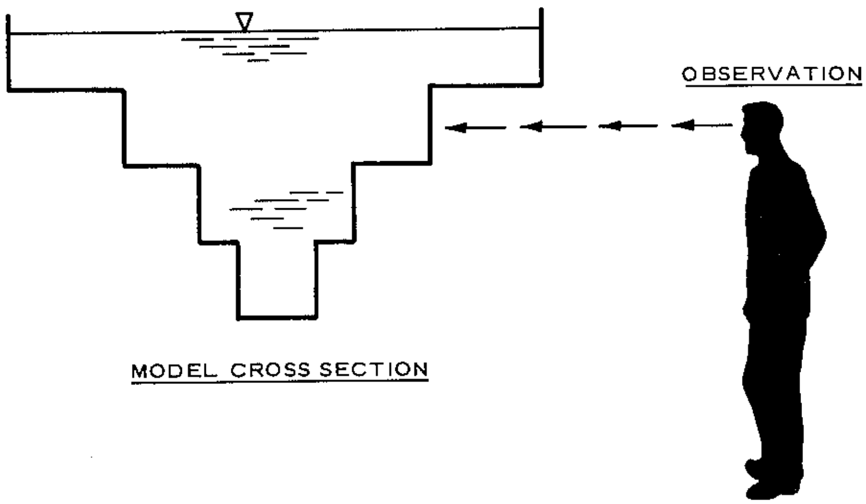

Figure 3. Example of model design for convenient observation

12. Saline and fresh waters reproduced the density variations that would exist in the prototype due primarily to temperature differences. Inflow and outflow hydrographs were produced with programmable variable flow pumps and mechanically actuated gates. Analog signals to the pumps and actuated gates were generated by card readers that tracked input data plotted on magnetic cards. A schematic of the model control system is shown in Figure 4. The model control board (Figure 5) allowed manual or automatic operation. Turbine flowmeters and rotameters were used to calibrate the pumps and gates and to monitor inflow and outflow quantities. Water-surface elevations were measured with acoustical water-surface detectors and staff gages.

Scale Relations

13. The predominant forces affecting density-stratified flows in lakes are inertia and gravity as modified by density differences. In such cases, hydraulic similarity between a model and prototype system requires that the ratio of inertial to gravitational forces, defined as the Froude number of flow, be the same in both the model and the prototype. With the density differences in the model equal to those in the prototype, the accepted equations of hydraulic similitude, based on the

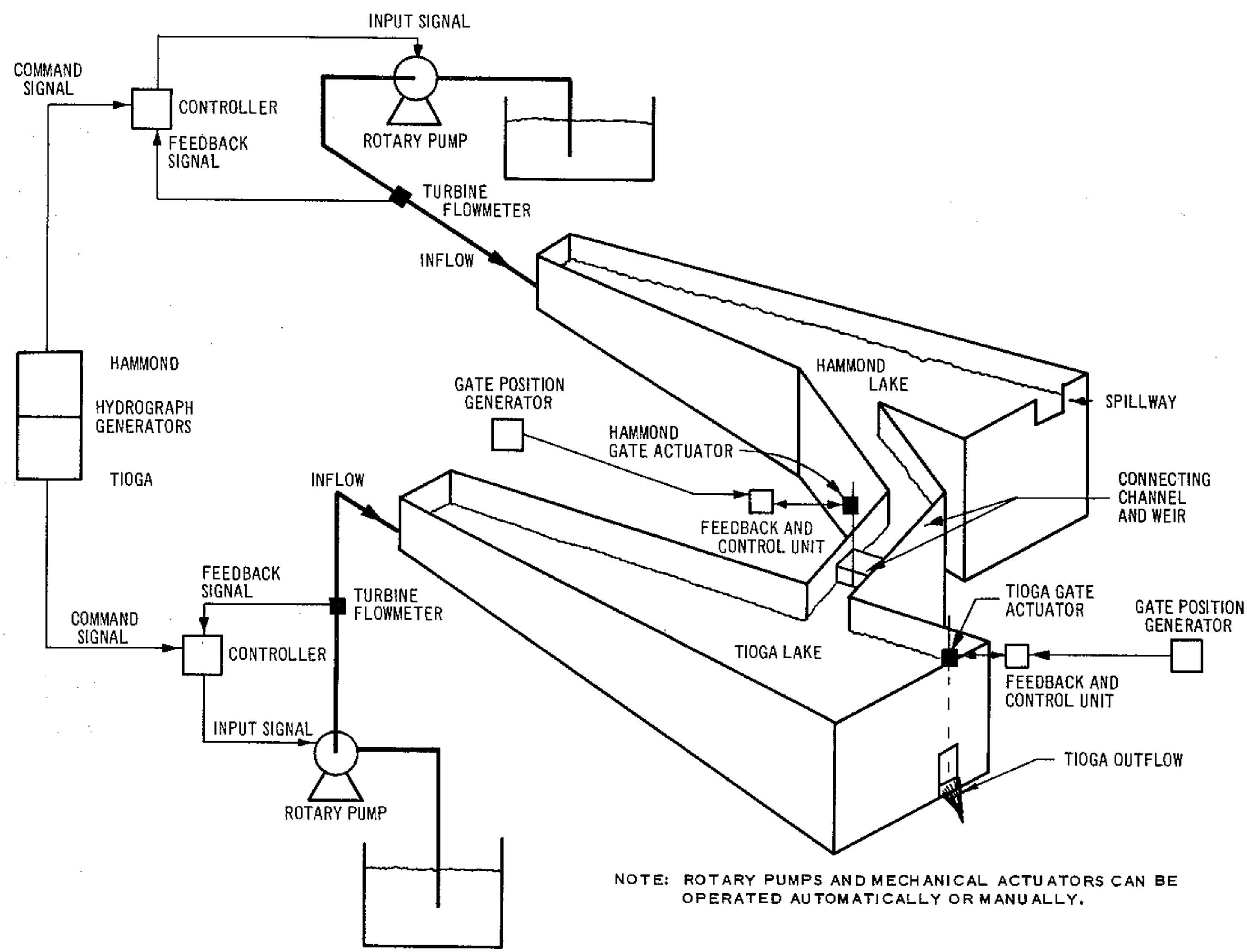

Figure 4. Schematic of model control system

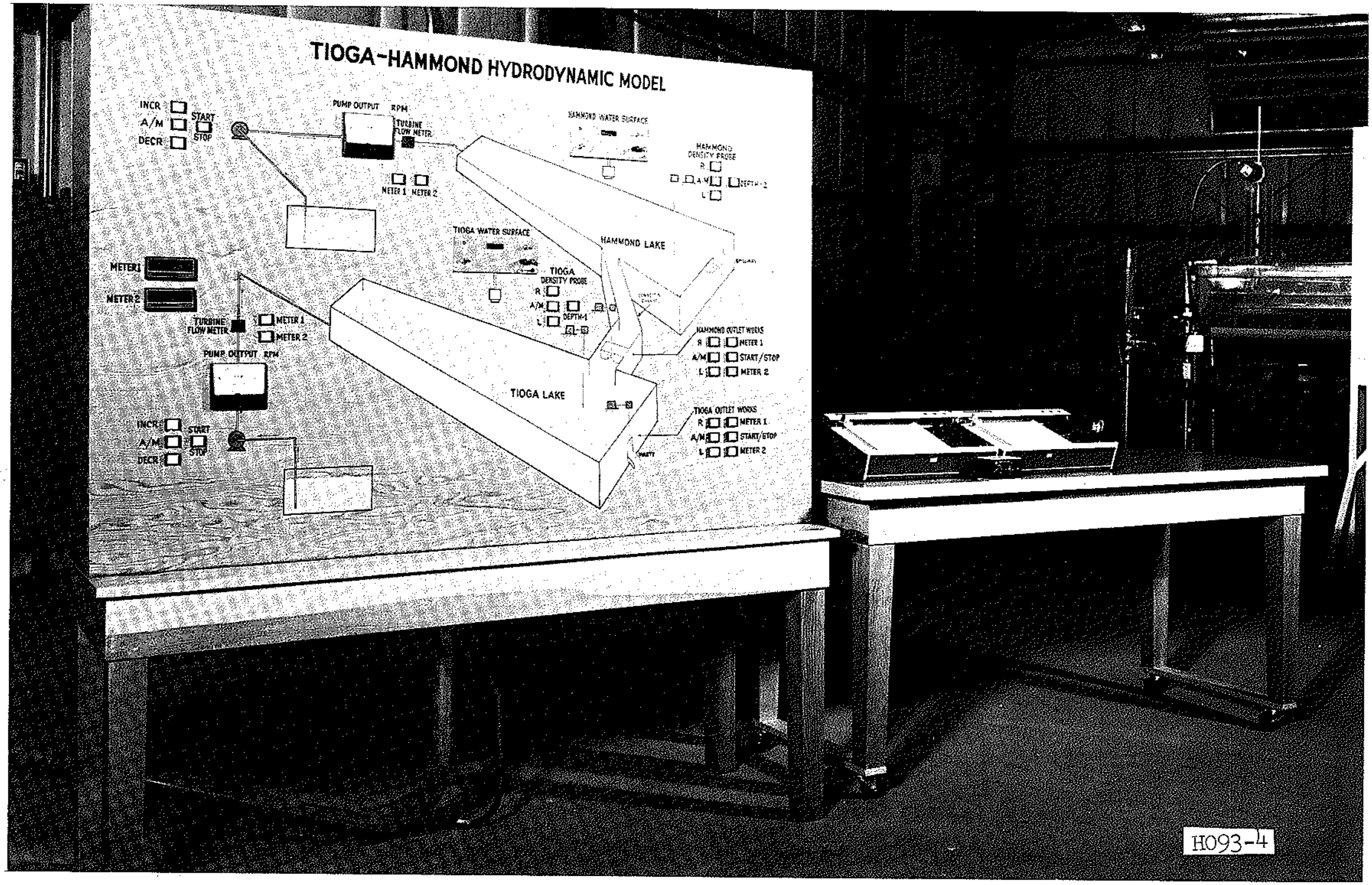

Figure 5. Model control board

Froudian relations, were used to express the mathematical relations between the dimensional and hydraulic quantities of the model and the prototype.

