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ALDEN RESEARCH LABORATORIES

WORCESTER POLYTECHNIC INSTITUTE

INDIAN POINT MODEL STUDIES

CONSOLIDATED EDISON COMPANY,
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THE ALDEN RESEARCH LABORATORIES

In 1894, Professor George I. Alden, head of the Mechanical Engineering Department of Worcester Polytechnic Institute, foresaw a need for research in hydraulics and fluid mechanics. He selected a 240-acre site in Holden on a power privilege which had flowage rights to a 150-acre pond. Through his efforts the site was given to the Institute and a laboratory constructed.

The laboratory was formally named the Alden Hydraulic Laboratory in 1915 when George Alden financed a meter station. Although he was not long in direct contact with the Laboratory, Professor Alden never lost interest in its progress. Through gifts or grants from his trust fund after his death additions to the facility were made in 1925, 1930, 1936 and 1937. Further generosity from his trust fund made possible the construction of the present main building in 1968.

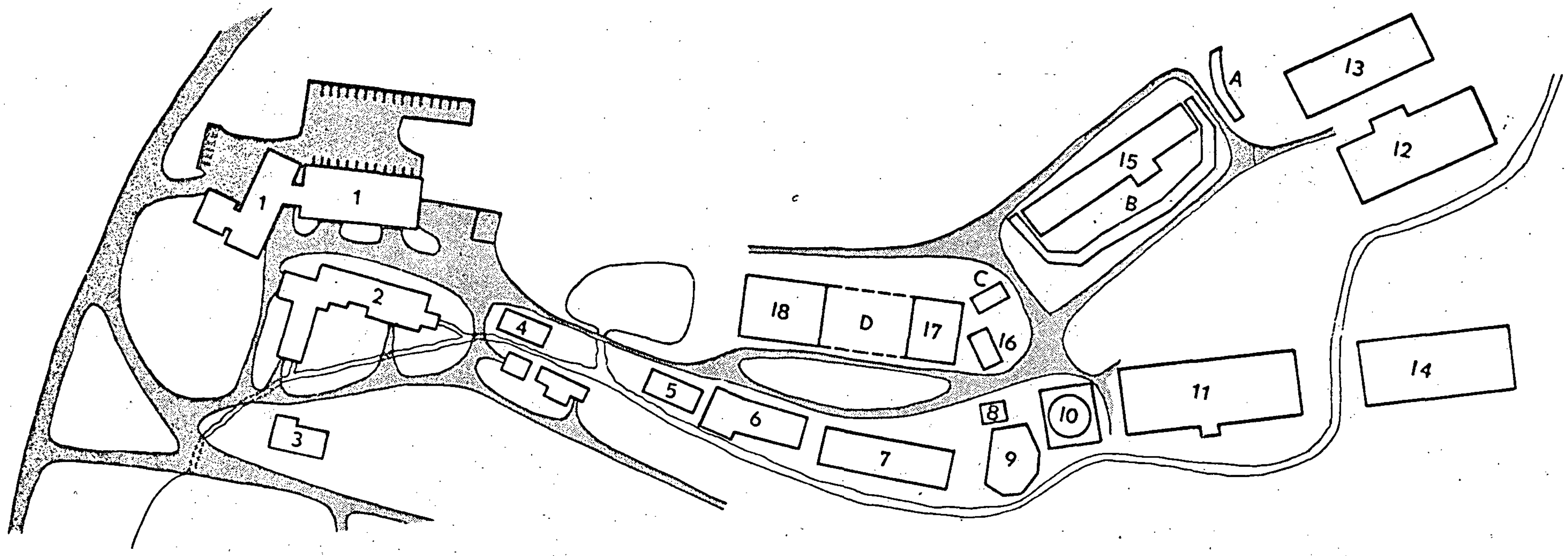
For nearly fifty years the Laboratory was directed by Charles M. Allen, a student of Professor Alden. His interests, personality and creative ability gave the Laboratory its character and reputation in the area of hydraulics.

He was succeeded as Director in 1952 by Professor Leslie J. Hooper. Through his efforts the scope of the research work and size of the facility was expanded. To reflect the broader scope of the Laboratories' graduate study program the name was officially changed to the Alden Research Laboratories in 1965. In 1968, Professor Lawrence C. Neale became the third Director of the Laboratory.

The Alden Research Laboratories are operated as a separate research facility of the Worcester Polytechnic Institute. Presently, its efforts are divided into four main work areas. The facility must first provide research facilities and instruction for graduate and undergraduate students studying at W. P. I. Second, the Laboratory provides services to industry in the area of flow calibration or flow studies of numerous devices used in pipe lines ranging in size from a fraction of an inch in diameter to 48 inches in diameter. The third area is concerned with naval ballistic studies associated with water entry, water exit or underwater studies.

