DETERMINATION OF WATER QUALITY WITHIN AND DOWNSTREAM OF BAY SPRINGS LAKE

By

S. C. Wilhelms,[1] F. L. Hebron[2]

INTRODUCTION

The Tennessee-Tombigbee Waterway will be a navigable waterway made up of natural rivers and streams and man-made canals and locks and dams. The waterway is located in Alabama, Mississippi, and Tennessee (Fig. 1). It will extend upstream from Demopolis, Alabama (on the existing Black Warrior-Tombigbee Waterway 217 miles (349 Km) above Mobile, Alabama), via the Tombigbee River to the east fork of the Tombigbee. The project then extends up into Mackey's Creek, through a deep cut in the Tennessee Divide to Pickwick Lake via Yellow Creek. The waterway joins the Tennessee River system in the Yellow Creek embayment near the common boundary of Mississippi, Tennessee, and Alabama.

The project is divided into three sections: River section, Canal section, and Divide section. The river section and canal section extend from Demopolis, Alabama, to the Bay Springs Lock and Dam in Mackey's Creek. These two sections are 213 miles (342 Km) long and will have nine conventional locks to overcome a difference in elevation of 257 feet (78 m). The divide section consists of an 84-ft (25-m) lift lock at the Bay Springs Dam and a 27-mile (43-Km) canal. The canal is to be cut through the Tennessee Divide and will extend into the Yellow Creek Embayment on Pickwick Lake (Fig. 2).

The main justification of the "Tennessee-Tombigbee" project is derived from the lessened transportation costs for trafficking barges from the Gulf of Mexico to the Tennessee River system. Instead of

---

[1] S. C. Wilhelms, Hydraulic Engineer, Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

[2] F. L. Hebron, Electronic Engineer, Instrumentation Services Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

tows navigating the Mississippi River and then the Ohio River to reach the Tennessee River system, tows can navigate directly from Mobile, Alabama, to the Tennessee system. Although the largest part of the economic justification was the decreased transportation cost, recreational benefits, fish and wildlife enhancement, and area development were also included.

DESCRIPTION OF PROJECT

The Bay Springs Lock and Dam Project is proposed for construction on Mackey's Creek in northeast Mississippi (Fig. 3). It is the first lock and dam on the "Tennessee-Tombigbee" waterway south of Pickwick Lake. The lock will provide the 84 ft (25 m) of lift necessary to overcome the elevation difference between Mackey's Creek and Pickwick Lake (Fig. 4).

Several unique features and unusual conditions associated with the Bay Springs Project necessitated an improved approach to study the quality of water to be expected within and downstream of the lake. With the exception of releases to sustain minimum flow in Mackey's Creek, outflow from Bay Springs Lake will occur only during operation of the lock. Excess runoff into the Bay Springs Lake will be passed through the divide-cut canal to Pickwick Lake and released through the Tennessee River system. However, any rise in the Pickwick pool will be reflected by a rise in the Bay Springs pool because of flow through the divide-cut canal from Pickwick to Bay Springs. The forecast of lockage rates ranged from 5 lockages per day to the maximum of 24 lockages per day. In addition to the dynamic nature of this system, the lock is to be located on an elevated plain (Fig. 5). The elevated local topography greatly influences the selective withdrawal characteristics of the lock and the hydrodynamics of the lake.

STUDY APPROACH

Four separate models were used in the investigation of Bay Springs Lake water quality. Two physical models were used in conjunction with two mathematical models. The first mathematical model was an unsteady flow model run by the U. S. Army Engineer District, Nashville. This model predicted discharge, stage, and velocity at various locations on the project. An undistorted, 1:80-scale physical model of the Bay Springs Lock intakes and and local topography (Fig. 6) was used to examine the selective withdrawal characteristics of the intakes. The model reproduced the lock walls and intakes and a portion of the upstream topography. The second physical model was a highly distorted (1:2400 horizontal, 1:80 vertical, scales) representation of the Bay Springs Lake (Fig. 7), divide-cut canal, and the Yellow Creek Embayment of Pickwick Lake. Determination of the response of the lake to unsteady state, density stratified flow conditions was the purpose of this model. The second mathematical model entitled WESTEX was used to simulate daily variations in the temperature and dissolved oxygen regimes within and downstream of the lake for various study years.

The unsteady flow model simulation of the Bay Springs Project produced results that were compared to the unsteady operation of the highly distorted hydrodynamic model of th lake. The stage hydrographs predicted by the unsteady flow model corresponded well to the stages encountered in the hydrodynamic model under the same conditions.

The 1:80-scale model of the lock intakes was constructed of Plexiglas and placed in a test flume. Density stratification similar to that expected in nature was reproduced using saline and fresh water. Several different flow rates were then withdrawn through the intakes. The resulting flow distributions in the stratified flume were determined using dye streaks and liquid dye. The depth of the hypolimnion (saline water) was changed while the water surface was maintained at a fixed elevation to simulate raising or lowering the thermocline in the pool. The flow patterns observed with steady state withdrawal corresponded to those predicted from the generalized WES selective withdrawal studies.[1] If the thermocline is high in the pool, i.e., above the local topography at the lock walls, withdrawal occurs throughout the full depth of the impoundment (Fig. 8). If the thermocline is below the elevation of that local topography, withdrawal only occurs in the upper stratum of the lake (Fig. 9). It was therefore concluded from these tests that the elevated topography at the lock would act as a submerged weir and control the vertical extent of water drawn into the lock intakes.

The highly distorted physical model (1:80 scale vertically and 1:2400 scale horizontally) was constructed of Plexiglas to simulate Bay Springs Lake, the divide-cut canal including four major inflows along the canal and Yellow Springs embayment of Pickwick Lake (Fig. 10). The anticipated density stratification was reproduced again using saline and fresh water. The model was calibrated under steady flow conditions. It was modified to reproduce the same withdrawal characteristics as those observed in the undistorted lock intake model with steady-state outflow. The control and operation of the system was achieved using computerized motor-driven actuators and solenoid valves. The actuators were operated from a device which output a continuous analog signal. This allowed the stage hydrograph of the Pickwick Lake and the hydrographs of the four major inflows along the divide-cut canal to be simulated in a smooth continuous manner. The solenoid valves were controlled with an input impulse to open and close. By varying the rate of the impulses, different rates of lockage were simulated. Data, such as water surface profiles, temperature, and conductivity (used in density determination),

---

[1] J. P. Bohan and J. L. Grace, Jr., "Selective Withdrawal from Man-Made Lakes," Technical Report H-73-4, March 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

were recorded on an automatic data acquisition system.

INSTRUMENTATION

The operations and controls for the Bay Springs model were completely automated. A Hewlett Packard Coupler/Controller was used in concurrence with the WES owned and operated Honeywell 635 Computer and a time-sharing terminal (Fig. 11). The coupler/controller served as an interface between the Honeywell 635 Computer and six control devices on the model. A computer program was written and used to coordinate the timing and sequence of the control devices via the coupler/controller interface.

The control devices on the model and their functions were as follows: (1) the motor-driven actuators were used to position gates at the four inflow points to the divide-cut canal; (2) the solenoid valves were used to reproduce the locking operation at Bay Springs Lake; (3) the water surface detectors were used in conjunction with other electronic equipment to control and detect the water surface at Pickwick Lake; and (4) the curve tracers were used to generate a continuous analog signal to each of the six control devices. Figure 12 illustrates the techniques used to generate hydrographs at the four inflow points to the divide-cut canal. Figures 13 and 14, respectively, illustrate the control schematics for Pickwick Lake water surface and the Bay Springs Lock.

Data acquisitioning played a large role in developing the instrumentation system for the model. Many of the control variables were monitored and recorded during the operation of the model. The four inflow points plus Bay Springs and Pickwick water surfaces were monitored and recorded on magnetic tape continuously by the model data acquisitioning system. In addition, a separate control system was built to automatically scan and record density profiles in Bay Springs Lake. Figure 15 illustrates the complete data acquisitioning system.

RESULTS

Under unsteady operation, an upstream current developed as a circulation pattern in the upper part of the hypolimnion when the thermocline elevation was above the local topography at the lock (Fig 16). These patterns were observed and recorded by hand, video tape, and time lapse photography. A relationship between outflow, thermocline elevation, and circulation was developed. This relation was used in WESTEX to mix temperatures and dissolved oxygen concentrations in the circulated strata. The time required for inflow to travel the length of the reservoir is also important to the dissolved oxygen concentration. The D.O. is consumed by biological organisms and chemical reactions as the water travels the length of the lake; the longer the travel time, the greater the depletion of the D.O. supplied by inflow. An empirical relationship of travel time to inflow and outflow was developed from the highly distorted physical model study.

The WESTEX mathematical model is a computer-executed numerical simulation of natural processes. The program basically budgets flow, heat, and water quality parameters into and out of an impoundment. With the basic mathematical model already available, changes were made to account for the specific conditions indicated by the physical model of Bay Springs Lake.