14. Allowing for vertical scale distortion, the general relations for transfer of model to prototype equivalents are as follows:

Dimension	Ratio	Scale Relation
Length in vertical direction	L_y	1:100
Length in horizontal direction	L_x	1:2,000
Area in vertical plane	$A_R = L_x L_y$	1:200,000
Area in horizontal plane	$A_R = L_x^2$	1:4,000,000
Volume	$V_R = L_x^2 L_y$	1:400,000,000
Velocity	$V_R = L_y^{1/2}$	1:10
Discharge	$Q_R = L_x L_y^{3/2}$	1:2,000,000
Time	$T_R = L_x / L_y^{1/2}$	1:200
Density difference	$\Delta\rho_R = 1.0$	1:1

Modeling Considerations

15. There was concern for the ability of the model weir to properly simulate the hydraulic characteristics of the prototype weir because of the small model-to-prototype scale ratio and large quantities of flow that pass over the connecting channel weir during floods. With a horizontal scale of 1:2000, the model weir was very narrow (0.10 ft). During the period March-June 1974, an undistorted 1:80-scale model*

* N. R. Oswalt and G. A. Pickering, "Connecting Channel for Tioga and Hammond Lakes, Tioga River and Crooked Creek, Pennsylvania; Hydraulic Model Investigation," Technical Report H-76-6, Apr 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

of the connecting channel weir was studied at the U. S. Army Engineer Waterways Experiment Station (WES). Comparisons of weir flow calibrations of the two models revealed that the discharge characteristics of the distorted scale model differed only about 6 percent from those of the undistorted scale model. This amount of difference was considered to be insignificant because the accuracy of the flow measuring devices ranged from 2 to 5 percent. Therefore, the weir of the distorted model was considered to be hydraulically similar.

16. Because of the large quantity and varying quality of outflow from Tioga Lake during the drawdown of a flood, it was necessary to provide proper simulation of the selective withdrawal characteristics of the Tioga outlet works in the model. An undistorted model of an intake structure and surrounding topography can be used to determine the selective withdrawal characteristics when unusual or complex geometries are involved. Then the selective withdrawal characteristics of the distorted model are compared with those of the undistorted model and, if necessary, the intake of the distorted model is modified to yield conformity. The intake geometry and approach topography of Tioga outlet works were not considered unusual; therefore, the generalized WES selective withdrawal technique* was used, rather than an undistorted model, to predict the selective withdrawal characteristics of the intake. The selective withdrawal characteristics obtained from this technique and the distorted physical model compared favorably; modifications to the model intake were not considered necessary.

17. The excessively steep bottom slope that exists in a vertically distorted hydraulic model necessitates exaggeration of the bottom roughness to achieve the same fundamental character of flow and the proper Froude number of open channel flow that exists in the prototype. Entrainment characteristics of flow into a lake can be affected by the velocity and depth (Froude number) of the entering flow. An air conditioning filter decreased the effects of the steep bottom slope by

* J. P. Bohan and J. L. Grace, Jr., "Selective Withdrawal from Man-Made Lakes; Hydraulic Laboratory Investigation," Technical Report H-73-4, Mar 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

increasing the bottom roughness and consequently ensuring subcritical and turbulent inflow into the model reservoirs. The roughness coefficient of the filter material was not determined; therefore, the prototype bed roughness simulated by the model was not known. However, the same subcritical, turbulent, and fundamental character of inflow must be preserved in such highly distorted models. Initial tests indicated that because of the large momentum of the incoming floods, the inflow traveled to within several miles of the dam before plunging* and entraining surface water. Because the plunge and entrainment point occurred remotely from the point at which flow entered the lake, the conditions at the inflow point, such as the velocity and depth of flow, were considered to have a negligible effect on entrainment compared with momentum effects created by the unit volume flow rate, q, at the plunge and entrainment point. Studies conducted by Singh and Shah** indicated that the plunge location is determined by the critical depth $(q^2/g')^{1/3}$, where

$$g' = \frac{g\Delta\rho}{\rho}$$

and $\Delta\rho$ and ρ are the density difference between the inflow water and reservoir water and the density of the inflow water, respectively. Their results indicated that Reynolds number and bed slope do not have a significant influence on the plunge depth and location. Therefore, the plunge and entrainment locations observed in the model are considered accurate since similitude for the critical depth was preserved by density dependent Froudian relations.

18. Accurate simulation of bottom slope and roughness conditions at the inflow point should be attempted for studies in which detailed descriptions of inflow entrainment, placement, and velocity distribution

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* The phenomenon in which the streamflow takes a plunge from the reservoir surface and flows as an underflow. Flow entrainment occurs at this point.

** B. Singh and C. R. Shah, "Plunging Phenomenon of Density Currents in Reservoirs," La Houille Blanche, Vol 26, No. 1, 1971, pp 59-64.

near the point of inflow are necessary. However, with the magnitude of inflows encountered in this study (inflow quantities ranging from 1.7 to 5.5 times the normal summer storage introduced in a prototype period of 1 to 2 days) and the remote location of the entrainment point from the inflow point, the entering flow conditions were not considered to have significant effects on entrainment and dilution of reservoir waters. Nevertheless, the same fundamental character of inflow that exists in the prototype should be preserved in the model.

PART III: TESTS AND RESULTS

Description of Tests

19. Model tests involved the investigation of the dilution and dispersion of waters in Tioga-Hammond Lakes resulting from a large, an intermediate, and a small flood. Test results pertinent to each flood are presented.

20. The initial stratification conditions used for simulation of each flood were those expected during the late summer of a year experiencing average hydrologic and meteorologic conditions as described in Tioga-Hammond Lakes,* Design Memorandum No. 18, Appendix D. With normal summer storage, these conditions consisted of approximately 65°F water on the bottom and 80°F water at the surface. Late summer stratification patterns were selected for the study because the highest concentrations of acidic substances are expected to exist in Tioga Lake at that time of the year. Acidic (H_2SO_4) and alkaline ($CaCO_3$) substance concentrations for Tioga and Hammond Lakes, respectively, of 50 mg/ℓ in the epilimnion and about 38 mg/ℓ in the hypolimnion were simulated in the model prior to each flood. These estimated concentration levels were furnished by the U. S. Army Engineers, Baltimore District (NAB).

21. The model simulated inflow temperatures of 65°F. This value has been observed in the field for late summer storms in this particular region. Because of the increased drainage area and streamflow resulting from a storm, H_2SO_4 and $CaCO_3$ concentrations are practically undetectable; therefore, the model simulations were conducted without any contribution of these substances in the inflow.

22. Density profiles in the vicinity of the dam were taken for both lakes prior to a flood simulation, immediately after the flood, and after drawdown of the flood. Inflow and outflow densities were also

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* Gannett Fleming Corddry and Carpenter, Inc., "Tioga-Hammond Lakes; Tioga River and Crooked Creek, Pennsylvania; Outlet Works and Connecting Channel," Design Memorandum No. 18, May 1973, U. S. Army Engineer District, Baltimore, CE, Baltimore, Md.

recorded. Density measurements made with conductivity and temperature sensors were converted to equivalent prototype temperatures. Because stratification in the model was accomplished with saline and fresh waters, the model was not capable of reproducing any stratification changes resulting from surface heat exchange that might occur during the testing period. The stratification changes observed in the study were representative of those resulting from the hydrodynamic phenomena. The durations of the simulations (maximum prototype time of about 10 days) were short so that hydrodynamic effects had a much greater influence on stratification than surface heat exchange.

23. Dyes were used to represent waters of differing quality. Visual observations and "time-lapse" color movies were used to determine water movement throughout the lakes. Fluorescent dyes sulpha rhodamine B and fluorescent disodium salt simulated acidic and alkaline substances. Water samples were collected at various depths and stations in the model lakes before a flood, after the flood, after drawdown, and in the outflow during drawdown. The samples were analyzed with a fluorometer to determine concentration of fluorescent dye. Dye concentrations were converted to equivalent concentrations of H_2SO_4 and $CaCO_3$ by the correlation of the maximum dye concentrations to the maximum concentrations (50 mg/ℓ) of H_2SO_4 and $CaCO_3$ expected for the project. Mass balances of the fluorescent dyes were conducted for each test to determine reliability of results. The mass balances indicated that the error ranged from 3 to 20 percent with an average error of about 10 percent. The dye traces were considered reliable with this error.

24. The maximum flood of record (June 1889) was selected for the study of the effects of a large flood. Modified versions of the October 1955 flood were used for intermediate and small flood simulations. The hydrographs for the three floods are shown in Plates 4-6. Drawdown releases at Tioga outlet works were held constant at 8300 cfs (bank-full capacity for the Tioga River at Tioga) for the large and intermediate floods. Drawdown for the small flood was initiated with a discharge of 8300 cfs and gradually reduced to 5200 cfs. When drawdown releases were discharged from Hammond Lake to Tioga Lake through the gate

structure of Hammond outlet works, the Hammond gates were opened fully. The flood hydrographs and drawdown procedures were furnished to WES by NAB.

25. Because of control limitations, the variable speed pumps which reproduced the hydrographs shown in Plates 4-6 could not be used for reproducing the much lower inflows that occur during drawdown. To create the smaller descending inflows that occur at the end of a flood, water was supplied to the inflow points of the model from elevated tanks and regulated by needle valves. The water elevation in each tank was allowed to fall as water left the tank; this continuous reduction in head produced a descending hydrograph. With the range of heads and valve openings available, the flows ranged from 4200 to 100 cfs.

Large Flood

Internal flows and stratification changes

26. The cold inflows of the large flood plunged and moved throughout the bottom layers of the lakes. The inflowing water pushed the initial lake waters up into the top layers of storage. The warmer epilimnetic waters experienced some mixing with the inflow but remained in the top of the lakes allowing stratification to remain after the flood. The existence of this stratification after the flood was demonstrated through the use of dyes. The stratification patterns were also measured and are presented in Plate 7.

27. During drawdown, Tioga Lake became mixed in the vicinity of the dam producing almost isothermal conditions at the dam as shown by Plate 7. Most of the warm water in the upper layers of Hammond Lake passed over the connecting channel weir into Tioga Lake during drawdown eliminating much of the stratification that existed in Hammond Lake after the flood. Little stratification remained near the surface of Hammond Lake after drawdown (Plate 7).

Dispersion of acidic
and alkaline substances

28. The acidic water in Tioga Lake prior to the flood was diluted by the inflow and displaced into the top layers of reservoir storage. As the Tioga pool elevation rose above the connecting channel weir, water in the upper and intermediate layers of Tioga Lake spilled over the weir and dispersed into the upper layers of Hammond Lake. This resulted in the highest concentrations of H_2SO_4 existing in the upper regions of both lakes. Alkaline water of Hammond Lake was also displaced upward. Concentrations of acidic and alkaline substances in Hammond Lake are shown in Plate 8. Because water flowed from Tioga to Hammond Lake during the flood, practically no $CaCO_3$ entered Tioga Lake until drawdown.

29. During drawdown, water flowed back over the weir from Hammond to Tioga Lake. The higher concentrations of H_2SO_4 found in the top layers of Hammond Lake after the flood moved back into Tioga Lake. The connecting channel weir enhanced the removal of H_2SO_4 from Hammond Lake by the creation of a withdrawal zone predominantly in the surface layers. Alkaline substances also passed over the weir and mixed mostly with the upper portion of Tioga Lake.