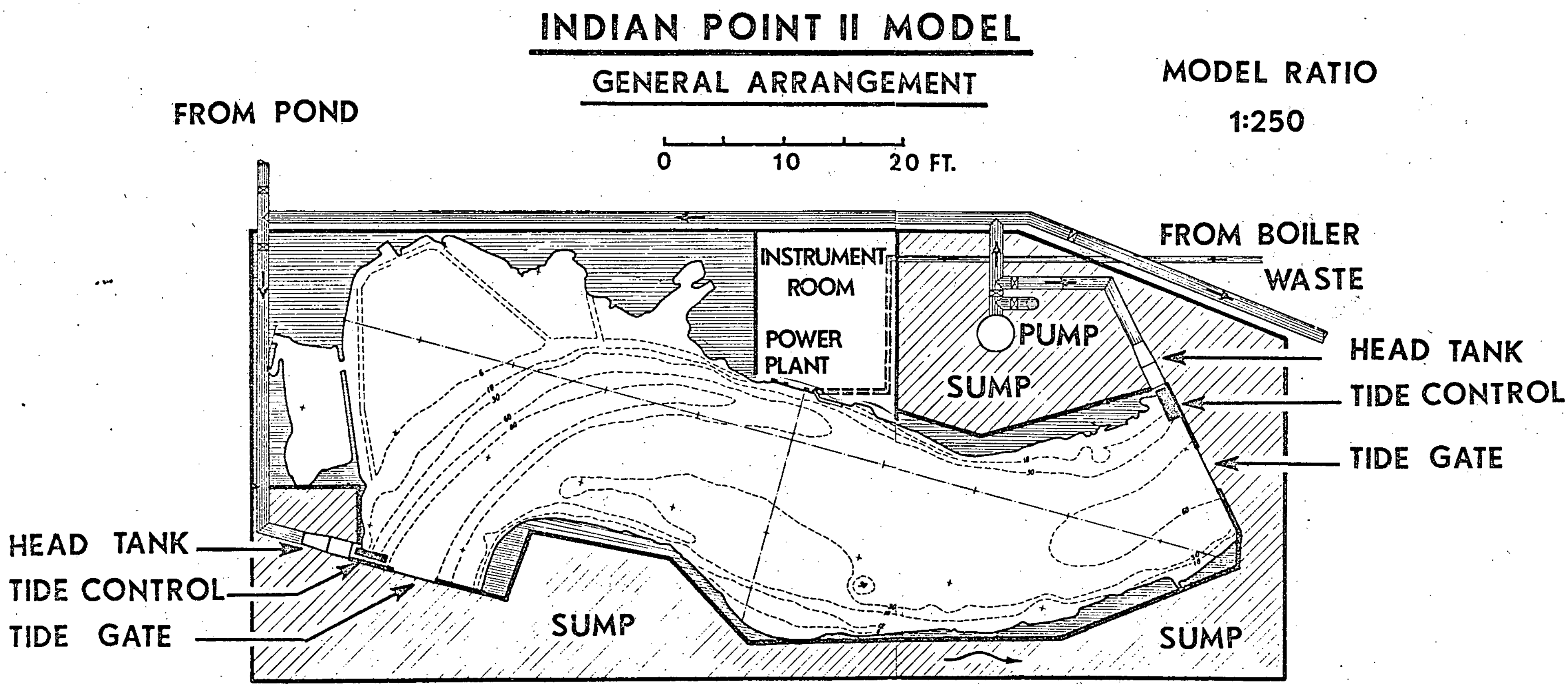
Lastly, the Laboratory has acquired a national and an international reputation in the area of model studies of rivers, dams, spillways, intakes, pumps, etc. In addition to a pump test facility there are currently 30 models in existence or under construction at the Laboratory. Of these models ten are in the area of flow through structures, eight for pump storage projects, ten for heat rejection studies and two miscellaneous studies.

In additon to the model studies, members of the staff are active participants on numerous national and international committees dealing in areas of fluid mechanics. This, in addition to consulting on numerous full scale projects, helps the Laboratory staff stay abreast of current work in its field.



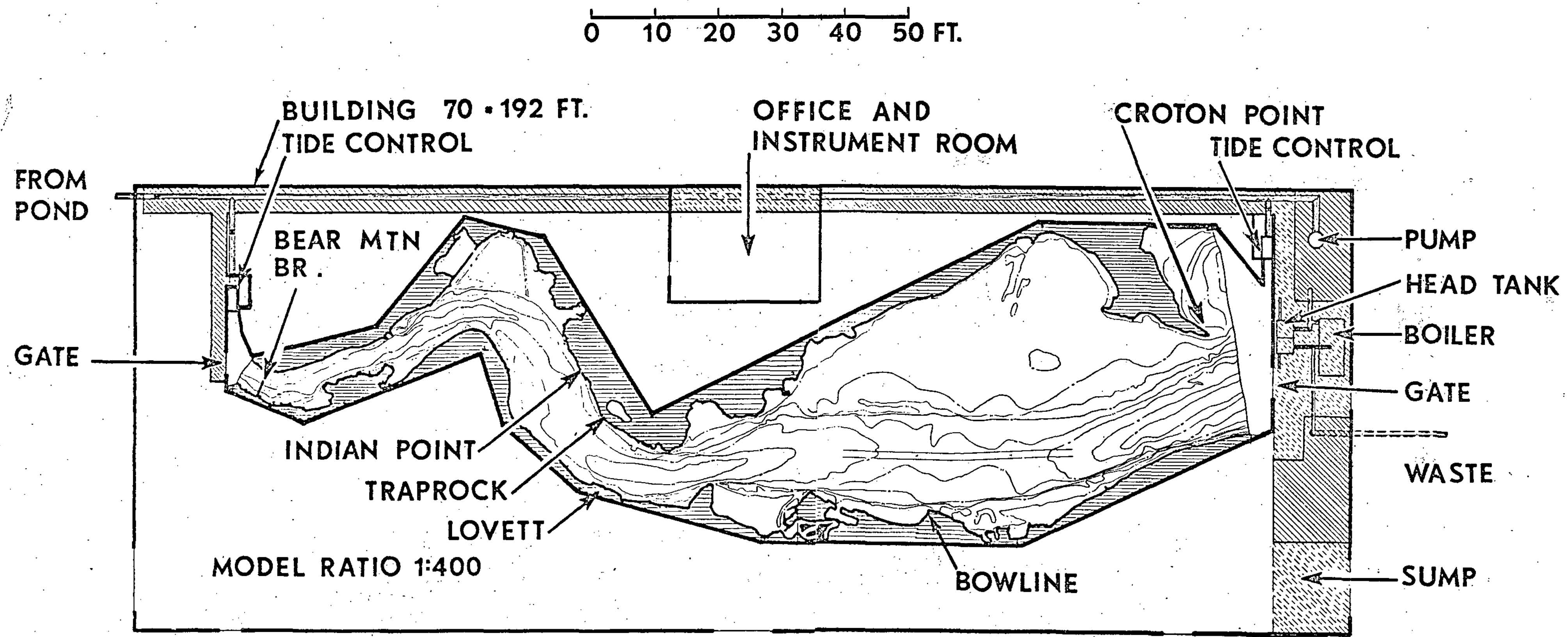
ALDEN RESEARCH LABORATORIES

1- NEW LAB BUILDING
2- OLD LAB BUILDING
3- LOW HEAD LAB
4- TECH OFFICE
5- SAMMIS I
VERMONT YANKEE
6- FOSTER WHEELER
7- CHALK POINT
8- RILEY STOKER
9- PILGRIM WAVE BASIN
10- BEAR SWAMP
11- MORGANTOWN
12- CALVERT CLIFFS
13- INDIAN POINT III
14- GILBOA
15- PEACH BOTTOM
16- JOCASSEE
17- BEAVER VALLEY
18- INDIAN POINT II
VT. YANKEE DISCHARGE
NORTHFIELD INTAKE
CORNWALL II
AREA A- OYSTER CREEK
AREA B- NORTHFIELD RIVER
AREA C- EASTON
AREA D- LUDINGTON
CORNWALL