Because flow can pass from Pickwick Lake to Bay Springs Lake or vice versa, the model had to account for two outlets. The lock was considered the first outlet and the second outlet was the canal. The model also had to account for two inflow points to Bay Springs Lake. The first inflow was the summation of all the local inflow; the second was the canal inflow when flow was in the direction of Bay Springs. When the daily flow in the canal is toward Bay Springs, the outflow from outlet 2 is zero. When the canal flows toward Pickwick, inflow from the second point is zero.

The dissolved oxygen of the lake is dependent on travel time of water flowing through the lake and the retention time of more stagnant waters in the impoundment. The relationship of travel time and D.O. was developed and used in the dissolved oxygen depletion routine. The travel time was calculated and the D.O. of the inflow was depleted accordingly. After this activity the WESTEX model placed the inflow at an elevation in the lake where the lake water had the same density as the incoming water. The model then executed the heat exchange between the atmosphere and the pool. Diffusion of the heat and D.O. into the lake was accomplished; the reservoir density structure was then checked and corrected by convective mixing for any instabilities due to density, i.e., having heavier water on top than on the bottom of any two layers. At this point, a withdrawal profile was calculated based on the elevation of the thermocline. When the thermocline elevation was below the elevation of the local topography at the back or above elevation 390 ft, the generalized selective withdrawal characteristics of submerged weirs were applied. If the thermocline was above the local topography around the lock walls but below the upper limit of elevation 390 ft, the generalized WES selective withdrawal technique was not used. A separate routine was developed based on withdrawal characteristics observed in the highly distorted physical model to calculate the withdrawal profile under these conditions. In conjunction with this routine another algorithm was developed to account for the circulation of the hypolimnion observed in the physical model of the lake. Based on outflow and thermocline elevation, an appropriate volume of water was circulated from the lower part of the hypolimnion to just below the thermocline. The stability of the density profile was checked again. Water in the impoundment was saturated with dissolved oxygen from the surface down to an elevation dependent on temperature. The D.O. was then depleted on a daily basis from surface to bottom. A schematic representation of WESTEX is shown in Fig. 17.

This correlation of physical and mathematical model results provides a better understanding and evaluation of the flow phenomenon and the temperature and dissolved oxygen regimes to be expected within and downstream of Bay Springs Lake.