30. With Hammond outlet works in the near vicinity of Tioga outlet works, $CaCO_3$ provided a strong contribution to the quality of outflow from Tioga Lake possibly providing some neutralization of the acidity. The concentrations of H_2SO_4 and $CaCO_3$ traced in the Tioga Lake outflow (Plate 9) were initially quite low due to the location of the intake at the bottom of Tioga Lake which resulted in the release of bottom water that was low in substance concentrations. As the bottom water was depleted, the pool dropped and more surface water, high in substance concentrations, was drawn through the outlet. This caused the concentrations in the outflow to increase during drawdown. When the pools dropped to the connecting channel weir crest (el 1101) and the Hammond gates were opened, $CaCO_3$ concentrations in the outflow started decreasing. Withdrawal velocities created by the gate structure were highest at the bottom of the connecting channel (el 1060) causing more

water to be released from the lower and intermediate layers of Hammond Lake. These waters had much lower concentrations of $CaCO_3$ which were reflected in the outflow from Tioga Lake as shown by the descending portion of the $CaCO_3$ plot of Plate 9.

31. Concentrations measured after drawdown revealed that most of the H_2SO_4 had been removed from Hammond Lake (Plate 8). The upper layers of Tioga Lake for several miles upstream of the dam remained high in H_2SO_4 concentrations after drawdown because less mixing occurred in this region than in the region of the dam and Hammond outlet works.

Intermediate Flood

Internal flows and stratification changes

32. Practically the same hydrodynamic phenomena occurred with the intermediate flood as with the large flood except that less mixing was experienced in the upper layers because of smaller flows. With less mixing, a stronger degree of stratification existed in both lakes after the flood and drawdown as shown in Plate 10. Even with a slightly warmer inflow, the incoming current moved along the hypolimnion displacing existing lake waters upward.

Dispersion of acidic and alkaline substances

33. Concentrations of acidic and alkaline substances traced throughout the two lakes for the intermediate flood simulation are presented in Plate 11. Concentrations of H_2SO_4 found in the upper and intermediate layers of Hammond Lake after the intermediate flood were higher than those dispersed by the large flood. With smaller flows and less dilution, the higher concentrations were expected.

34. High concentrations of H_2SO_4 remained in the upper region of Hammond Lake after drawdown. This condition is attributed to the size of the flood. With a smaller flood and lower peak pool elevation with respect to the weir crest, the weir crest elevation was not low enough to withdraw all of the H_2SO_4 from the upper pool of Hammond Lake.

Similarly, higher concentrations of $CaCO_3$ (compared with the large flood) remained in Hammond Lake after drawdown (Plate 11) providing some neutralization.

35. Substance concentrations in the outflow from Tioga Lake are shown in Plate 12. The higher concentrations found in both lakes after the flood resulted in higher concentrations in the outflow when a comparison was made of the drawdown of the intermediate and large floods. The $CaCO_3$ traces in the outflow from Tioga Lake did not recede until the Tioga pool elevation had dropped to el 1092 compared with el 1101 for the large flood. This is attributed to the higher concentrations of $CaCO_3$ that existed within Hammond Lake after the flood between el 1075 and 1100 and which were released through the Hammond gate structure.

Small Flood

Internal flows and stratification changes

36. Small flood conditions also resulted in the cold inflows moving into the bottom and intermediate regions of the lakes displacing water upward. A small amount of mixing occurred within the upper layers, but a high degree of stratification prevailed as shown in Plate 13. The cold inflows to Tioga Lake enlarged the hypolimnion; however, drawdown through the low level outlet (flood control outlet) returned the lake to practically the same stratification condition that existed before the flood. Very small stratification changes were experienced in Hammond Lake (Plate 13).

Dispersion of acidic and alkaline substances

37. The peak Tioga pool elevation for the small flood (el 1099) was below the connecting channel weir crest so that Tioga Lake water and H_2SO_4 did not enter Hammond Lake. Concentrations of H_2SO_4 remained very high in the top 25 ft of the Tioga pool (Plate 14). Concentrations at the surface ranged from 30 to 40 mg/ℓ. Hammond Lake was drawn down by the release of water through the gate structure of Hammond outlet works.

Without flow over the connecting channel weir during drawdown, there was no mixing with Hammond water in the top layers of Tioga Lake. Therefore, the concentrations of H_2SO_4 remained high in the top 6 ft of Tioga Lake after drawdown. The high concentrations of H_2SO_4 (30-40 mg/ℓ), which only occupied the top 1 to 2 ft of Tioga Lake after the flood, occupied the top 5 to 6 ft of pool after drawdown because of the depth-storage relationship for the lake. This caused the increase in H_2SO_4 concentrations after drawdown shown for the top layer of Tioga Lake in Plate 14.

38. Flow entering Tioga Lake through the gate structure from Hammond Lake caused considerable mixing in the intermediate layers of Tioga Lake near the dam. These releases from Hammond Lake contained $CaCO_3$ which could provide some neutralization of acid in Tioga Lake. The alkaline substances were also found in the outflow from Tioga Lake (Plate 15). "Time-lapse" color movies showed that flow entering Tioga Lake through the gate structure from Hammond Lake was strongly influenced by the outflow from Tioga Lake. Most of the Hammond water mixed with the intermediate layers of Tioga Lake as it entered, remained near the dam, and was withdrawn through Tioga outlet works. Very little $CaCO_3$ went into storage in Tioga Lake upstream of the confluence of the connecting channel. This "short circuiting" of flow was also indicated by the low concentrations of $CaCO_3$ found in the upstream reaches of Tioga Lake (Plate 14) and the sharp increase of $CaCO_3$ in the outflow from Tioga Lake (Plate 15) when the Hammond gates were opened. The Hammond gates were not opened until after the Tioga pool had dropped to el 1092 at which point the Tioga pool was below the water-surface elevation of Hammond Lake.

PART IV: DISCUSSION OF RESULTS

39. The dilution and dispersion of acidic and alkaline substances for three flood conditions were determined from the model study. The results provide information for the estimate of water quality conditions within and downstream of the project for similar flood conditions and guidance for the limitation of adverse quality during drawdown.

40. There are several features of the project that are conducive to the limitation of the concentration of H_2SO_4 throughout and downstream of the lakes during flood flows. The crest elevation of the connecting channel weir is high enough to prevent contamination of Hammond Lake during small floods and confine the acidic water that spills during large floods to just the upper layers of Hammond Lake. Flow that passed over the weir from Hammond to Tioga Lake during drawdown removed much of the acidic substances that entered Hammond Lake during a flood. The cold inflows that enter Tioga Lake during a flood are expected to be practically void of acidic substances. These inflows filled the bottom layers of Tioga Lake leaving only a small trace of H_2SO_4 in the bottom region after a flood. Therefore, the low level intake of Tioga outlet works, which would be used during flood control flow, provides the best possible withdrawal location during flood conditions for limiting the concentration of H_2SO_4 in the outflow from Tioga Lake. The proximity of Hammond outlet works to Tioga outlet works enhances the quality of releases from Tioga Lake. The proximity of the structures allowed much of the alkaline water released from Hammond Lake to be withdrawn from Tioga Lake as illustrated by the sharp increase in $CaCO_3$ concentration in Plates 9, 12, and 15. The contribution of $CaCO_3$ to the outflow from Tioga Lake should provide some neutralization of the acidity.

41. To minimize the concentration of H_2SO_4 in the outflow from Tioga Lake during drawdown, releases from Tioga Lake should not be initiated until after the flood has risen to about maximum pool or the flood hydrograph has terminated. This procedure maximizes the depth and contribution of good quality water (inflows low in H_2SO_4 concentration that fill the bottom region) available for withdrawal through

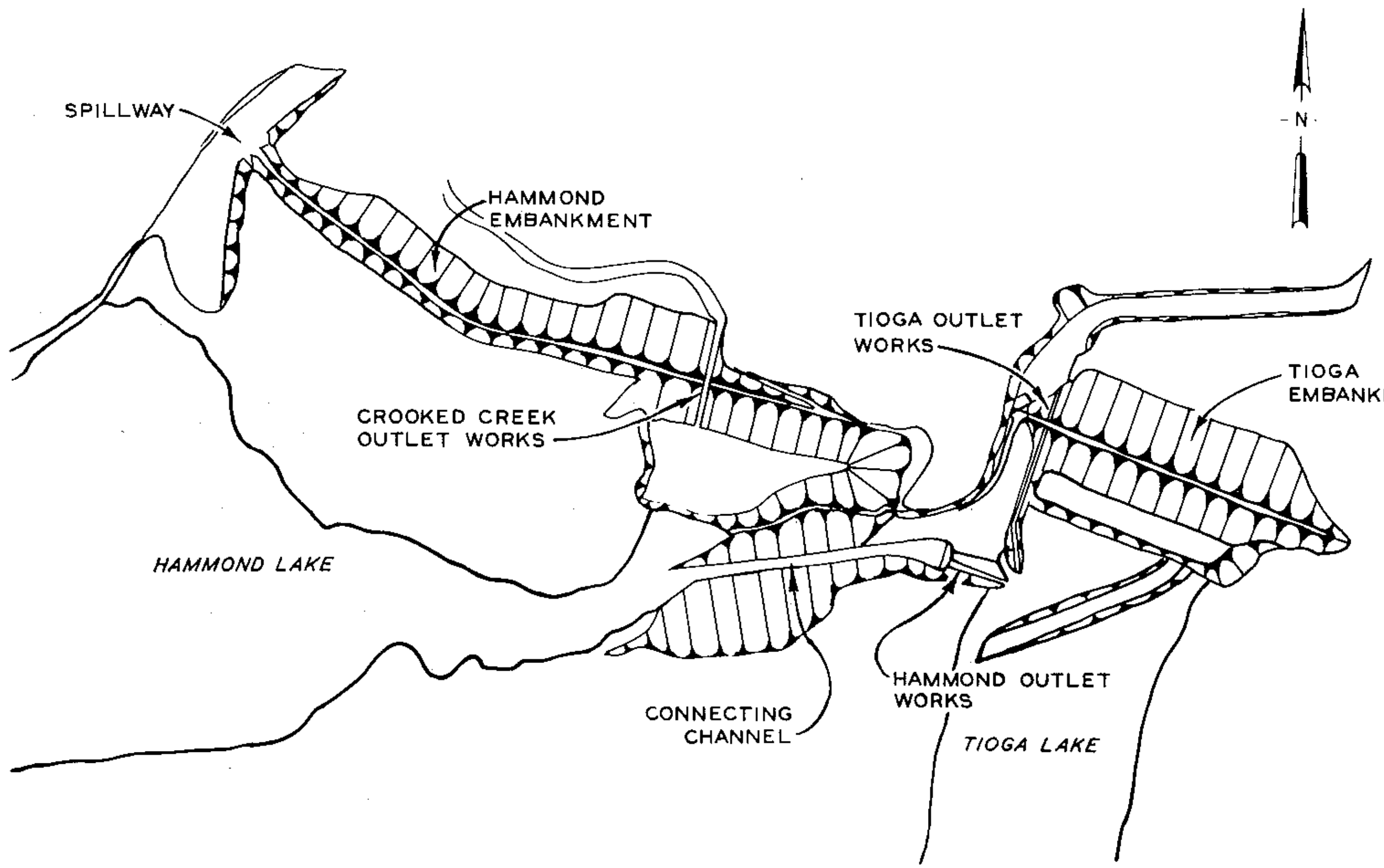
the low level outlet of Tioga outlet works.