INDIAN POINT II MODEL
GENERAL ARRANGEMENT
MODEL RATIO
1:250
FROM POND
0
10
20 FT.
FROM BOILER
WASTE
INSTRUMENT
ROOM
POWER
PLANT
PUMP
SUMP
HEAD TANK
TIDE CONTROL
TIDE GATE
HEAD TANK
TIDE CONTROL
TIDE GATE
SUMP
SUMP

INDIAN POINT III MODEL

GENERAL ARRANGEMENT



RELATIONS BETWEEN PROTOTYPE AND MODEL PROPERTIES

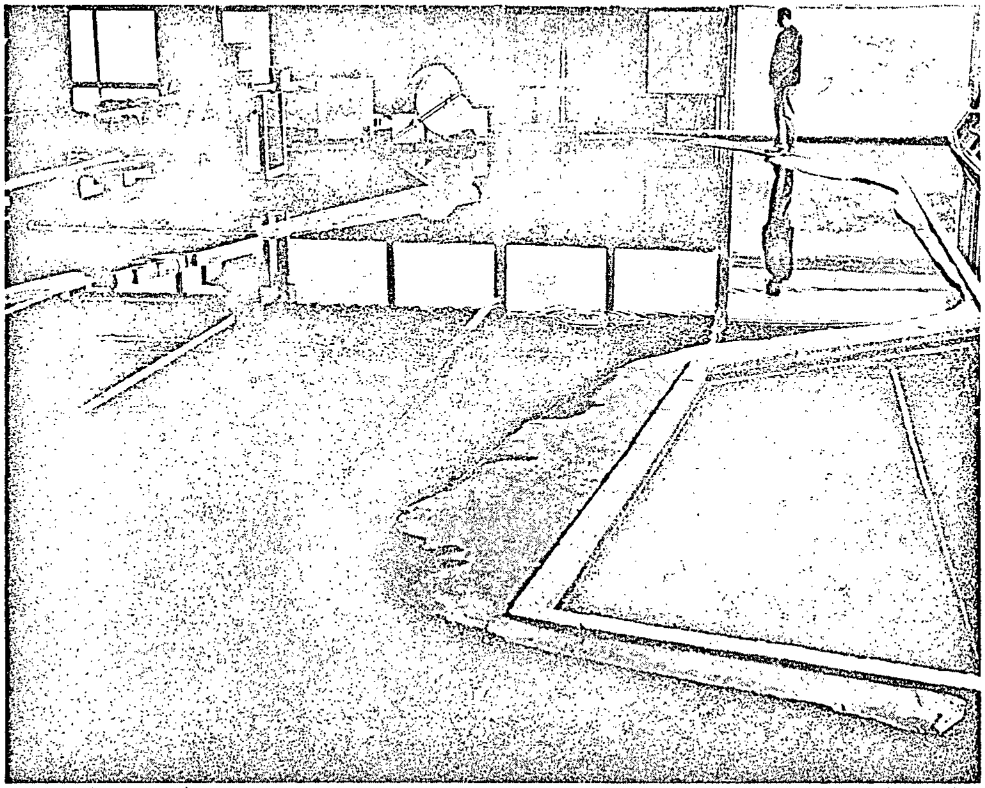
		INDIAN POINT II MODEL	PROTOTYPE
GEOMETRIC	Length	1 Foot	250 Feet
	Width	1 Foot	250 Feet
	Depth	1 Foot	60 Feet
	Volume	1 $Foot^3$	375,000 $Feet^3$
KINEMATIC	Time	1 Second	32.2 Seconds
	Velocity	1 FPS	7.74 FPS
	Flow Rate	1 CFS	116,000 CFS
DYNAMIC	Pressure	1 PSI	60 PSI
	Gravity Force	1 Pound	375,000 Pounds
TEMPERATURE		1°F	1°F

The Kinematic-Dynamic-and Temperature Ratios are based on Froud Scaling i.e. Gravity and Inertia Forces are considered dominant forces.