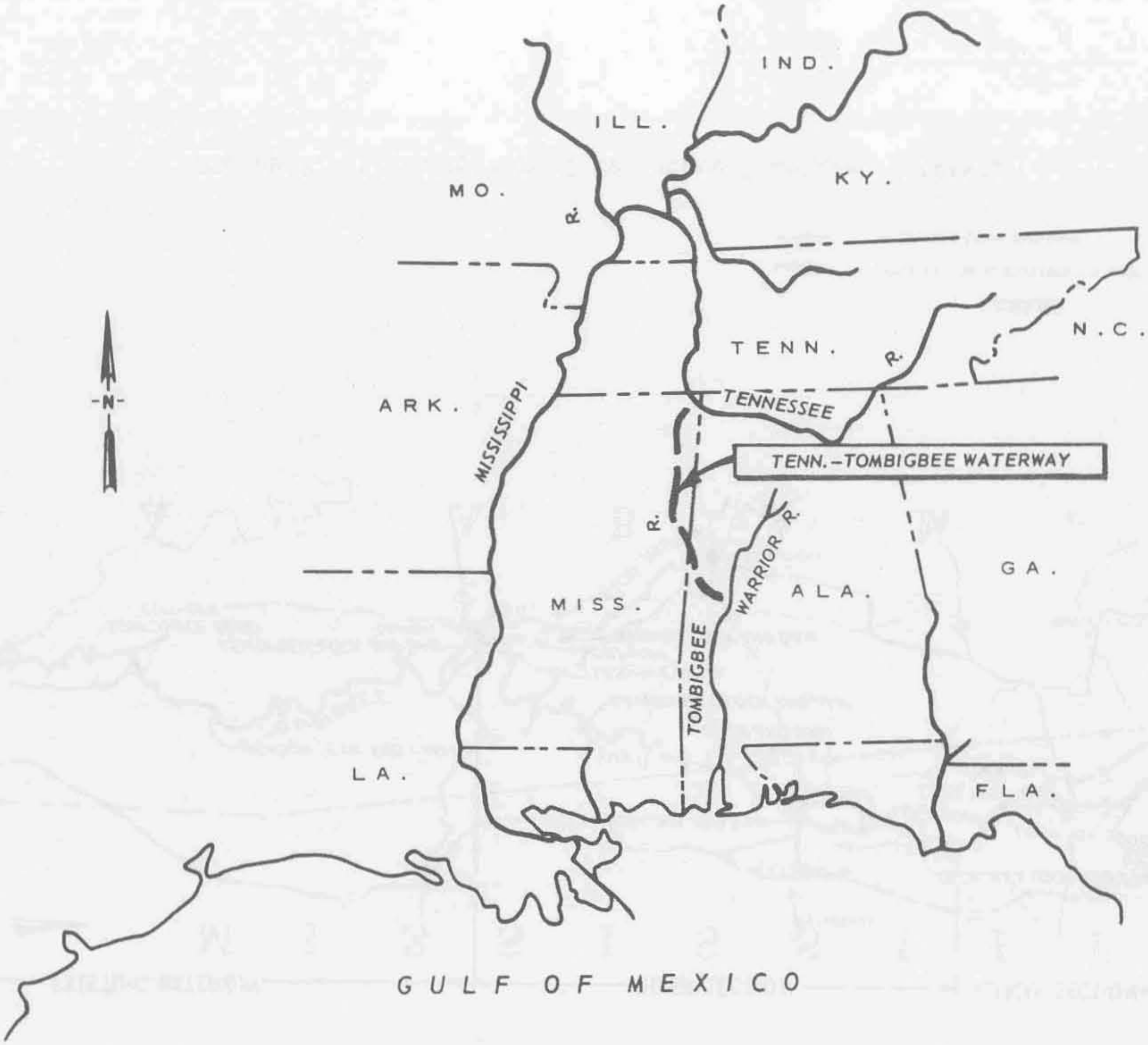

Figure 1. Location of Tennessee-Tombigbee Waterway

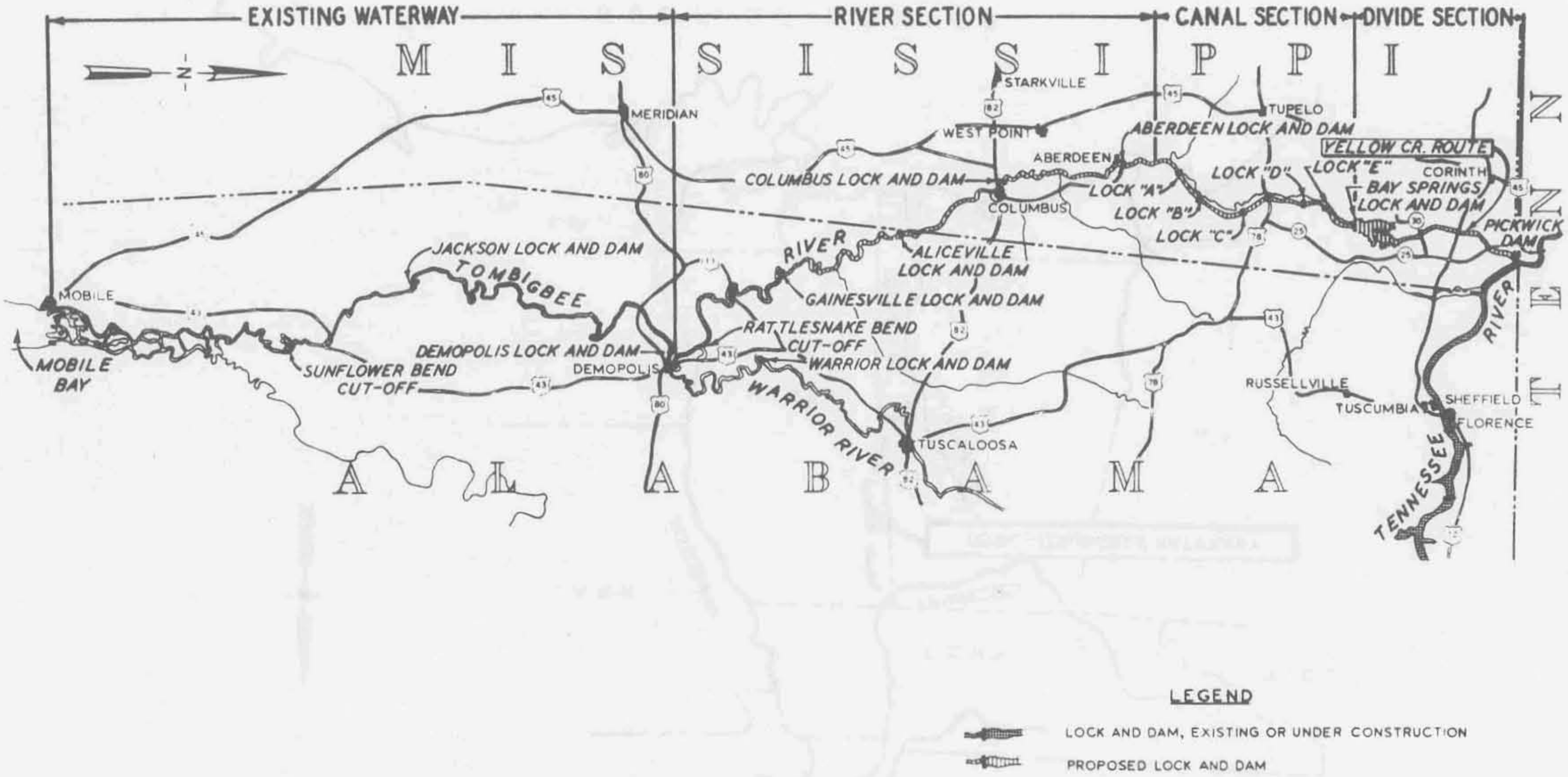

Figure 2. Vicinity map of Tennessee-Tombigbee Waterway

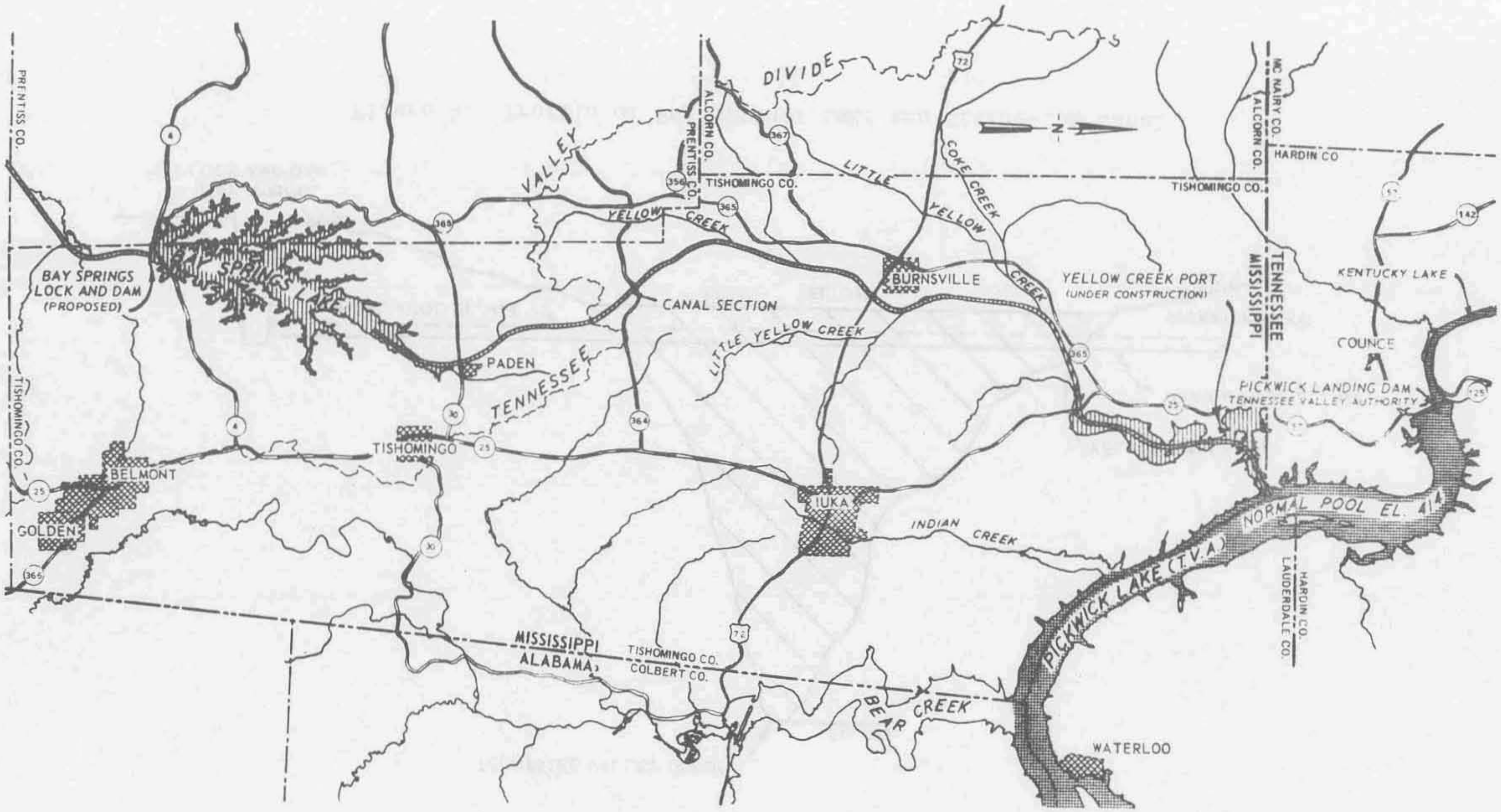

Figure 3. Location map of Bay Springs project