42. The normal drawdown procedure (constant release from Tioga Lake of 8300 cfs--bank-full capacity for the Tioga River) should be suitable for the limitation of the acidity of releases from Tioga Lake for intermediate and large flood conditions. For these conditions, the model indicated (Plates 9 and 12) that the concentration of $CaCO_3$ in the outflow from Tioga Lake increased as the H_2SO_4 concentration increased providing some neutralization.

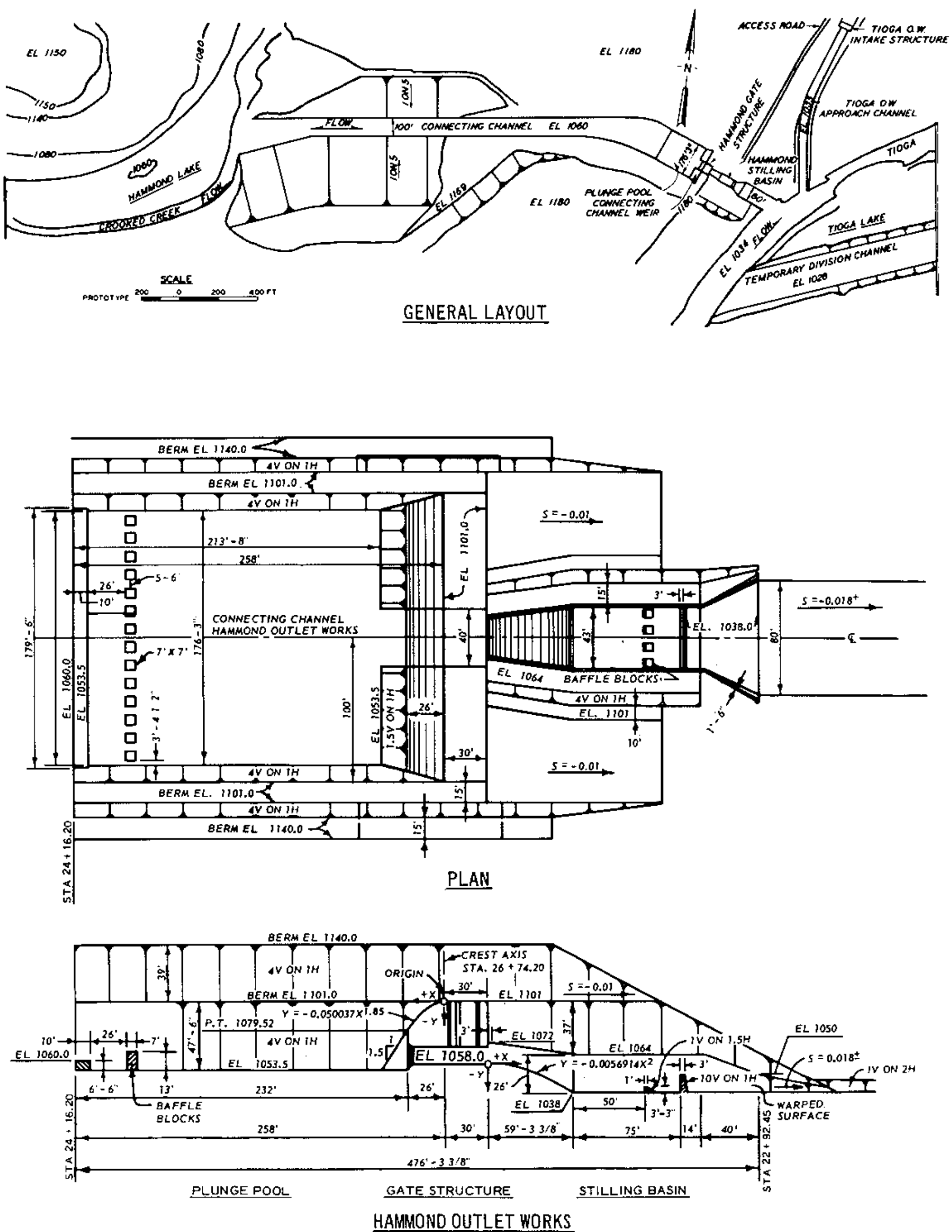
43. Smaller releases (less than 5000 cfs) through the low level outlet of Tioga outlet works would reduce H_2SO_4 concentrations in the outflow during the first portion of drawdown from a small flood (when there is no flow from Hammond to Tioga Lake). Application of the WES generalized selective withdrawal technique to the conditions existing after the small flood indicated that initial releases of 4000 and 3000 cfs would reduce H_2SO_4 outflow concentrations from 10 mg/ℓ (Plate 15) to 8 and 7 mg/ℓ, respectively. The selective withdrawal technique indicated that a discharge of 5000 cfs would not reduce the H_2SO_4 concentration. During drawdown of the small flood, the gates at Hammond outlet works were fully opened after the Tioga pool had dropped lower than the Hammond pool elevation. Full gate openings at Hammond outlet works and large releases at Tioga outlet works (8300-5200 cfs) during this portion of drawdown would maximize the flow from Hammond to Tioga Lake and the contribution of $CaCO_3$. Maintaining a small discharge (less than 5000 cfs) during the first part of drawdown and increasing the discharge above 5000 cfs after opening the Hammond gates would be an unusual drawdown procedure. The quality of releases can be improved by such a procedure, but the reduction in H_2SO_4 concentration (from 10.0 to about 8.0 mg/ℓ) is not substantial. The expected drawdown procedure (Plate 6) produced the outflow concentrations shown in Plate 15, which may be within acceptable limits.

44. Where application of a mathematical model would have been impractical, the physical model was demonstrated to be a useful tool for the evaluation of dilution and dispersion characteristics resulting from unsteady and very dynamic flows. The most interesting results from the

study was the high contribution of $CaCO_3$ to the outflow from Tioga Lake. This contribution was primarily attributed to the proximity of Tioga and Hammond outlet works.