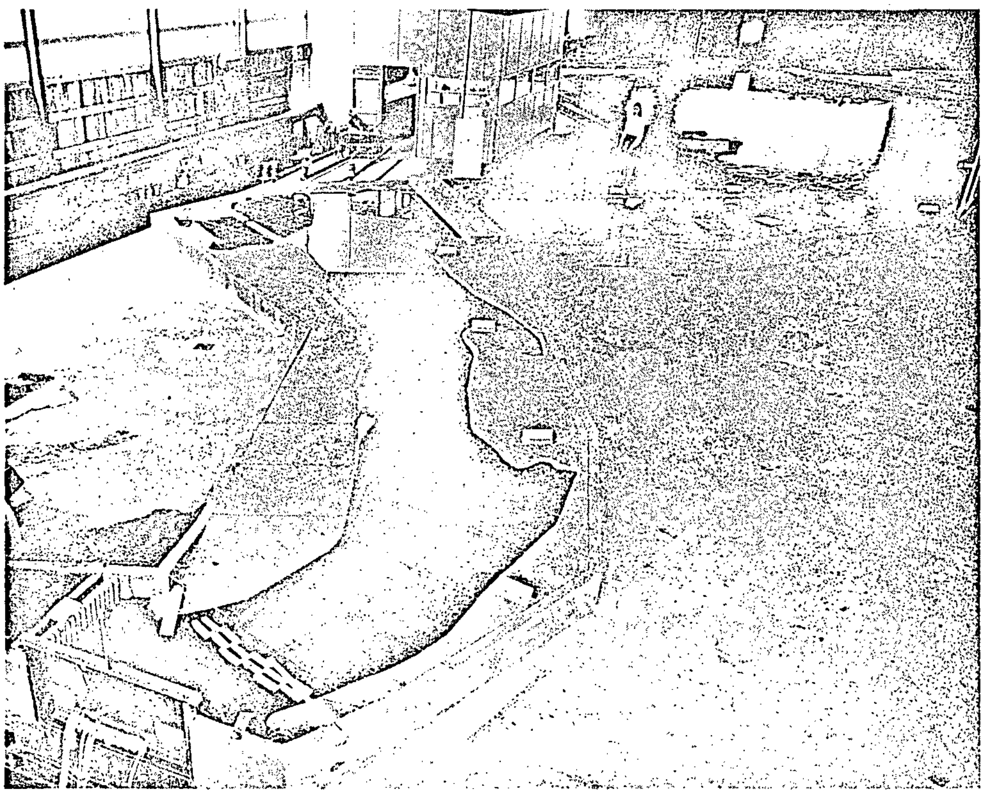
RELATIONS BETWEEN PROTOTYPE AND MODEL PROPERTIES

		INDIAN POINT III MODEL	PROTOTYPE
GEOMETRIC	Length	1 Foot	400 Feet
	Width	1 Foot	400 Feet
	Depth	1 Foot	80 Feet
	Volume	1 $Foot^3$	12,800,000 $Feet^3$
KINEMATIC	Time	1 Second	44.7 Seconds
	Velocity	1 FPS	8.9 FPS
	Flow Rate	1 CFS	286,000 CFS
DYNAMIC	Pressure	1 PSI	80 PSI
	Gravity Force	1 Pound	12,800,000 Pounds
TEMPERATURE		1° F	1° F

The Kinematic-Dynamic-and Temperature Ratios are based on Froud Scaling i.e. Gravity and Inertia Forces are considered dominant forces.



INDIAN POINT II MODEL



INDIAN POINT III MODEL

THE USE OF RIVER MODELS IN POWER PLANT HEAT EFFECT STUDIES

Lawrence C. Neale*

INTRODUCTION

The use of hydraulic models in the study of various hydraulic phenomena such as flow over spillways, flow around bridge piers, and flow in canals has been known and applied for centuries. Numerous examples of this type of model can be found in the history of science. However, the widespread use of such models has waited until the twentieth century. It is now the rare hydraulic project of significant size or scope that is not modelled for some detail during its design.

The use of river models for heat effect studies has been of more recent origin. Such studies have been conducted over the past 15 years at the Alden Research Laboratories of Worcester Polytechnic Institute. Six such studies involving cooling water for thermal plants have been completed during this period. Similar studies have been carried out in other laboratories such as the laboratories of the Army Engineer Corps at Vicksburg and at the TVA laboratories at Norris. In addition, there has been a considerable effort devoted to the development of the theoretical aspects, both of the prototype problem and the modelling of these problems. The rest of this discussion will be concerned with how this effort has developed at the Alden Research Laboratories. It should be pointed out that the Alden Research

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Laboratories development has resulted from the support and confidence of a number of clients. These include the Philadelphia Electric Company, Potomac Electric Power Company, Consolidated Edison Company, Duquesne Power Company, American Electric Power Company and Stone and Webster Engineering Corporation.

The river models at the Alden Research Laboratories have tended to be rather large, in terms of the usual river model, with model ratios ranging from 1/10 to 1/200. There are several reasons for this trend. First, a relatively large model tends to provide greater accuracy of any measurements made on the model. Second, a larger model allows a better reproduction of the details of topography and structures which tends to produce a better reproduction of the prototype flow patterns. Third, the turbulence level in the larger models tends to be greater and therefore more nearly duplicates the prototype.

There are several features of the Alden Research Laboratories' plant that have made the use of large models possible. The laboratory is situated on a natural water site with a reservoir of approximately 100 acres draining an area of 4-1/2 square miles, which affords a dependable and relatively large water supply for experimental use. Also, a large portion of the 200 acres of land at the laboratory is available for river model studies.

CONSTRUCTION

It has been found that for model heat studies, the model must be completely enclosed. This allows the atmospheric conditions over the model to be stabilized and to eliminate the solar effects which can vary widely. Therefore the first step in the construction of a model is to provide a suitable enclosure. Photograph No. 1 shows such a building under construction.

A concrete slab is first placed as a base in preparing a model site and then the limits of the model are defined by placing reinforced concrete walls. These walls are usually 4" thick and vary in height from several inches to several feet. Thus, the model is provided with permanent boundaries that can be used for instrument placement and measurement control, as well as a water tight basin.

Wooden templates are cut in the carpenter shop to the profile of the topography of the river bottom. These templates may be as long as 80 or 90 feet and vary in height according to the topography being reproduced. These templates are located on the model from a control such as a grid that is usually etched on the slab and also on the concrete walls. This grid can be used to locate model structures that may be required and can be used to locate instruments. This grid, depending upon the model scales, is usually developed with an interval of between 3 and 5 feet.

After the templates have been placed and are set on grade with an engineer's level, the space between the templates is filled with sand and gravel, which is tamped in place to within approximately one inch of the upper edge or contoured surface of the templates. A coating of topping concrete is then placed to reproduce the topography and to provide an impervious coating on the model. Photograph No. 2 shows a model under construction and Photograph No. 3 shows a completed model. The model does not need to be completely water tight, since the water will be confined within the concrete walls. Usually, the models are painted to allow better observation of tracers and to facilitate photography of dye, paper chips or floates which are used to trace flow patterns, and to determine the velocity distribution. The structures such as bridges, plant inlets, and outlets, and other pertinent features usually are wooden, but fiberglass, steel or other appropriate materials may be used.