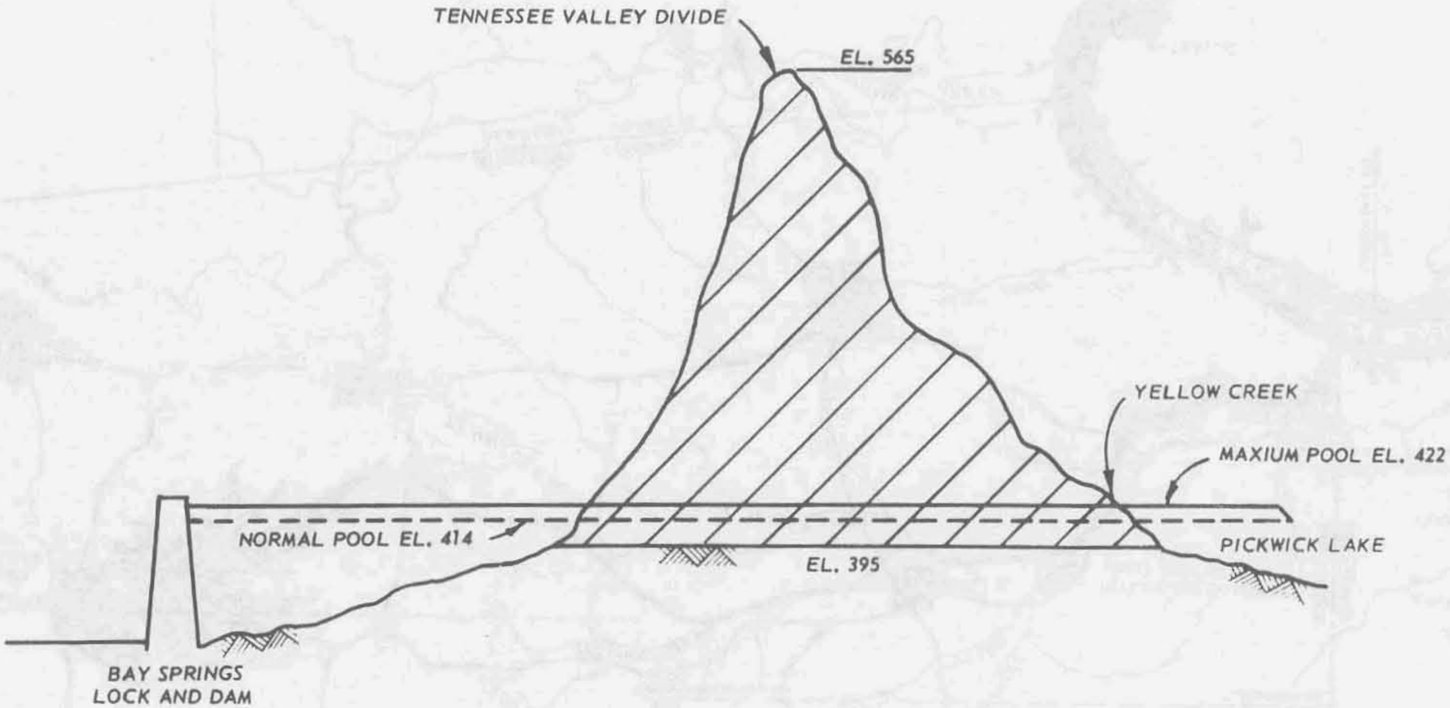

Figure 4. Profile of Bay Springs Lake and Divide-Cut Canal

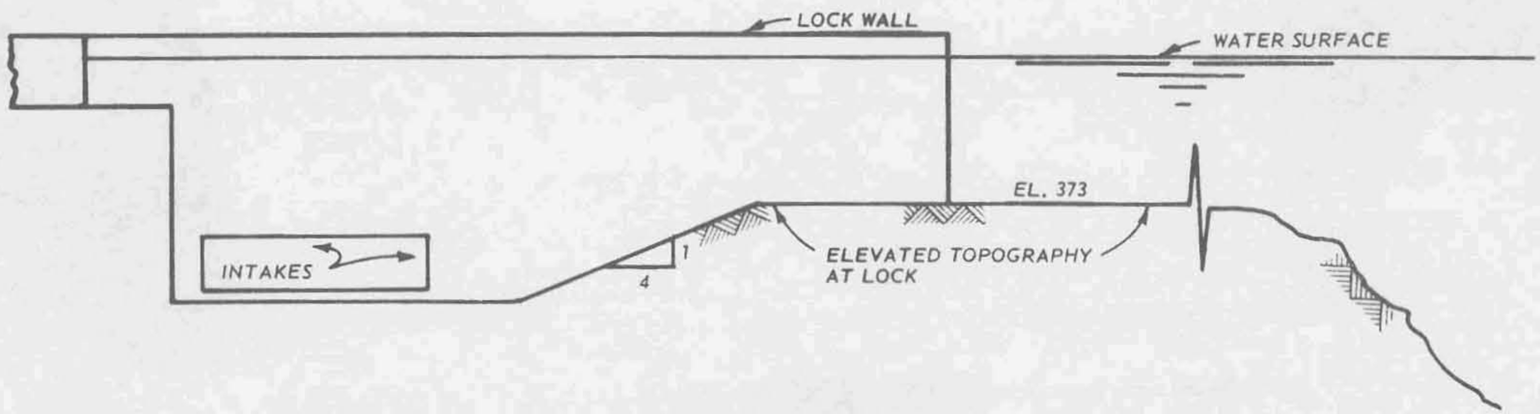

Figure 5. Local topography at Bay Springs Lock

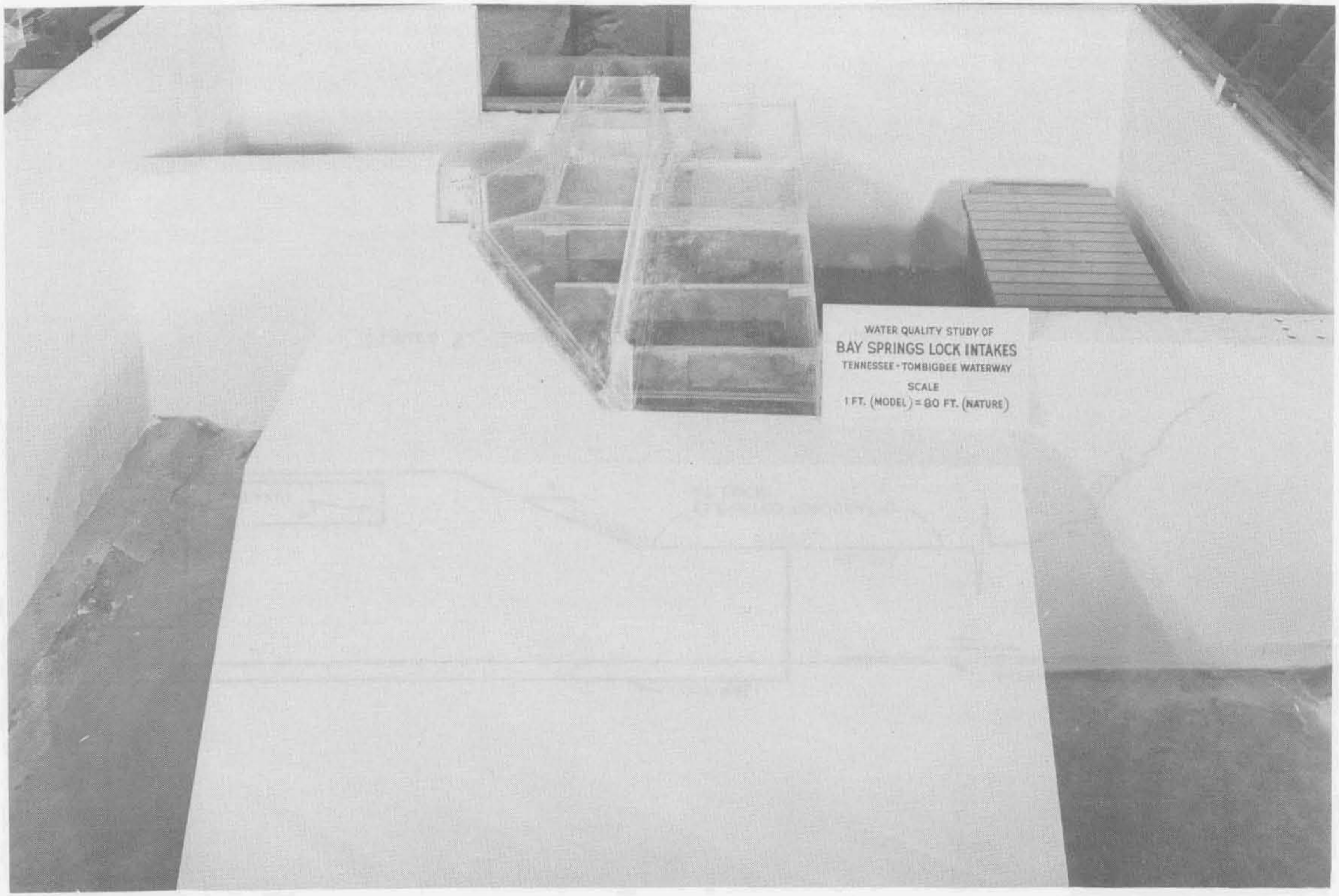