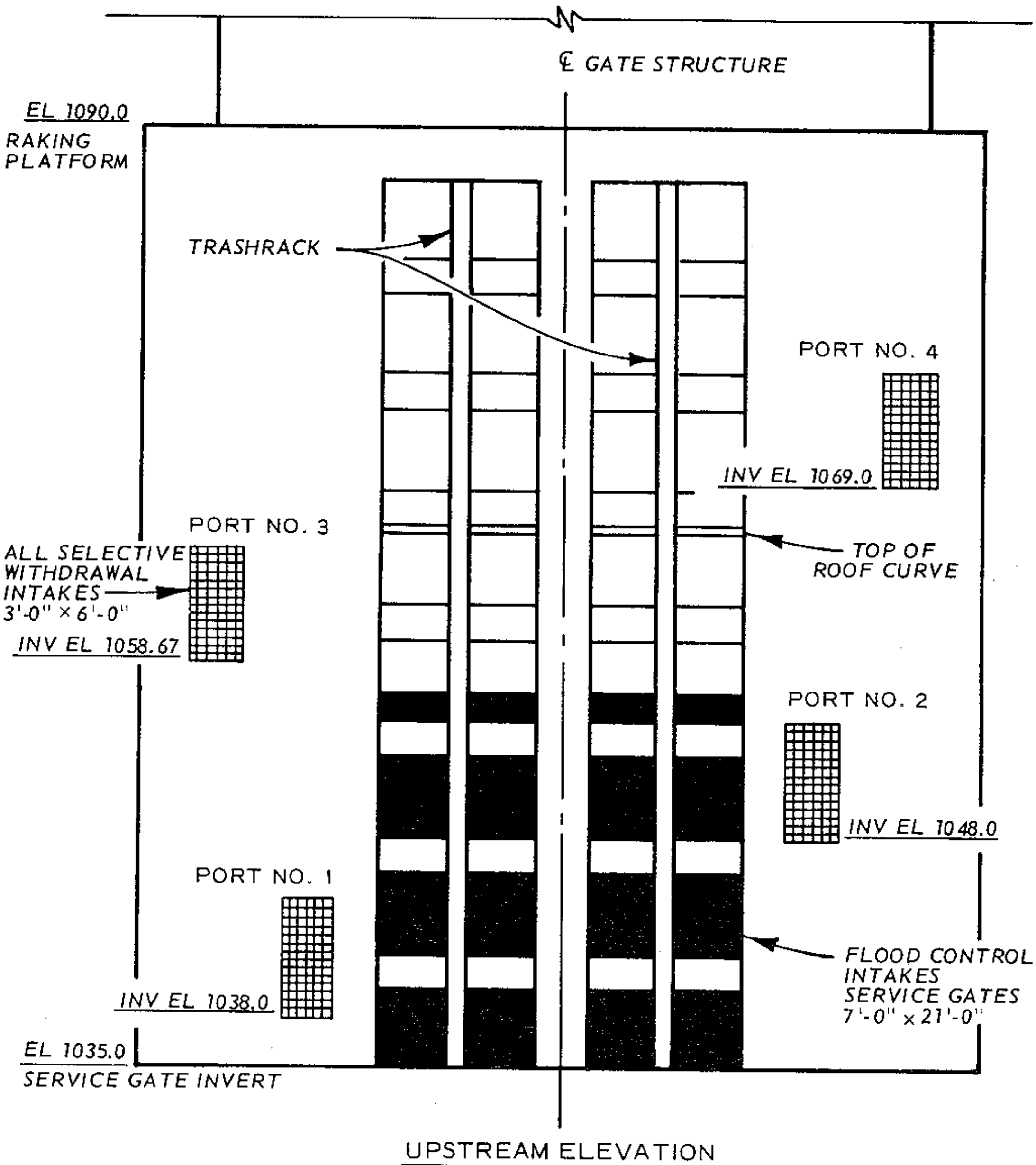


GENERAL PLAN

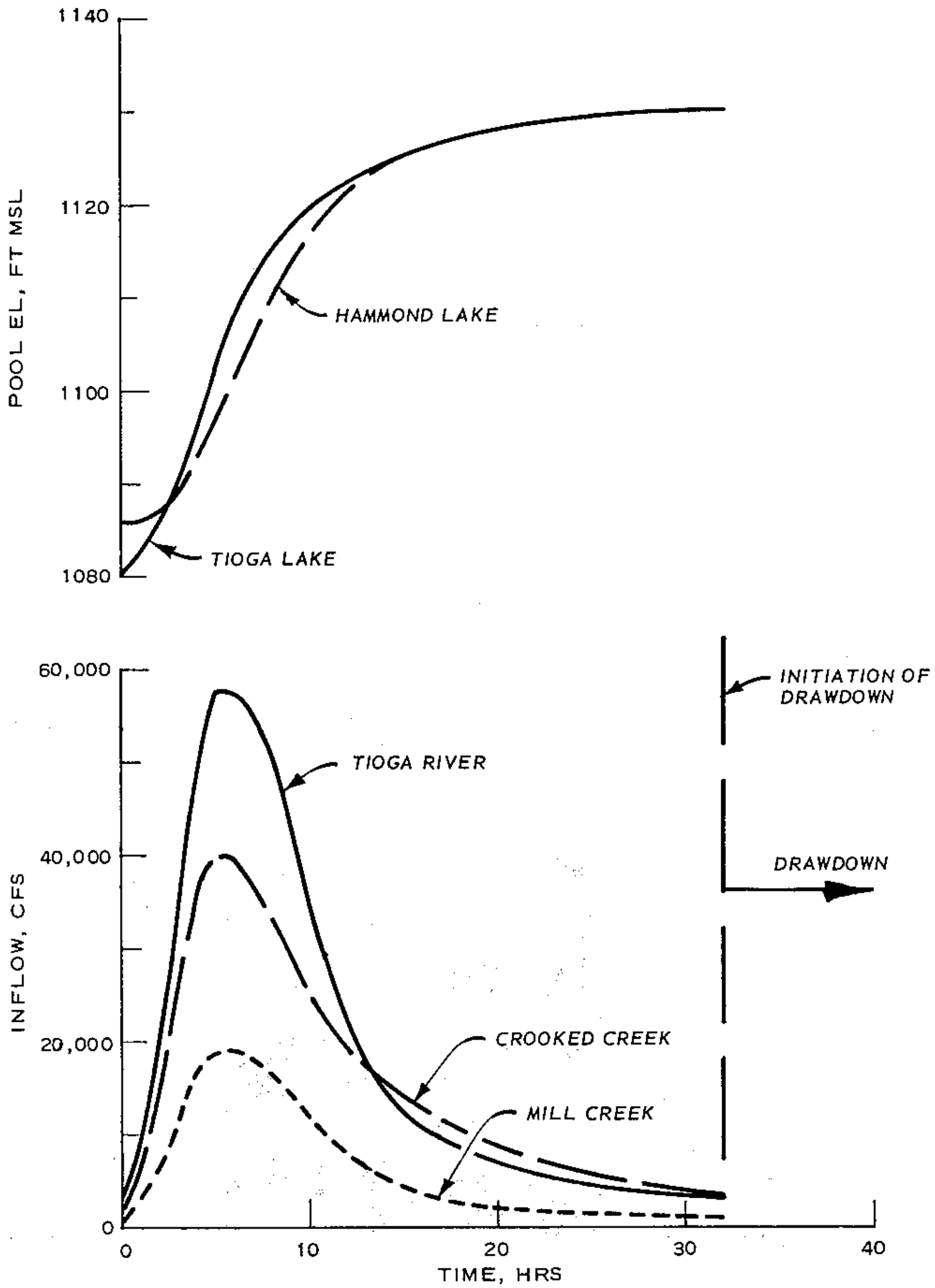


PLAN FOR HAMMOND OUTLET WORKS

GENERAL LAYOUT AND ORIGINAL DESIGN CONTROL STRUCTURES



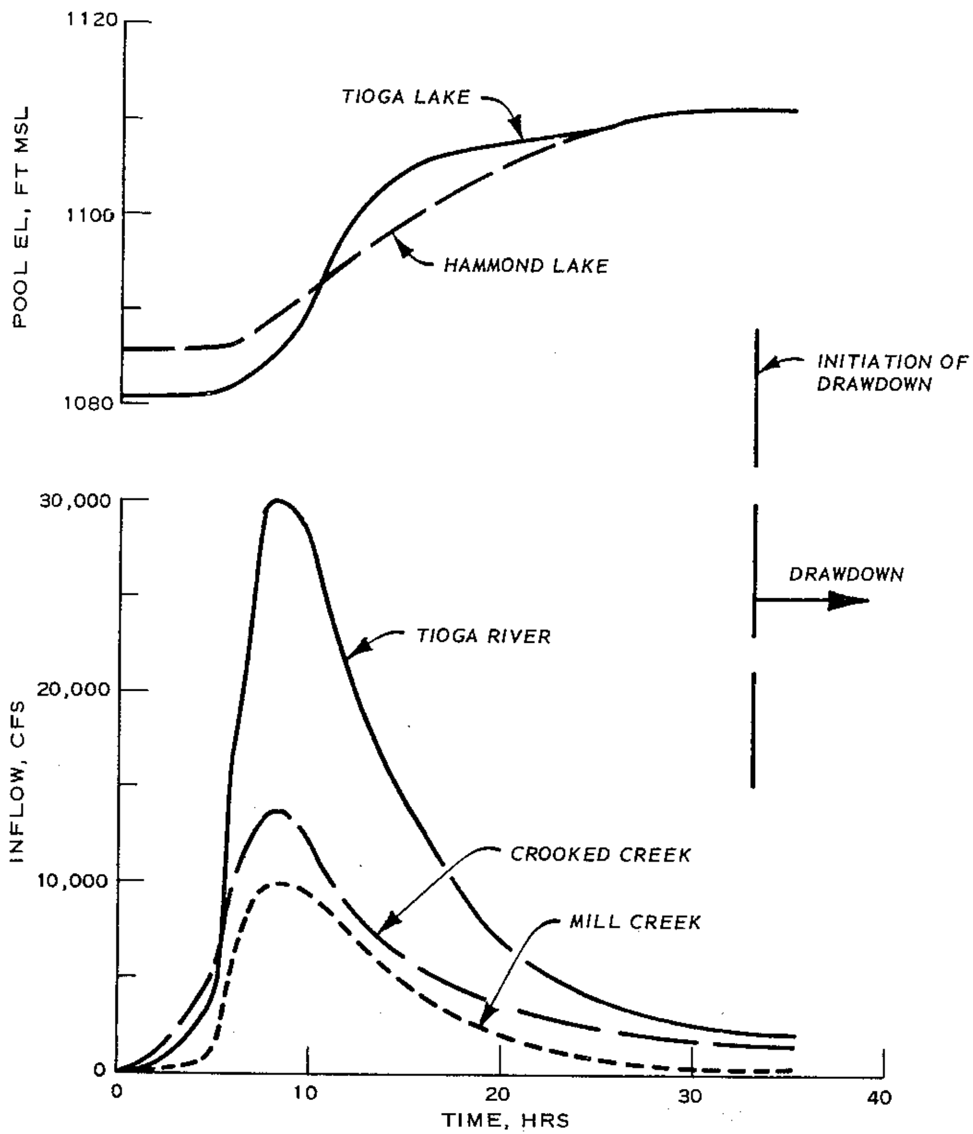
INTAKE CONFIGURATION FOR
TIOGA OUTLET WORKS



NOTES:

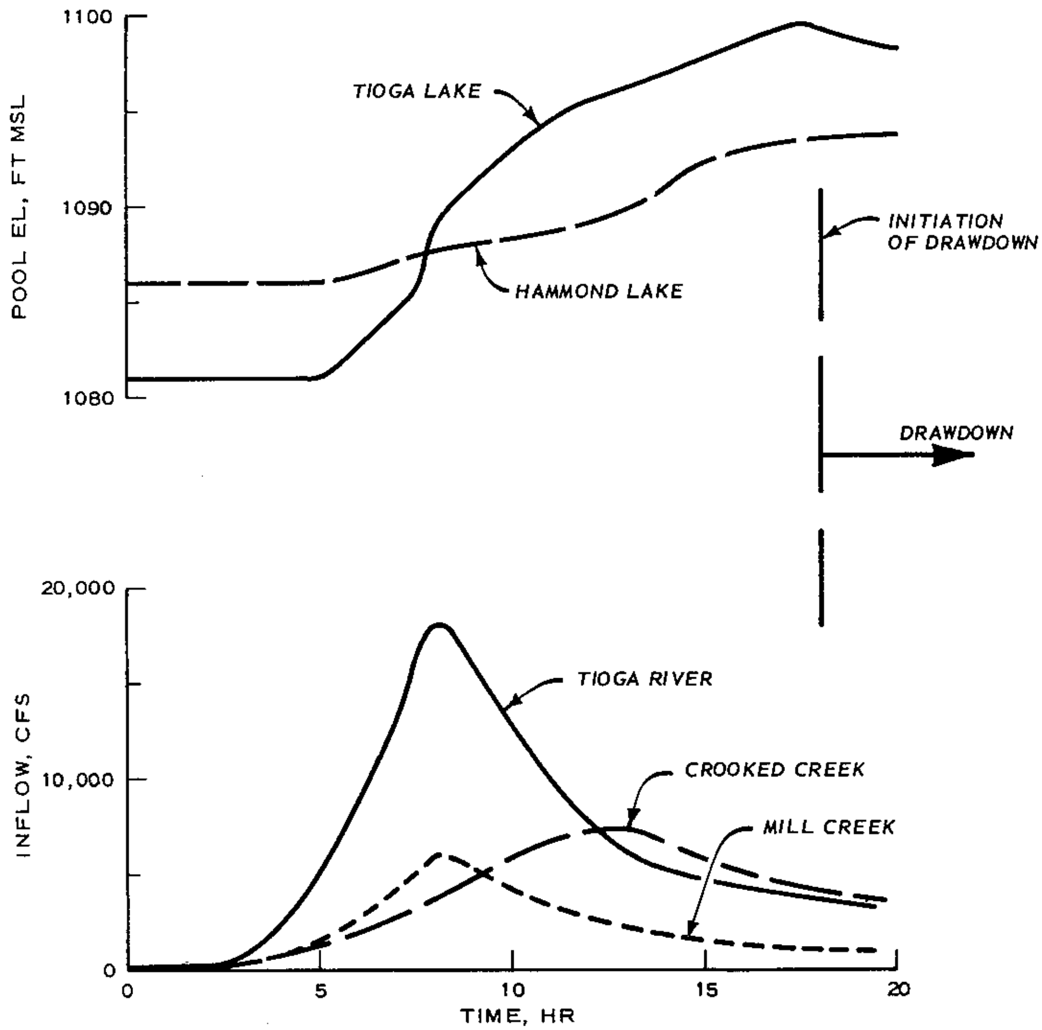
1. A CONSTANT RELEASE OF 8300 CFS AT TIOGA OUTLET WORKS WAS MAINTAINED THROUGHOUT DRAWDOWN.
2. WHEN THE POOL HAD DROPPED TO THE WEIR CREST (EL 1101), HAMMOND GATES WERE OPENED FULLY FOR THE REMAINDER OF DRAWDOWN.