The flow is usually provided from an outside sump and pumped to the model inlets and structures through appropriate pipe lines installed around the outside of the model. Adjacent to the sump, an oil fired or electrically operated heater for the water is set up to provide a variation of the water temperatures in the sump and river, as re-required to duplicate prototype conditions, as well as the temperature differentials planned for the cooling water flow. A boiler to perform this task may be rated as high as 100 HP and burn up to 25 gallons of oil per hour.

INSTRUMENTATION

Calibrated flow meters are installed in each of the supply pipe lines for flow measurement and valves for flow regulation. Point gages and staff gages are used to determine water surface elevations. The temperature measurements are made with either thermister type or thermocouple temperature sensors. These sensors are located at the critical locations such as the inlet and outlet sections of the model and the inlet and outlet of the model plant. In addition, the sensors are placed in various sections of the model to provide data which will allow a development of temperature distribution and flow patterns of the warm water. Temperature records at a variety of depths are needed in many instances in order to obtain data on the possible stratification in the model. It is usually desirable to record all temperature indications continuously. The number of temperature sensors have varied for the models which have been studied at the laboratory, the smallest number in some of the early studies was tenty and the largest number utilized to date is 250. In addition, there is usually a need for portable probes. The temperature indicators or recorders may or may not be portable but the sensor coverage must be sufficient to allow determination of temperature in any area that is not covered by the permanently installed temperature sensors.

The apparatus necessary for a tidal model is more involved since the water surface elevation and flow rate must be controlled at each end of the model to reproduce the complete tide cycle continuously and automatically. It was learned in some of the earlier studies that steady state model operation could not be used to study the tidal effects. It was apparent in these cases that completely valid data was not obtained until the model was operated manually through a number of tide cycles. Therefore, the automatic model can be run through many tide cycles without stopping, thus allowing a development of residual temperatures as may be expected in a long estuary

Sometimes regulated rivers can present just as complicated flow requirements as a tidal model. Since hydro-electric plants are more and more being used for peak loads, the resulting flow in a river can be anything but stable. In a recent model it was necessary to study the operation of two hydro-electric plants and a pump storage plant all operating in conjunction with a nuclear plant on the same reservoir. The optimum loading of the system was determined by a computer program for a number of average river flows. It was necessary to operate the model on a weekly cycle.

TEST PROCEDURE

A period of model adjustment must be carried out in operating all river models before actual testing can begin. During this period the model is studied and modified until it performs as the prototype. Thus it is important to have data from the field, not only on the physical features but on flow phenomena, such as water surface elevations, velocity, flow patterns and flow rates. In some cases, where this data is not available it is necessary to go into the field and obtain sufficient information to adjust the model. Data is also obtained on model performance during the period of adjustment that serves as a basis of comparison with later tests and modifications. However, in all cases, photographic data is taken to supplement recorded temperatures, elevations, flows and the like. The photographic data takes the form of both motion pictures and stills and usually involves tracers in the form of dyes, paper chips and floats. The detailed operating procedure for these models differs widely with respect to the type of model and type of plant operation that is planned.

The simplest form of model which has been tested at the Alden Research Laboratories is the river model with the heat effect superimposed. In this type of model, the testing involves setting a variety of river flows and river stages on the model and then superimposing the steam plant cooling water flows at the proper locations. At the model steam plant, this means withdrawing the correct flow from the river at the plant intake location and introducing the heated flow at the selected discharge or outlet point. The flow patterns developed by the hot water and the changes in the flow pattern of the river, with the hot water being introduced and the cooling flow withdrawn, are then documented. It has been desirable to reproduce river temperature over the range from summer to winter operation. In the extremes this has required a river temperature variation from 32° to 85°F., representing extreme winter and summer conditions. This requirement means that there must be a large amount of water heated and available.

In the case of rivers where the hydro-electric development is complete, large quantities of water at various temperatures must be available to allow the model to be operated over some cyclical program, such as a weekly cycle. In most cases, the operation of such a model is carried out for at least two weeks of operation. The first week is run to develop the proper distribution in the reservoir and the second week is run as the test of record. This system allows the model to start and run through a typical week for the record.

The operation of the tidal models also involves some time in developing a quasi-steady state. The model must be run through a number of tide cycles, with the cooling water being withdrawn, heated and re-introduced, in order for the heat distribution to develop over the whole section being modelled. The number of tide cycles necessary to produce this state must be determined for each model by monitorir its operation after adjustment. Data on the temperatures is recorded versus time and the time is usually developed in portions of the tide cycle.

In all of the model studies data reduction has been an increasing problem. Thus it has been necessary to turn to computer techniques of data reduction as well as data recording compatible with the computer. At the present time, data is being read and transferred to punched cards directly. All the latest model data will go directly onto magnetic tape for data processing.

SCALING

The Reynolds Number (ratio of inertia and viscous forces in all modelling work must be greater than certain minimum limits in order for the model to perform in a turbulent manner similar to the prototype. Also in river model work the Froude number (ratio of gravitational and inertia forces) must be maintained for both model and prototype. The normal Froude relationship is applied to the various quantities to be scaled such as distances, flows, velocity and time. On this basis, for a model scale of 1/1000 horizontal and 1/100 vertical, which happens to be those for a model under construction at the moment, the following ratios developed:

Length $$\frac{L_m}{L_p} = {}^1/1000$$

Height $$\frac{H_m}{H_p} = {}^1/100$$

Flow $$\frac{Q_m}{Q_p} = \frac{L_m H_m^{3/2}}{L_p H_p^{3/2}} = 1,000,000$$

Velocity $$\frac{V_m}{V_p} = \frac{\sqrt{H_m}}{\sqrt{H_p}} = {}^1/10$$

Time $$\frac{T_m}{T_p} = \frac{V_m/L_m}{V_p/L_p} = {}^1/10$$

Also involved with the warm water flow into the reservoir or river is the densimetric Froude number which is normally written as:

$$F = \frac{V_o}{\sqrt{\frac{\Delta \rho}{\rho} g D_o}}$$

where V_o = jet velocity

ρ = mass density of jet

g = acc. gravity

D_o = dia. jet

This special form of the Froude number is used in determining the density difference of the warm water and the receiving water for correct modelling. This relationship reduces to the form:

$$\left(\frac{\Delta \rho}{\rho}\right) \text{ for Prototype} = \frac{\Delta \rho}{\rho} \text{ for Model}$$

which means that if the temperatures of warm water and the receiving water are the same model and prototype, then the mixing characteristics will be the same.