Fig. 6. Bay Springs lock intakes model

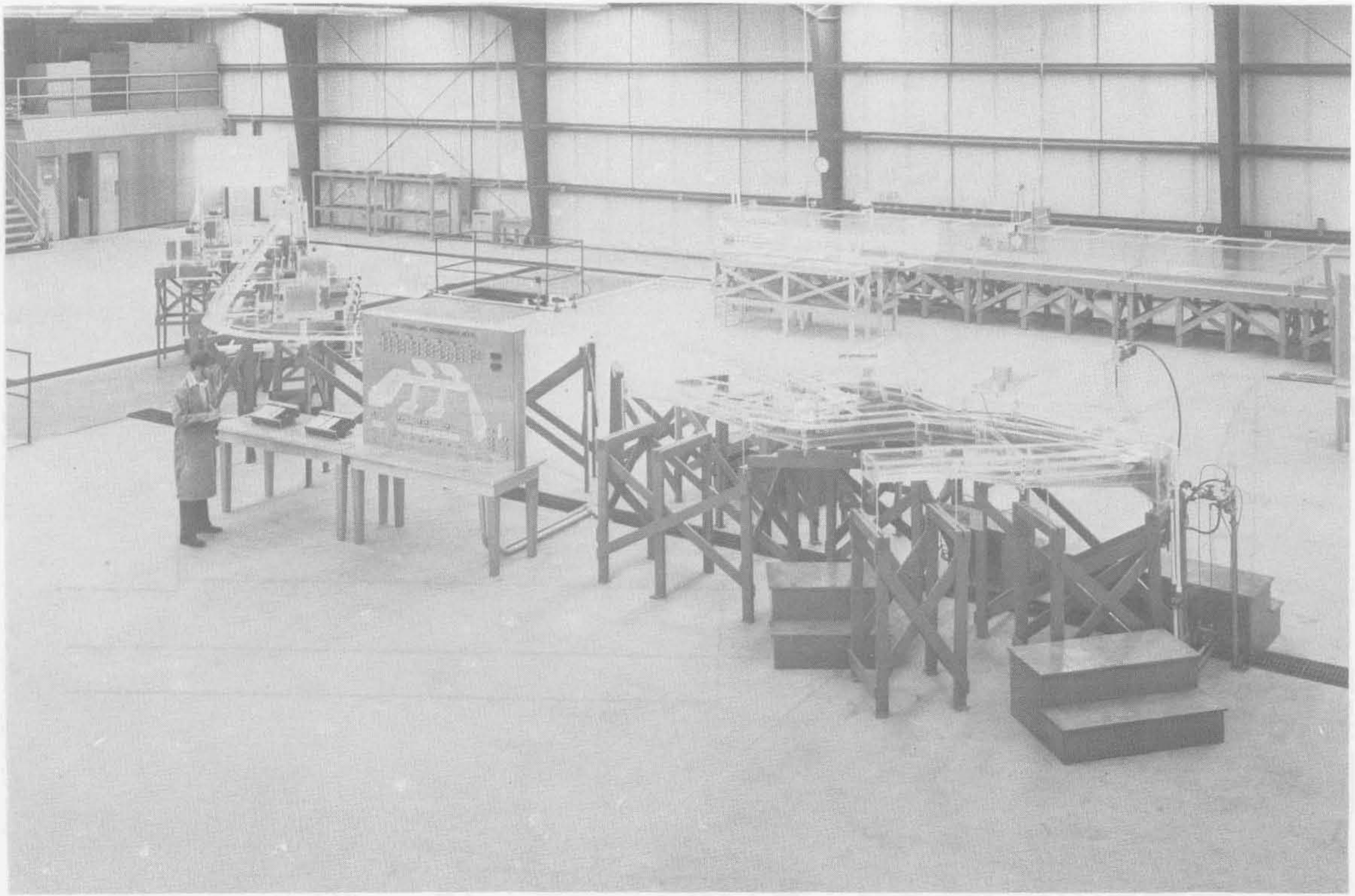

Fig. 7. Bay Springs hydrodynamic model

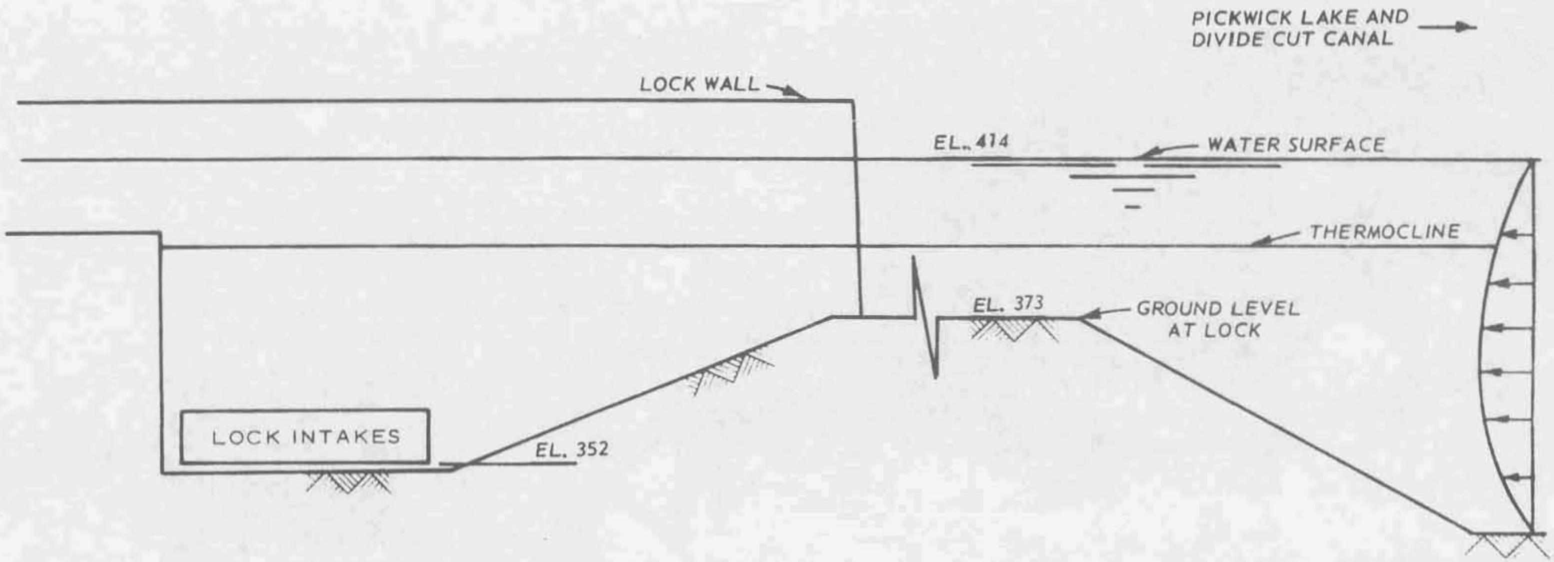

Figure 8. Withdrawal patterns when thermocline is high in pool

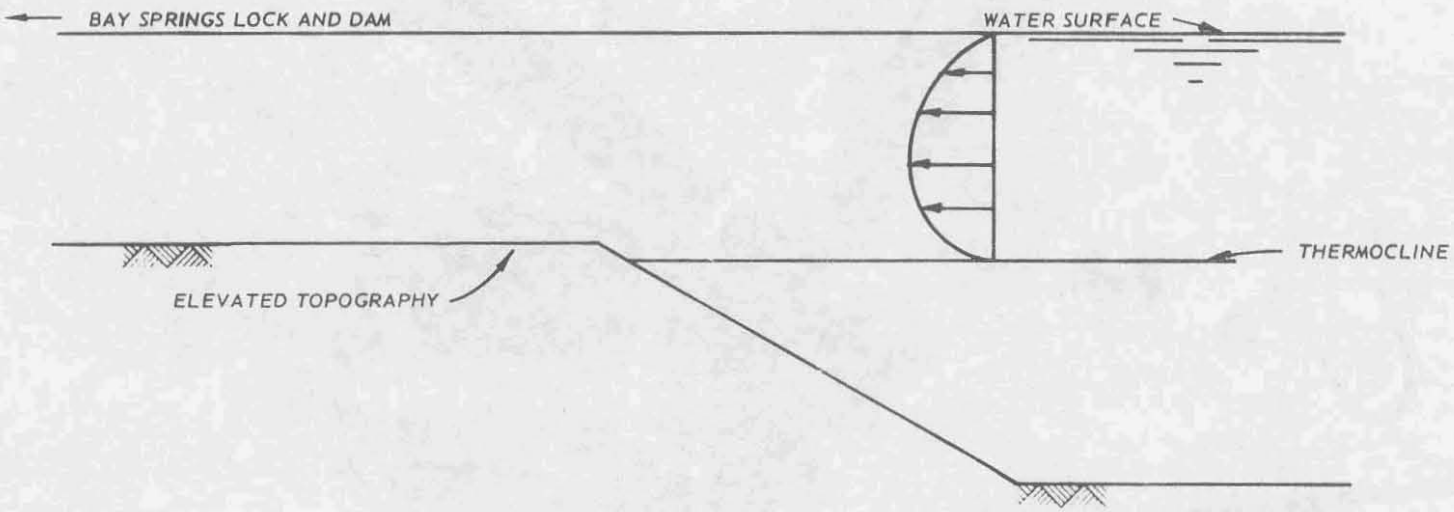