LARGE FLOOD HYDROGRAPH
(JUNE 1889)



NOTES:
1. A CONSTANT RELEASE OF 8300 CFS AT TIOGA OUTLET WORKS WAS MAINTAINED THROUGHOUT DRAWDOWN.
2. WHEN THE POOL HAD DROPPED TO THE WEIR CREST (EL 1101), HAMMOND GATES WERE OPENED FULLY FOR THE REMAINDER OF DRAWDOWN.

INTERMEDIATE FLOOD HYDROGRAPH
(OCTOBER 1955 - MODIFIED)



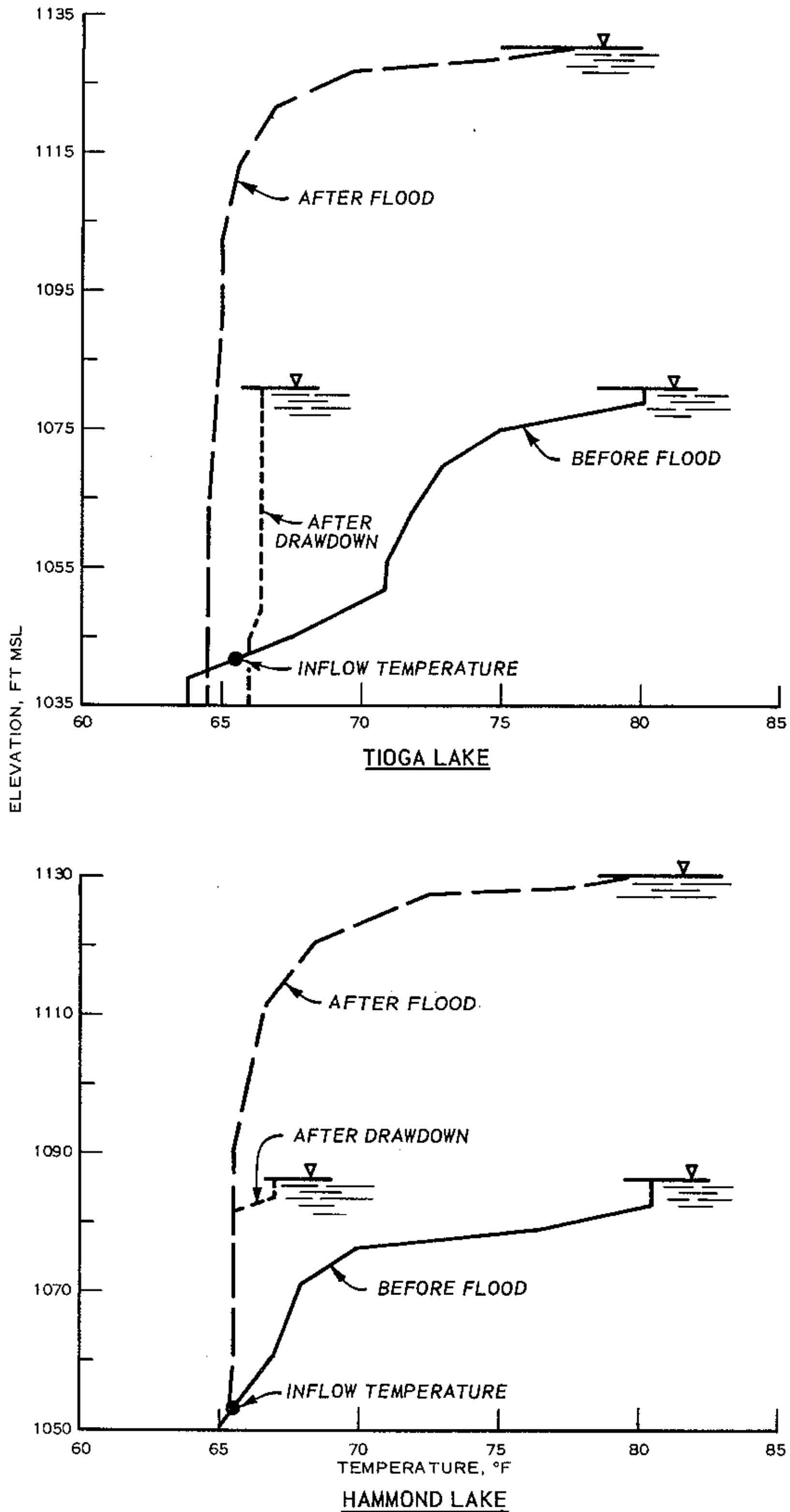
NOTES:

1. THE DRAWDOWN PROCEDURE AT TIOGA OUTLET WORKS WAS AS FOLLOWS:

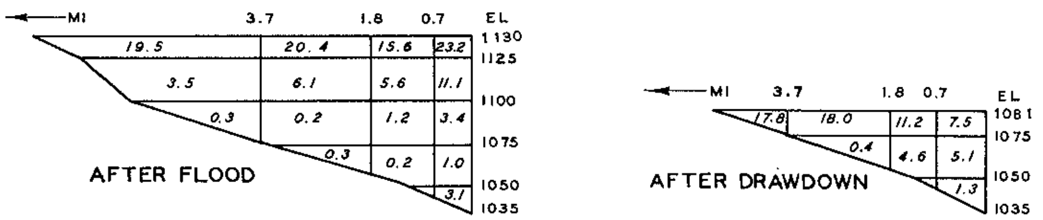
   8300 CFS FOR 12 HR
   6200 CFS FOR 8 HR
   5200 CFS FOR THE REMAINDER OF DRAWDOWN

2. AT HOUR 31 HAMMOND GATES WERE OPENED FULLY TO DRAW DOWN HAMMOND LAKE

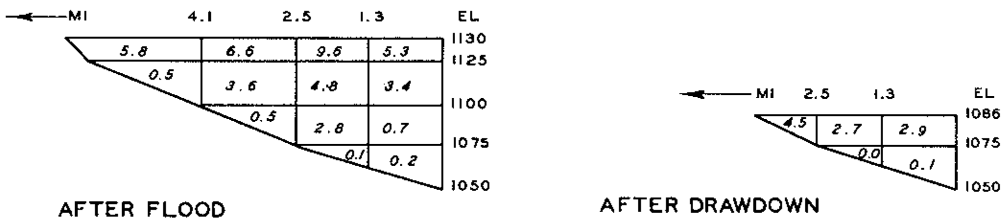
SMALL FLOOD HYDROGRAPH
(OCTOBER 1955 - REDUCED)