Finally, a distorted model has certain advantages in addition to the R_n limit, namely that certain combinations of scales allow the model to theoretically scale the heat transfer phenomena.

Since the amount of heat added to the reservoir is the flow rate in pounds per second multiplied by the temperature rise, the ratio of model and prototype is given as the following relationship:

$$\frac{\gamma_m Q_m (\Delta t_m)}{\gamma_p Q_p (\Delta t_p)} = \text{Ratio of heat added}$$

where γ = specific weight of water

Q = volume flow rate

t = temperature

Since in the Froude scaling above

$$\frac{Q_m}{Q_p} = \frac{L_m H_m^{3/2}}{L_p H_p^{3/2}}$$

and $\gamma_p = \gamma_m$

$$\Delta t_p = \Delta t_m$$

The heat transfer in both model and prototype is dependent upon a surface area so the

$$\frac{(\text{Heat Trans})m}{(\text{Heat Trans})p} = \left(\frac{L_m}{L_p}\right)^2$$

Then in order to have these terms modelled properly from the prototype, the scale ratios must be such that

$$\left(\frac{L_m}{L_p}\right)^2 = \frac{L_m H_m^{3/2}}{L_p H_p^{3/2}}.$$

or $$\frac{L_m}{L_p} = \left(\frac{H_m}{H_p}\right)^{3/2}$$

as, for example, the ratio of

$$\frac{L_m}{L_p} = 1/1000 \text{ and } \frac{H_m}{H_p} = 1/100$$

does satisfy this relationship.

RESULTS

The results from the model studies can be presented in a number of ways in order to make maximum utilization of the tests. The various methods are all aimed at showing how the flow patterns of the warm water have developed and predicting the extent of the effects in the prototype. All of the studies have indicated that the basic patterns developed in the model are similar to those of the prototype. This means that with the pattern defined by the model, the transfer from model to prototype is involved with evaluating the temperature difference intensity. This basically is what has been done for model studies where receiving water has ranged in temperature from 32° to 85°F. and temperature differentials produced by condenser cooling have varied from 0° to 45°F.

Thus, once the basic patterns have been established, it is possible to use these patterns and the prototype operating conditions, including atmospheric conditions, to predict the resulting warm water distribution. In addition, this allows an evaluation of such things as, the amount of re-circulation that will be experienced at the power plant and the overall effect on the body of receiving water. Temperature gradients, both in terms of time and depth, can be established at specific locations.

It is important to note that in going from the model to the prototype, there are a number of basic parameters that must be taken into account. First, in the model tests, within the building the wind velocities are maintained practically at zero; second, because of the closed building and the lack of circulation and changing of air, the relative humidity over the model is extremely high; finally, because of the completely enclosed structure, the solar effects are eliminated from the model. Experience has shown that the net result of these various differences between prototype and model, tend to produce a heat loss from the model to the atmosphere that is considerably less than a normal situation in the prototype. It has been found, in all cases to date, from data taken in the field, that the temperatures tend to be a bit higher for a given set of operating conditions in the model than the prototype.

Figure 1 shows the model layout of a heat study for a relatively simple run of the river situation. There are peculiarities to each particular study and the details will bring this out, even in this more or less typical case. It will be noted that there is a water supply and distributor box at the upper end of the model to provide a controlled, measured and variable river flow. In addition, at the plant location, there is provision for taking water from the river, at the intake for each unit of the plant, and provision for heated water, at the proper temperature and amount, to be re-introduced to the model through the outlets on the individual units as designed. The individual features that make this model study a bit different is the fact that there is an existing unit and that its intake and outlet are not rearranged in the light of additional future units downstream. It will also be noted that the fuel barges moored offshore from the plant are in place during the studies. This was necessary in order to duplicate the flow patterns that would take place with fuel barges in the moored positions, as they will be for a major portion of the time that the plant is in operation.

In this particular study, a number of thermistors were used for sensing temperatures at different locations and at different depths in the model. These sensors were placed on a frame that could be moved up and downstream and across the model. A minimum of 24 individual readings could be taken at a particular time, and over the period of about one hour, a survey of well over 200 test points could be obtained. Because of the steady state condition of a particular river flow and plant operating condition, it was not necessary to get simultaneous readings over a large area of the model. In most instances, it was found that the model for a particular operating condition and river stage would stabilize in five to ten minutes. However, in most cases, the model was not subjected to a data survey for at least one half hour after all the flows and temperatures had been set and operating in a constant or stable manner.

Figures 2 through 5 indicate the type of data and results obtained from this model work. These take the form of isotherms of excess temperature, based on ambient river water temperature,plotted on a plan view of the model. Figures 2 and 3 are with the old plant, plus units one and two of the new plant, operating with a river flow of 7000 cfs. This means the river flow exceeds the total plant flow by a factor of a little over three to one. Figure 2 is an indication of isotherms for the water surface obtained in the general area of the plant. It should be noted that the guide wall at the outlet for Units 1 and 2, as well as the fuel barges, have an apparent effect on the flow patterns of the warm water. Figure 3 is a similar plot of conditions 2 feet (prototype) below the surface. Figures 4 and 5 are similar plots but for a larger river flow, but the same plant conditions. The river flow in this case, about 25 times the total plany flow. It is now seen from the isotherms plotted for the surface and for a depth of two feet, how a much larger river flow tends to moderate the excess temperature in the area of the plant. An added aspect in this particular model study, was a study of the sedimentation or bed load motion that occurred in the general vicinity of the plant and a prediction of the dredging requirements that would be necessary to maintain the intake.