Figure 9. Withdrawal patterns when thermocline is below local topography at lock

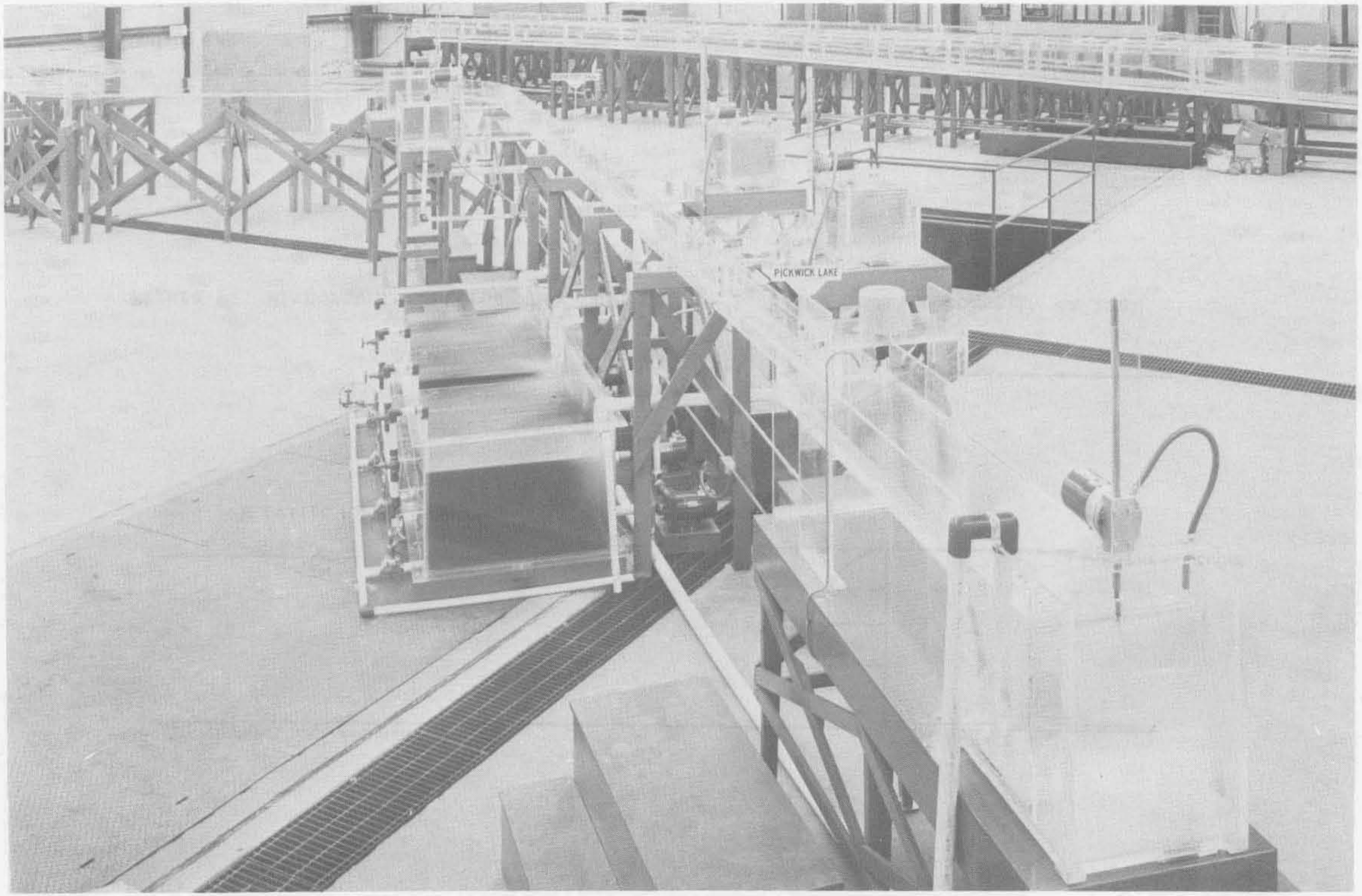

Fig. 10. Model representation of Pickwick Lake and Divide-Cut Canal

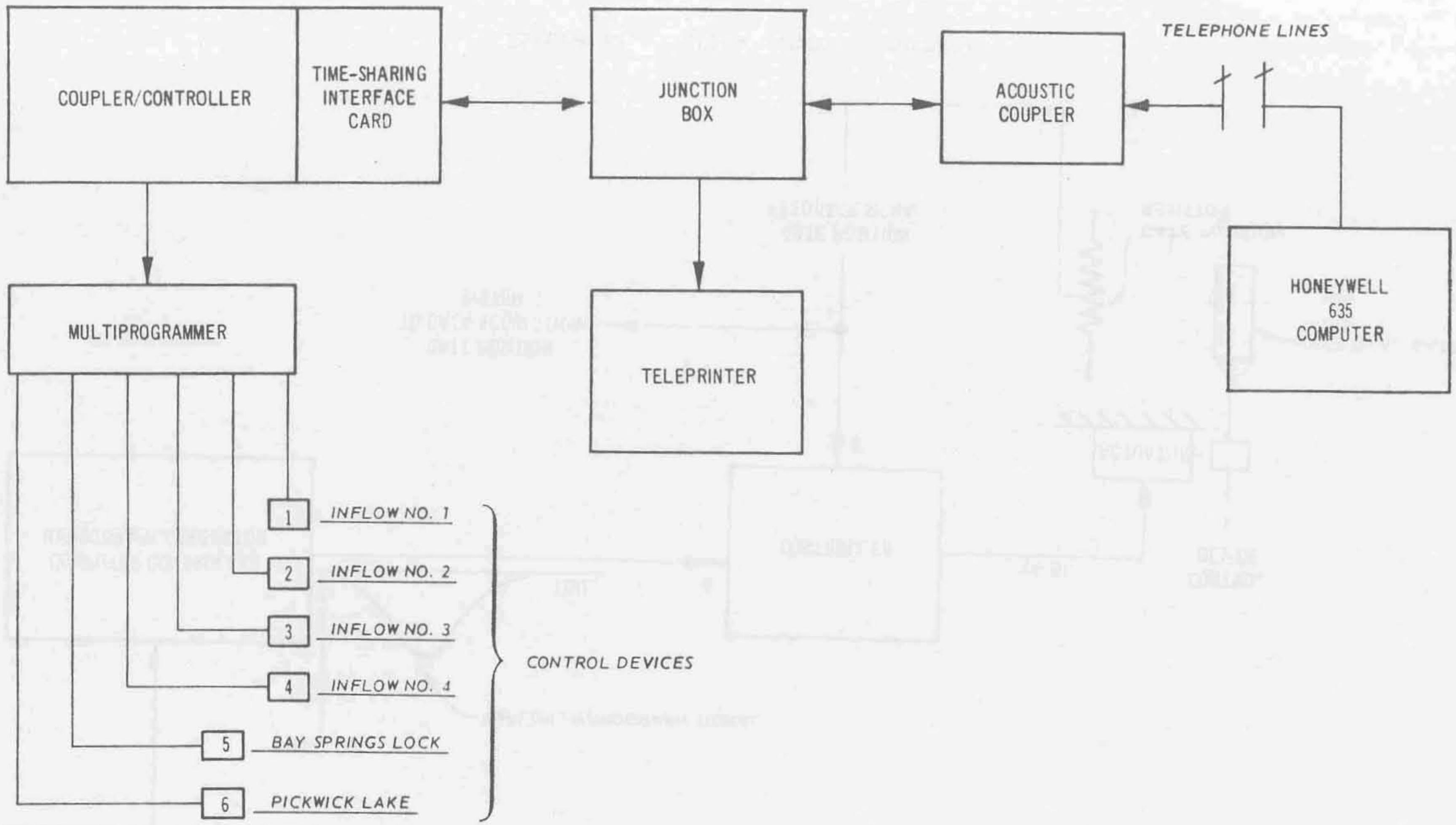