STRATIFICATION CHANGES
LARGE FLOOD
TIOGA LAKE AND HAMMOND LAKE

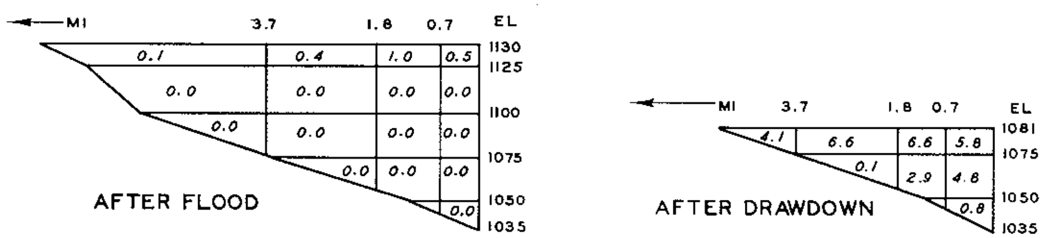


TIOGA LAKE

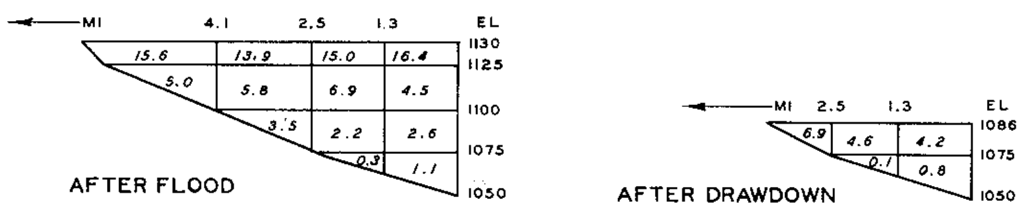


HAMMOND LAKE

H_2SO_4 CONCENTRATIONS



TIOGA LAKE

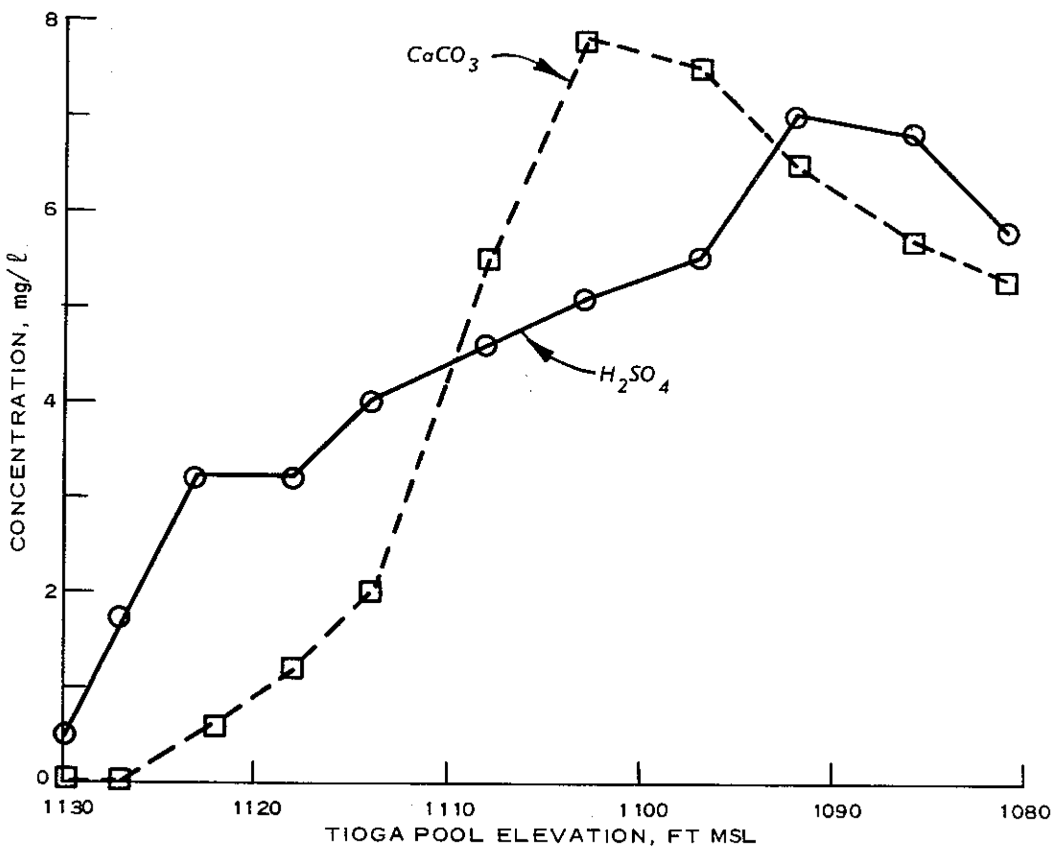


HAMMOND LAKE

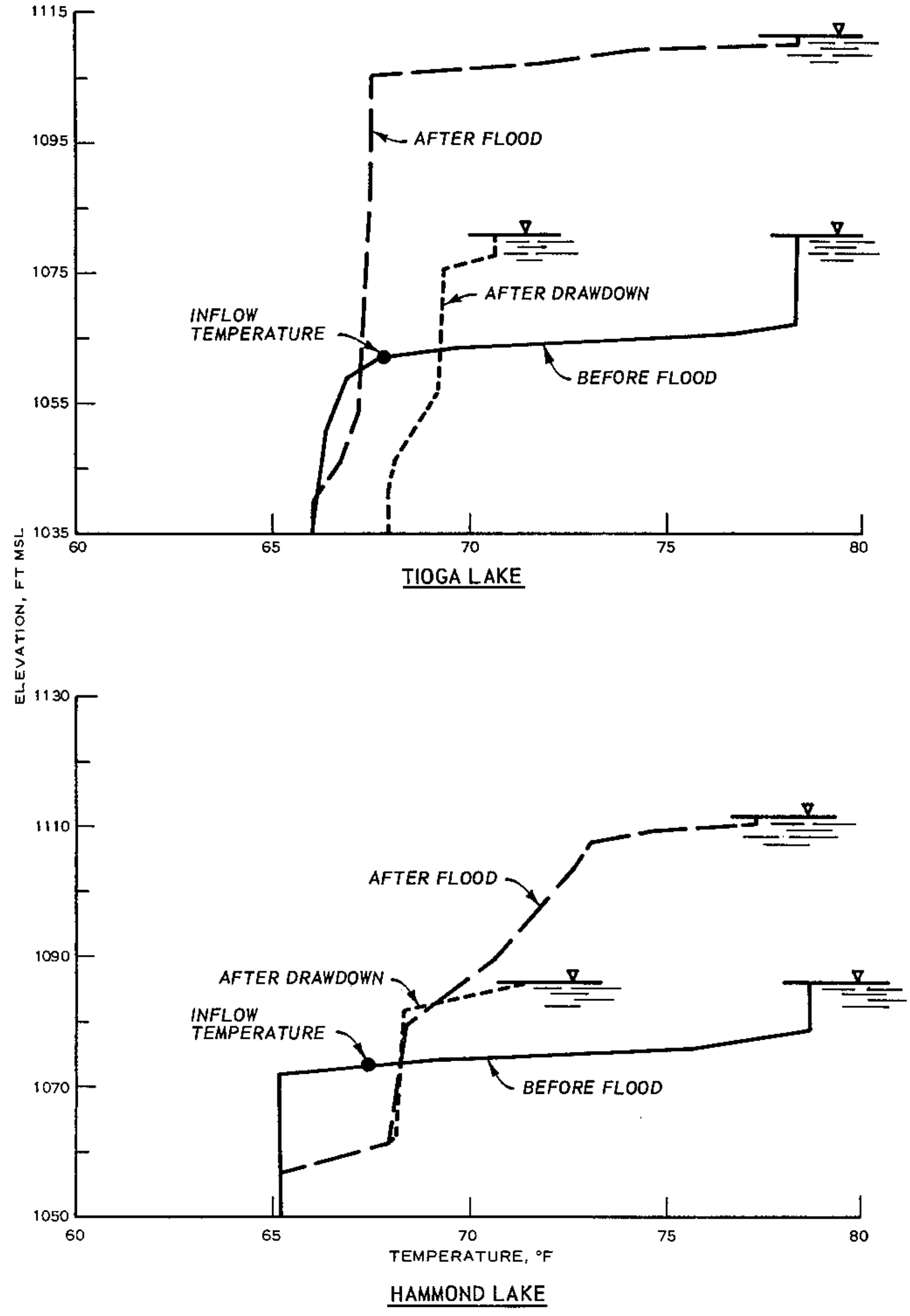
$CaCO_3$ CONCENTRATIONS

NOTE:
1. CONCENTRATIONS OF SUBSTANCES ARE IN mg/ℓ
2. FLUORESCENT DYES REPRESENTING H_2SO_4 AND $CaCO_3$, WERE USED TO TRACE CONCENTRATIONS
3. INITIAL CONCENTRATIONS OF H_2SO_4 IN TIOGA LAKE BEFORE THE FLOOD WERE
   50.0 mg/ℓ – EPILIMNION
   38.3 mg/ℓ – HYPOLIMNION
4. INITIAL CONCENTRATIONS OF $CaCO_3$ IN HAMMOND LAKE BEFORE THE FLOOD WERE
   50.0 mg/ℓ – EPILIMNION
   38.8 mg/ℓ – HYPOLIMNION

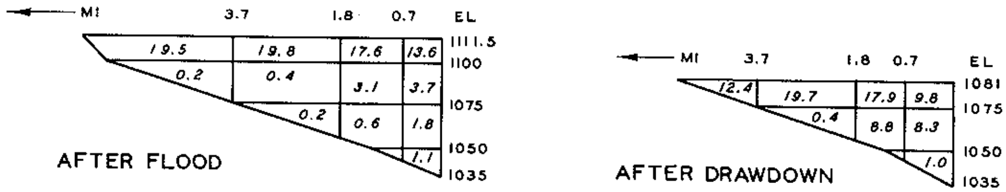
DISPERSION OF H_2SO_4
AND $CaCO_3$
LARGE FLOOD



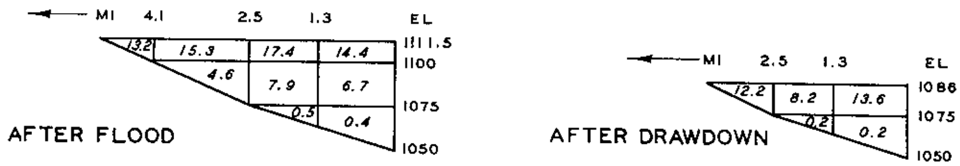
H_2SO_4 AND $CaCO_3$
CONCENTRATIONS IN OUTFLOW
FROM TIOGA LAKE
DRAWDOWN OF LARGE FLOOD