The second study to be reviewed is that of the completely developed river and a thermal plant located on the reservoir. The flow in this reservoir is, to a large extent, controlled by the operation of these plants and by a pump storage plant, which uses the reservoir as the lower basin of its two basin system. The weekly cycle was found to vary with the predicted flow of the undeveloped river. Because of this schedule, the model has been required to operate on the weekly time schedule. The scales of the model are such that a weekly prototype time period consumes a model test time of roughly three hours and forty minutes. As indicated previously, in order to properly duplicate this time cycle and the flow patterns in it, at least two weekly cycles are run in succession, in order to obtain meaningful data. The temperature probes are spotted at the critical locations over the model, as well as in other areas that are considered important, and for basically three different elevations, one at the surface, and five feet below the surface and one ten feet below the surface There are 240 sensors taking data at a rate of better than every 50 seconds. The general arrangement of the model is shown in Figure 6. The supply lines to the various hydro-electric plants should be noted as well as the direction of the flow at each plant. The sump is necessary to supply the water at the required basic reservoir temperatures and the boiler and appropriate pipe lines provide heated water as required.

Figures 7, 8, 9, and 10 are isotherms of excess temperature at the reservoir surface and at a depth of ten feet for two times in the weekly cycle. Figures 7 and 8 show the isotherms for a Thursday afternoon situation. While Figures 9 and 10 show the isotherms for Sunday morning conditions. It is apparent from an inspection of these figures that the time of the day and week are significant to the temperature effects in specific sections of the model. The differences noted, in reviewing the isotherms, point up the influence of the hydro-electric station's flows on the reservoir. After a weekend when pumping has been most active at the pump storage plant, the excess temperatures are moving well upstream in the reservoir, due to the draw down and the draft of the pump storage plant and its location relatively far up the reservoir on the opposite bank from the thermal plant.

It is apparent that the type of outlet structure can influence the flow patterns of the warm water effluent from the plant. There is a possibility of varying the influence of the cooling water flow on the reservoir by the structural arrangement at the thermal plant outlet.

Figure 11 shows a general layout for one of the tidal models studied at Alden Research Laboratories. The location of the controls and water supply necessary to vary the water level and the flow into and out of the model at either end are shown. The sump, oil-fired water heater and pumping supply necessary to produce these tidal flows at any temperature between 40° and 90°F. are indicated. It should be pointed out that in most tidal studies the cooling water flows are small relative to the maximum flow. The cyclical variation of tidal flow with the smaller heated flow thus becomes the critical aspect in the study. In addition, to the permanent sensors, a portable probe with eight thermocouple sensors in a vertical array is provided to probe any area throughout the model. This probe provides information to develop the vertical profiles of temperature. The operation of the model, with the scales that were chosen, requires that the complete tidal cycle take about thirty minutes. Usually it is found necessary to operate the model for about four hours or about eight tide cycles before taking data for as many tidal cycles as required. The data being taken was always referenced to the tide phase so that any specific point or bit of data could be considered in its proper time sequence. Figures 12, 13 and 14 are plots of surface isotherms of the middle section of the model showing the results of structural changes to the outlet canal. Figure 12 is for the longest structure while the other two show the results of different amounts of shortening. These are all for the same phase of the tide. Additional data was developed for other tide phases and model arrangements.

The results presented in this report have been taken directly from the model studies and no attempt has been made to make any of the necessary adjustments to the prototype. Also, in all cases, the arrangements shown have been subject to further revision so that final conclusions can not be drawn from the data shown.

ACKNOWLEDGEMENT

The entire staff of the Alden Research Laboratories have participated in developing the techniques and results discussed in this paper. Much of the technical material used has been the work of Mr. A. G. Ferron while Professor L. J. Hooper and Mr. F. P. Colon have also reviewed the text.

SUMMARY

A number of river model studies have been undertaken at the Alden Research Laboratories to determine the influence of heated water effluent on bodies of water. The flow patterns developed from these model studies have been used to predict the flow patterns and temperature patterns in the prototype. This type of study, using similar techniques, has been applied to rivers, reservoirs and estuaries. Although it is difficult to obtain detailed data from the field after completion of projects, the results that have been obtained indicate good agreement with those of the model study. It is hoped that the future will see a further improvement in the modelling techniques and instrumentation and that the theoretical development will allow more complete analytical treatment of the problem. It is also apparent that more detailed data on accomplished projects are necessary to the whole process.