Figure 11. Interfacing with the time-sharing computer

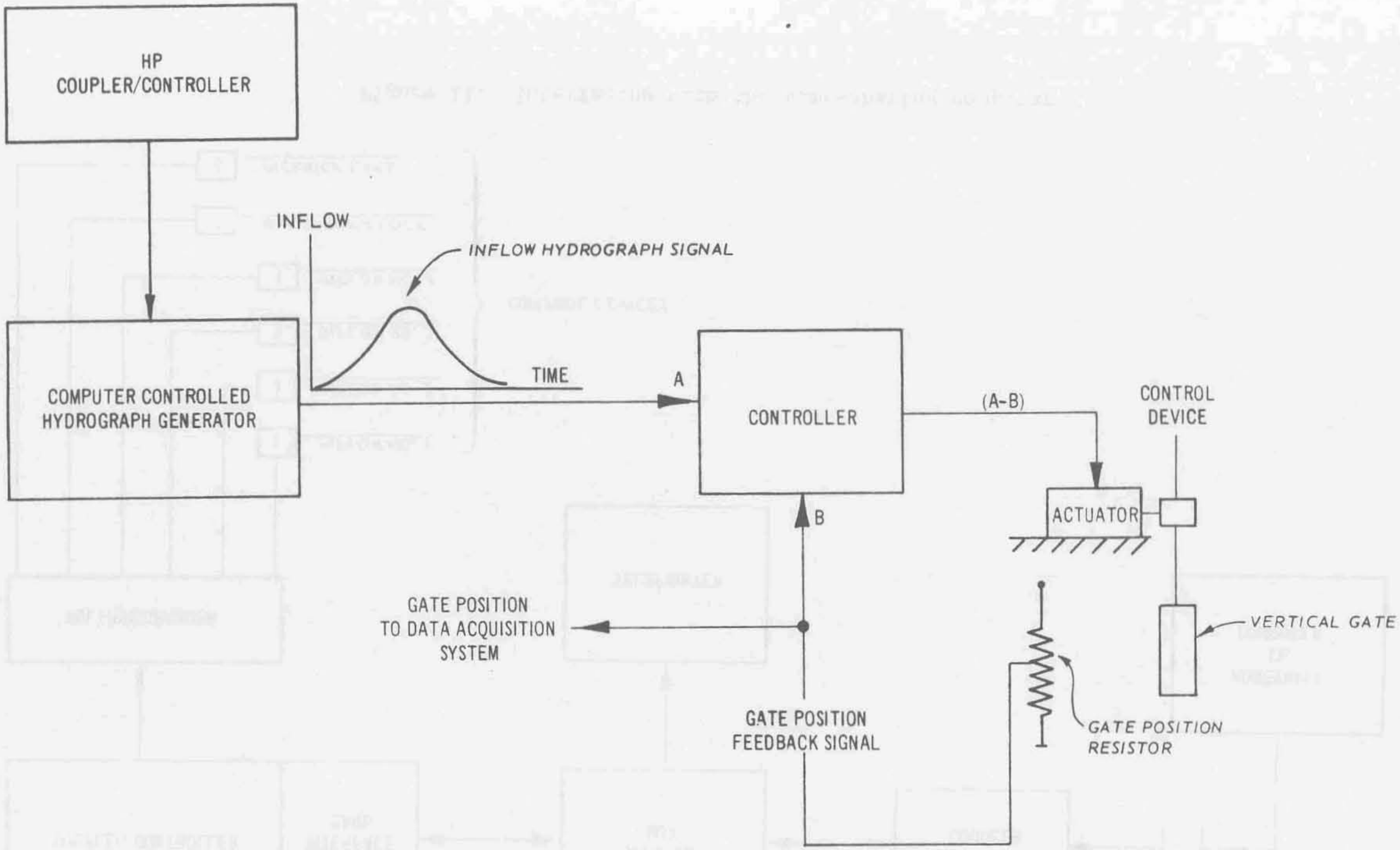

Figure 12. Inflow control schematic

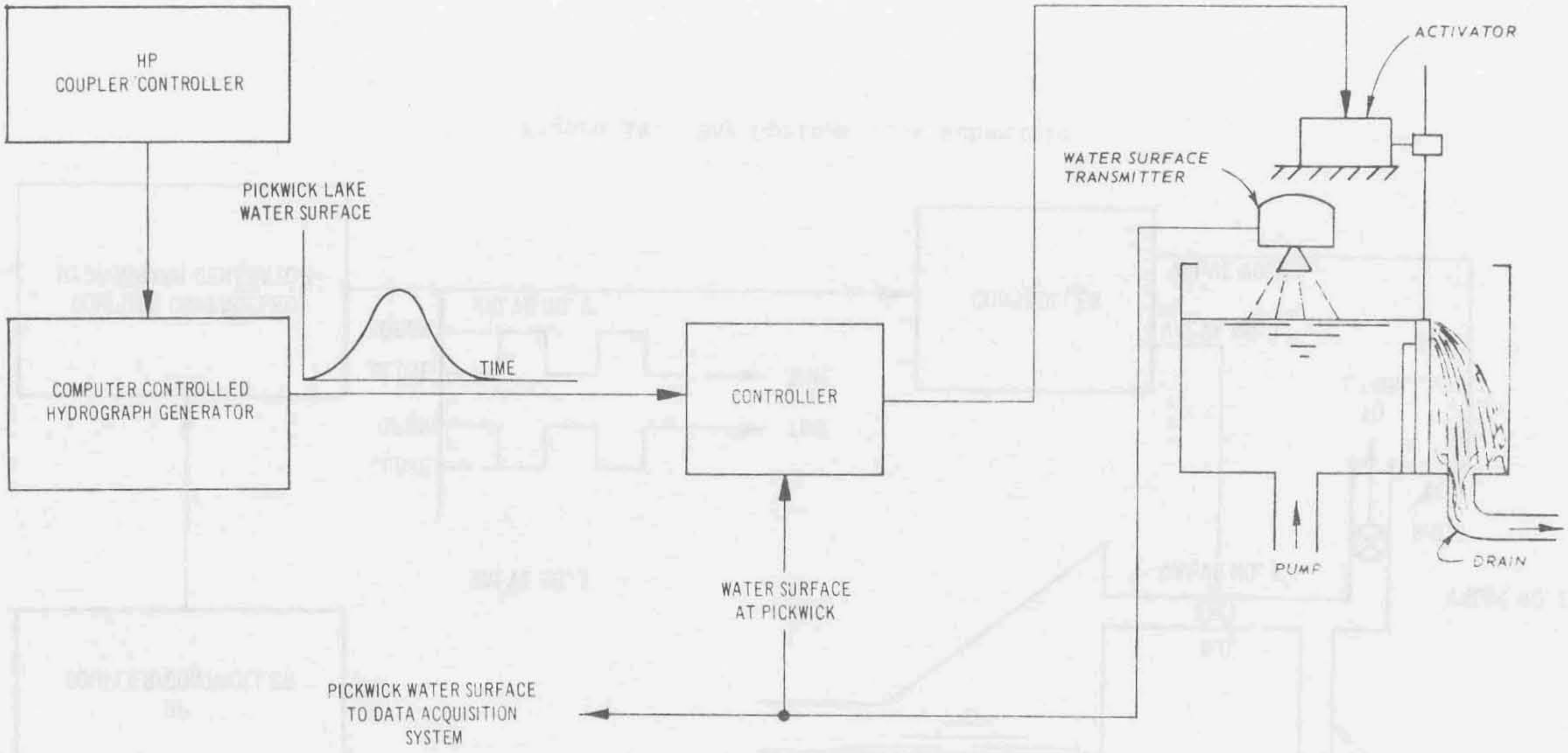

Figure 13. Pickwick Lake control schematic

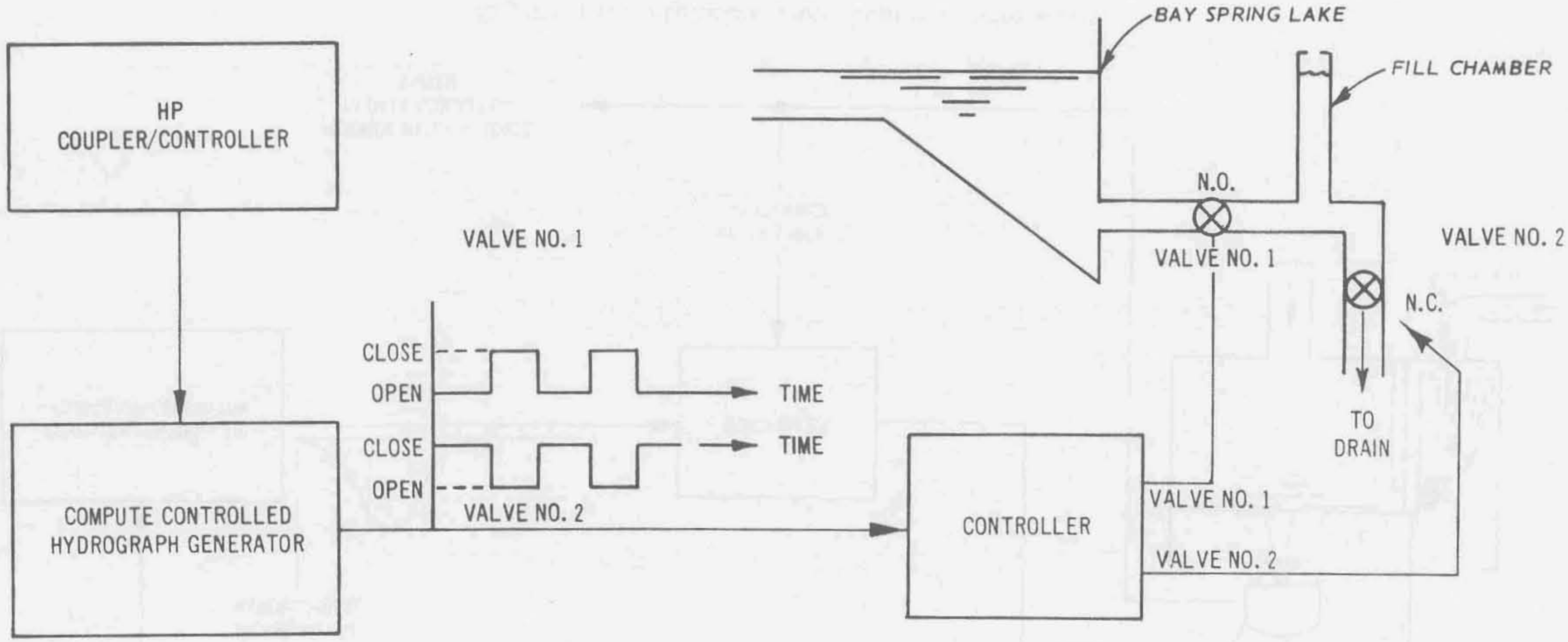

Figure 14. Bay Springs lock schematic