STRATIFICATION CHANGES
INTERMEDIATE FLOOD
TIOGA LAKE AND HAMMOND LAKE

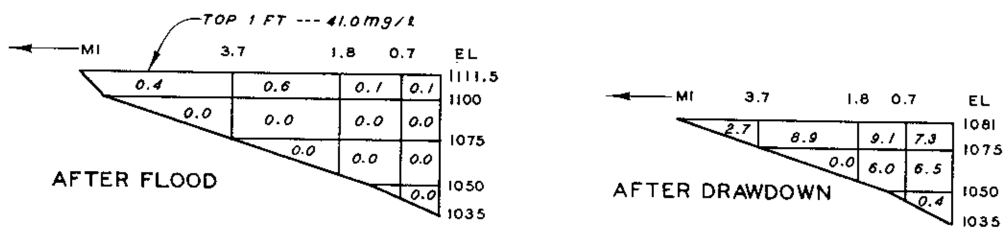


TIOGA LAKE

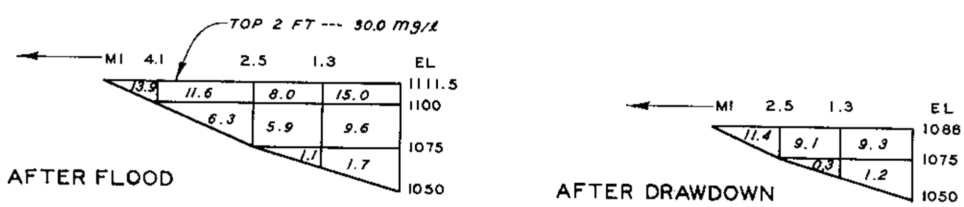


HAMMOND LAKE

H_2SO_4 CONCENTRATIONS



TIOGA LAKE

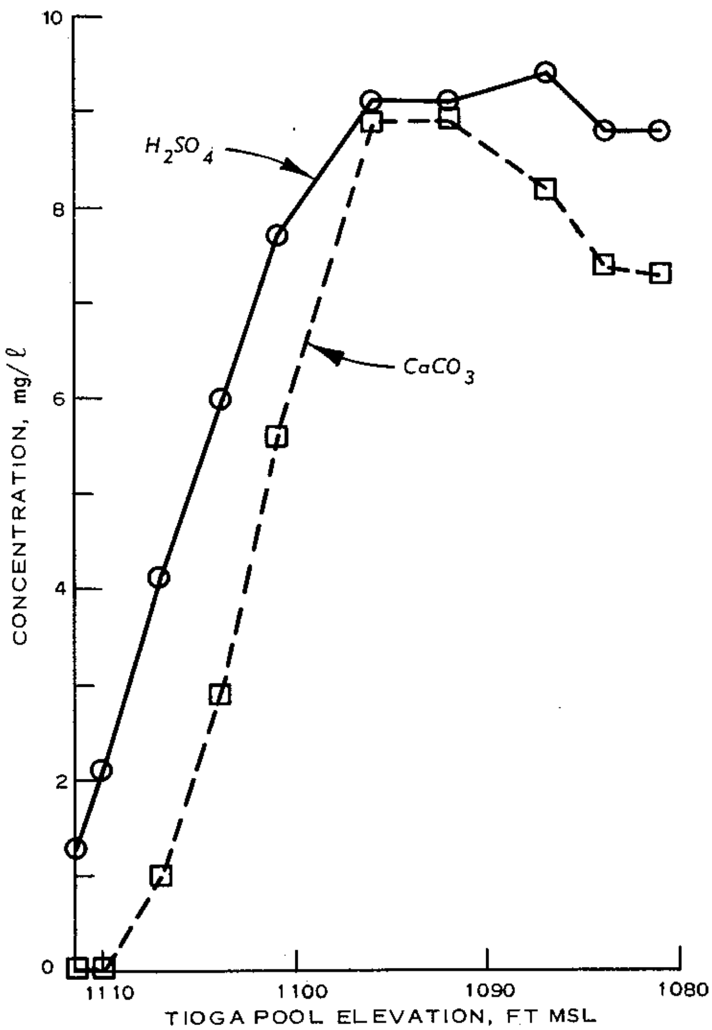


HAMMOND LAKE

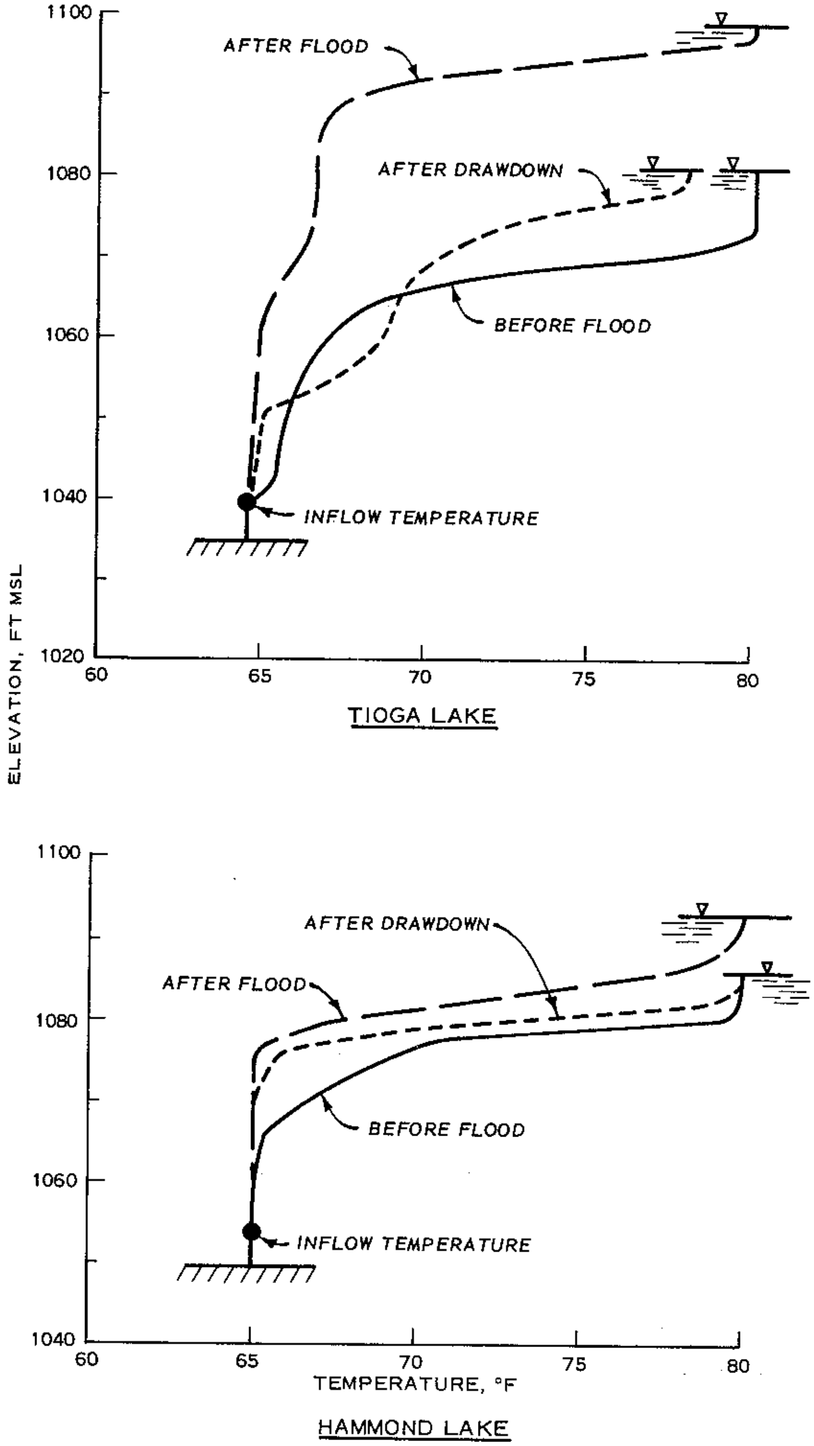
$CaCO_3$ CONCENTRATIONS

NOTE: 1. CONCENTRATIONS OF SUBSTANCES ARE IN mg/ℓ
2. FLUORESCENT DYES REPRESENTING H_2SO_4 AND $CaCO_3$, WERE USED TO TRACE CONCENTRATIONS
3. INITIAL CONCENTRATIONS OF H_2SO_4 IN TIOGA LAKE BEFORE THE FLOOD WERE
50.0 mg/ℓ – EPILIMNION
38.5 mg/ℓ – HYPOLIMNION
4. INITIAL CONCENTRATIONS OF $CaCO_3$ IN HAMMOND LAKE BEFORE THE FLOOD WERE
50.0 mg/ℓ – EPILIMNION
38.2 mg/ℓ – HYPOLIMNION

DISPERSION OF H_2SO_4 AND $CaCO_3$ INTERMEDIATE FLOOD

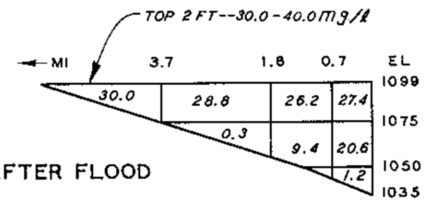


H_2SO_4 AND $CaCO_3$
CONCENTRATIONS IN OUTFLOW
FROM TIOGA LAKE
DRAWDOWN OF INTERMEDIATE FLOOD

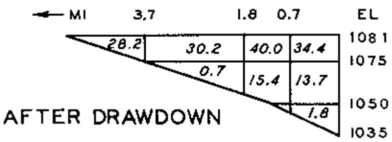


STRATIFICATION CHANGES
SMALL FLOOD
TIOGA LAKE AND HAMMOND LAKE

AFTER FLOOD



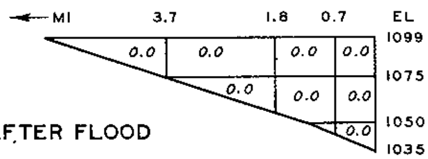
AFTER DRAWDOWN



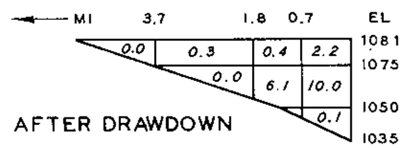
TIOGA LAKE

H_2SO_4 CONCENTRATIONS

AFTER FLOOD

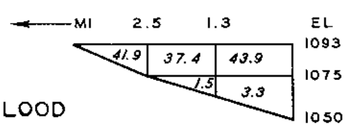


AFTER DRAWDOWN

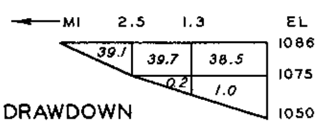


TIOGA LAKE

AFTER FLOOD



AFTER DRAWDOWN

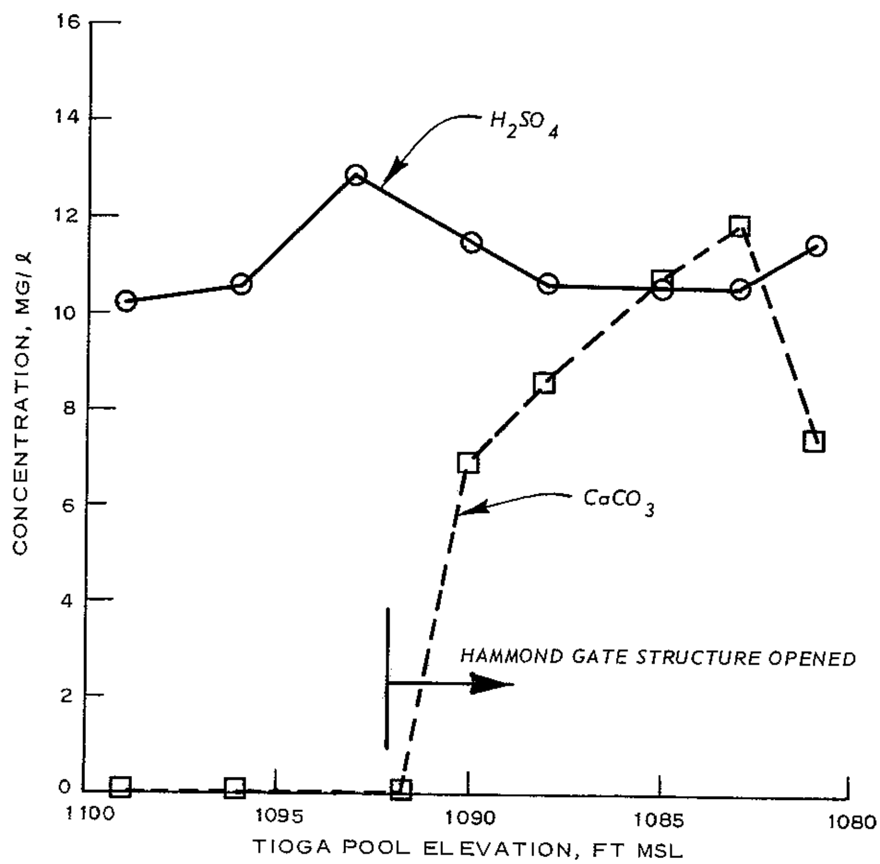


HAMMOND LAKE

$CaCO_3$ CONCENTRATIONS

NOTE: 1. CONCENTRATIONS OF SUBSTANCES ARE IN mg/l
2. FLUORESCENT DYES REPRESENTING H_2SO_4 AND $CaCO_3$, WERE USED TO TRACE CONCENTRATIONS
3. INITIAL CONCENTRATIONS OF H_2SO_4 IN TIOGA LAKE BEFORE THE FLOOD WERE
50.0 mg/l - EPILIMNION
39.0 mg/l - HYPOLIMNION
4. INITIAL CONCENTRATIONS OF $CaCO_3$ IN HAMMOND LAKE BEFORE THE FLOOD WERE
50.0 mg/l - EPILIMNION
35.0 mg/l - HYPOLIMNION

DISPERSION OF H_2SO_4 AND $CaCO_3$ SMALL FLOOD



H_2SO_4 AND $CaCO_3$
CONCENTRATIONS IN OUTFLOW
FROM TIOGA LAKE
DRAWDOWN OF SMALL FLOOD

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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27 p., 15 p. of plates illus. 27 cm. (U. S. Waterways Experiment Station. Technical report H-76-11)
Prepared for U. S. Army Engineer District, Baltimore, Baltimore, Maryland.
Bibliographical footnotes.

1. Acidic water. 2. Alkaline water. 3. Floods. 4. Hammond Lake. 5. Hydraulic models. 6. Tioga Lake. 7. Unsteady flow. 8. Water analysis. 9. Water flow. 10. Water quality. I. U. S. Army Engineer District, Baltimore. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report H-76-11)
TA7.W34 no.H-76-11