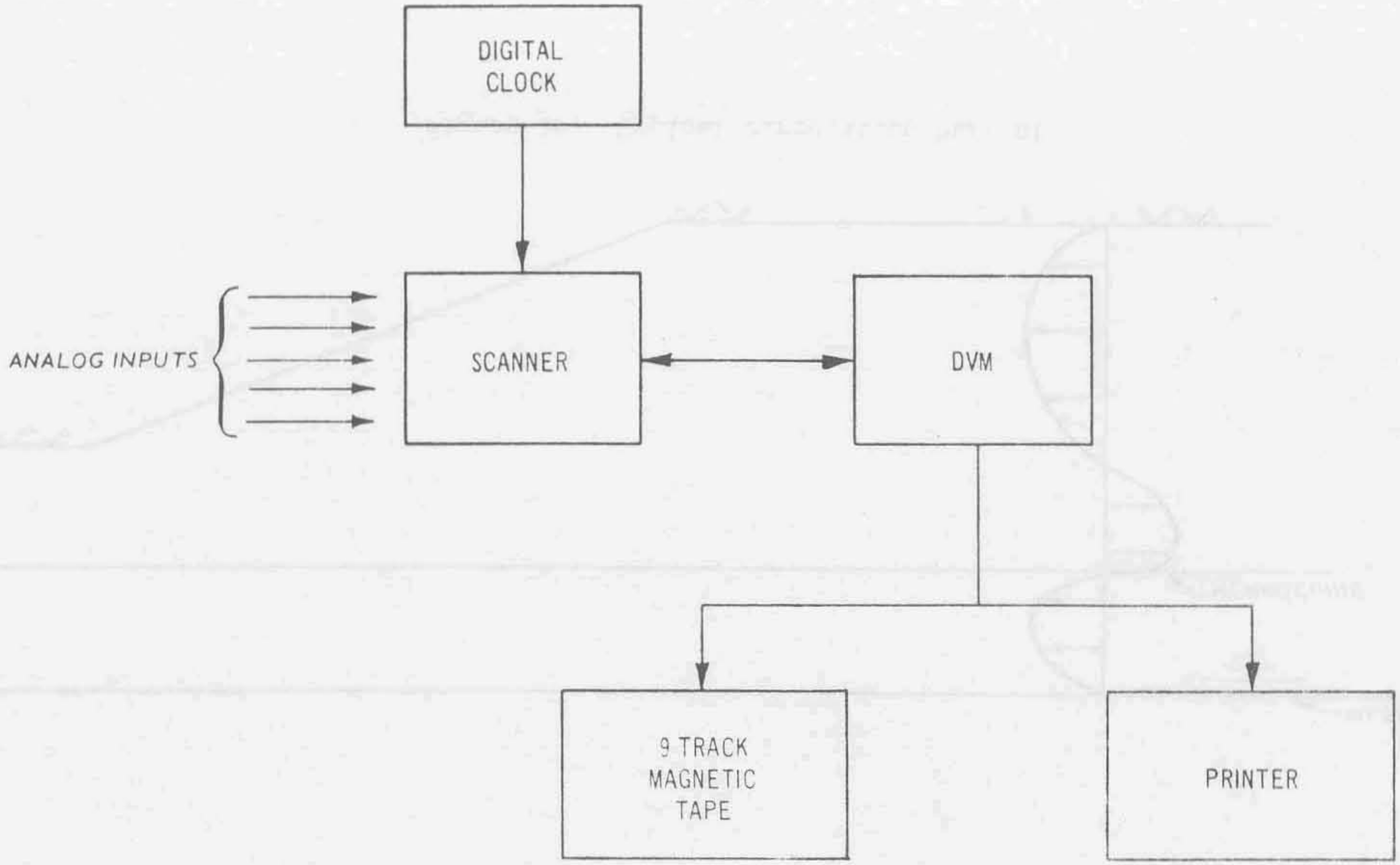

Figure 15. Data acquisition system

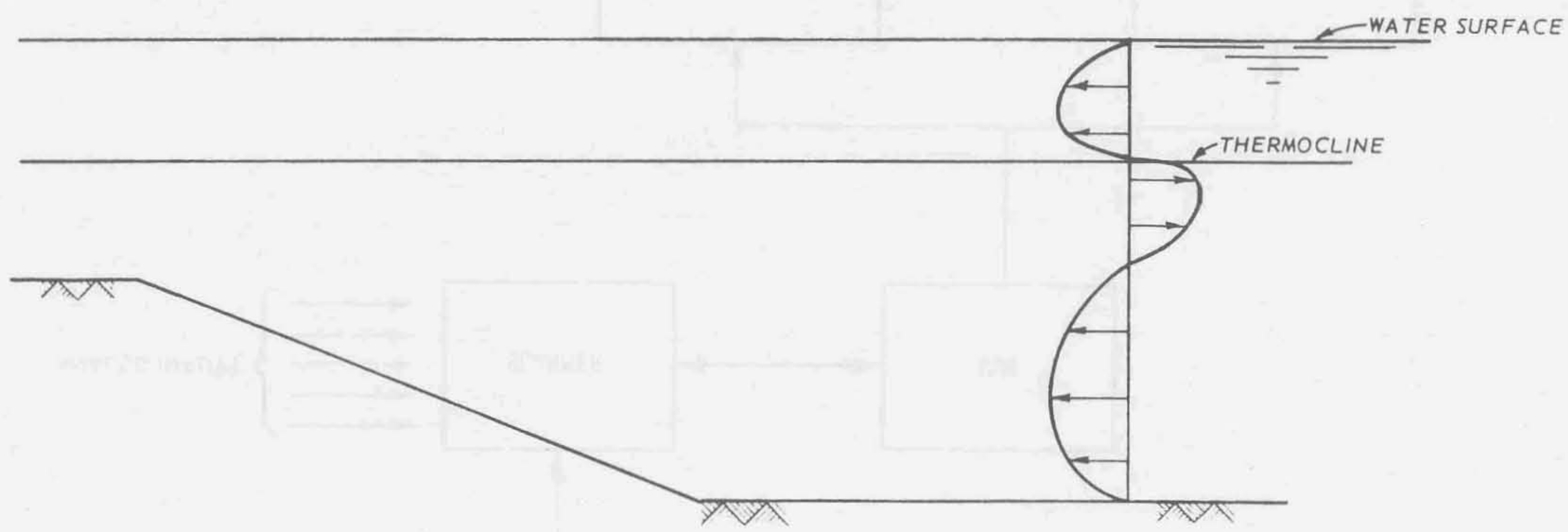

Figure 16. Typical circulation current

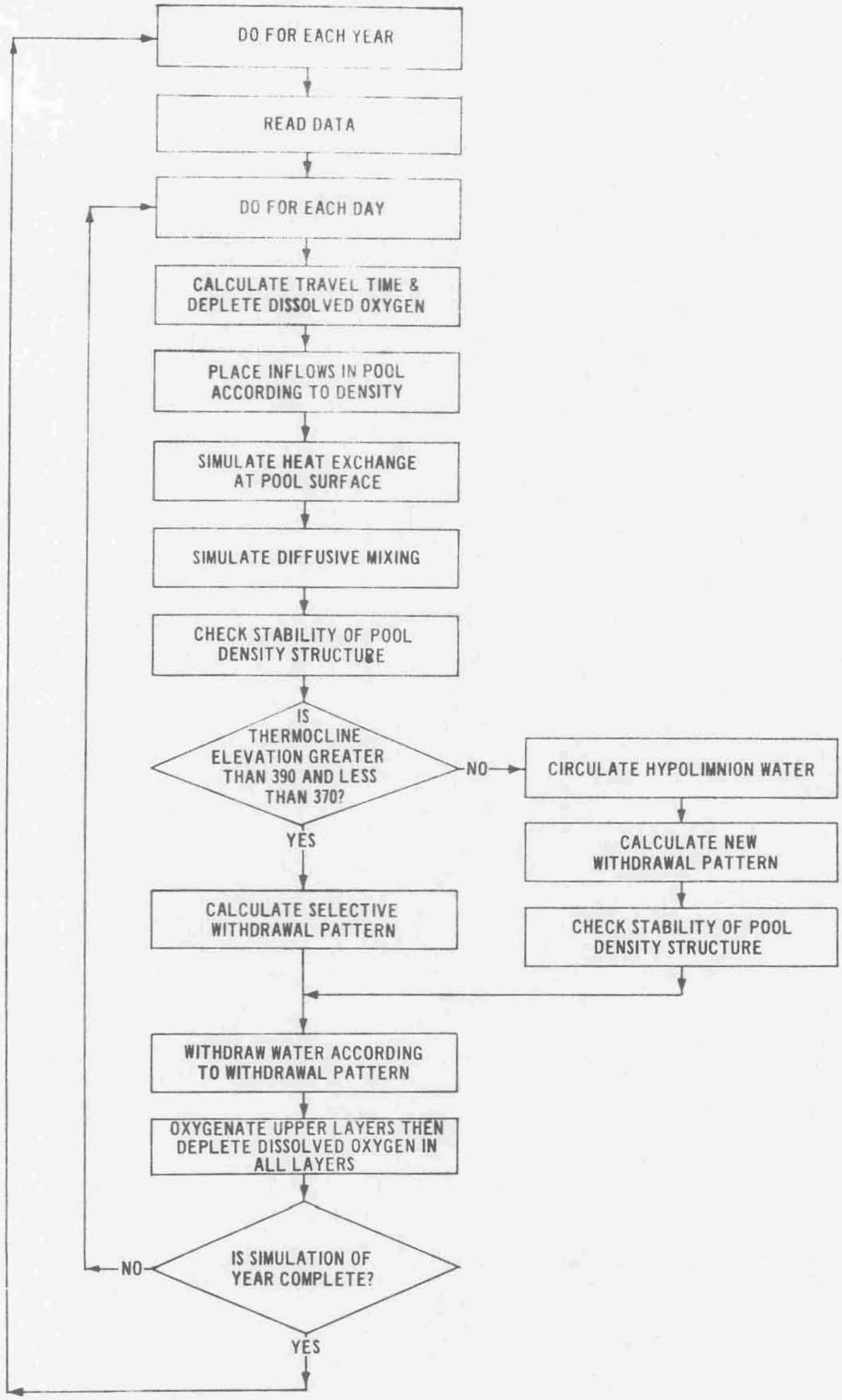

Figure 17. Schematic of WESTEX operation