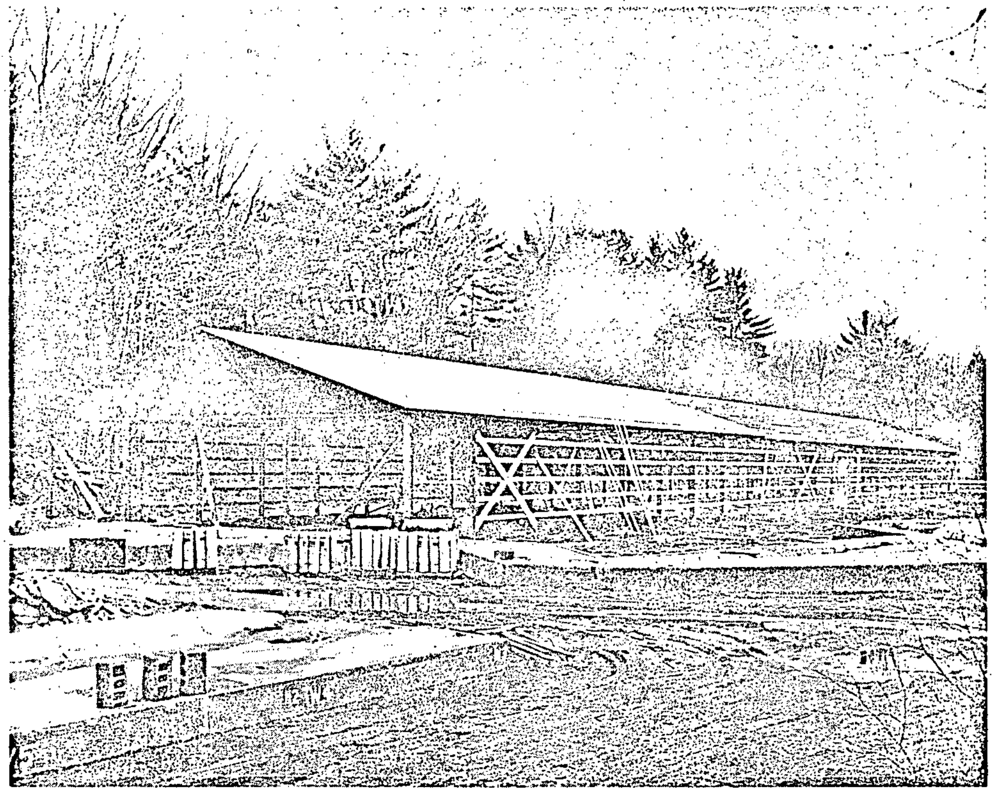


Photo 1

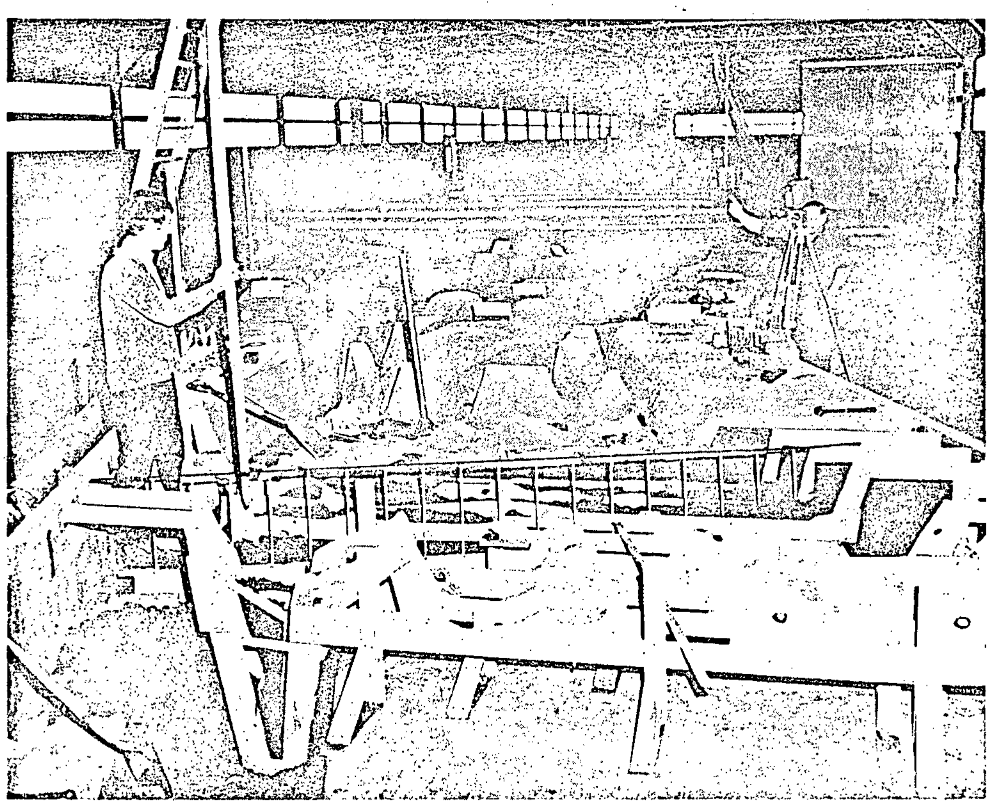


Photo 2

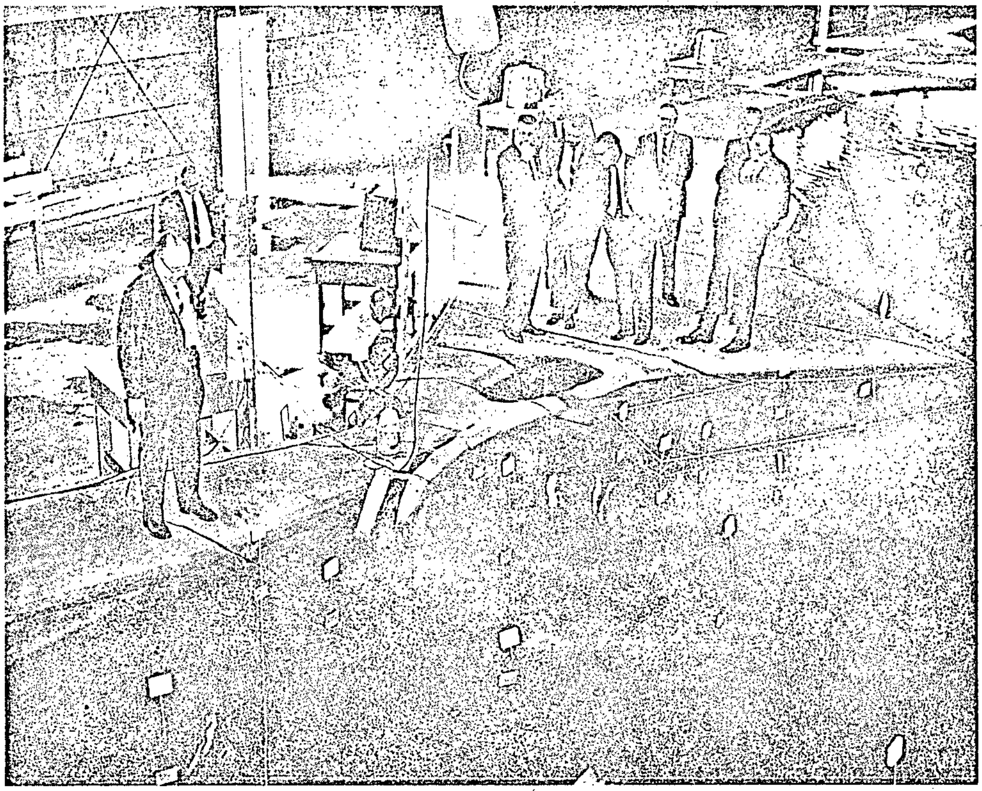
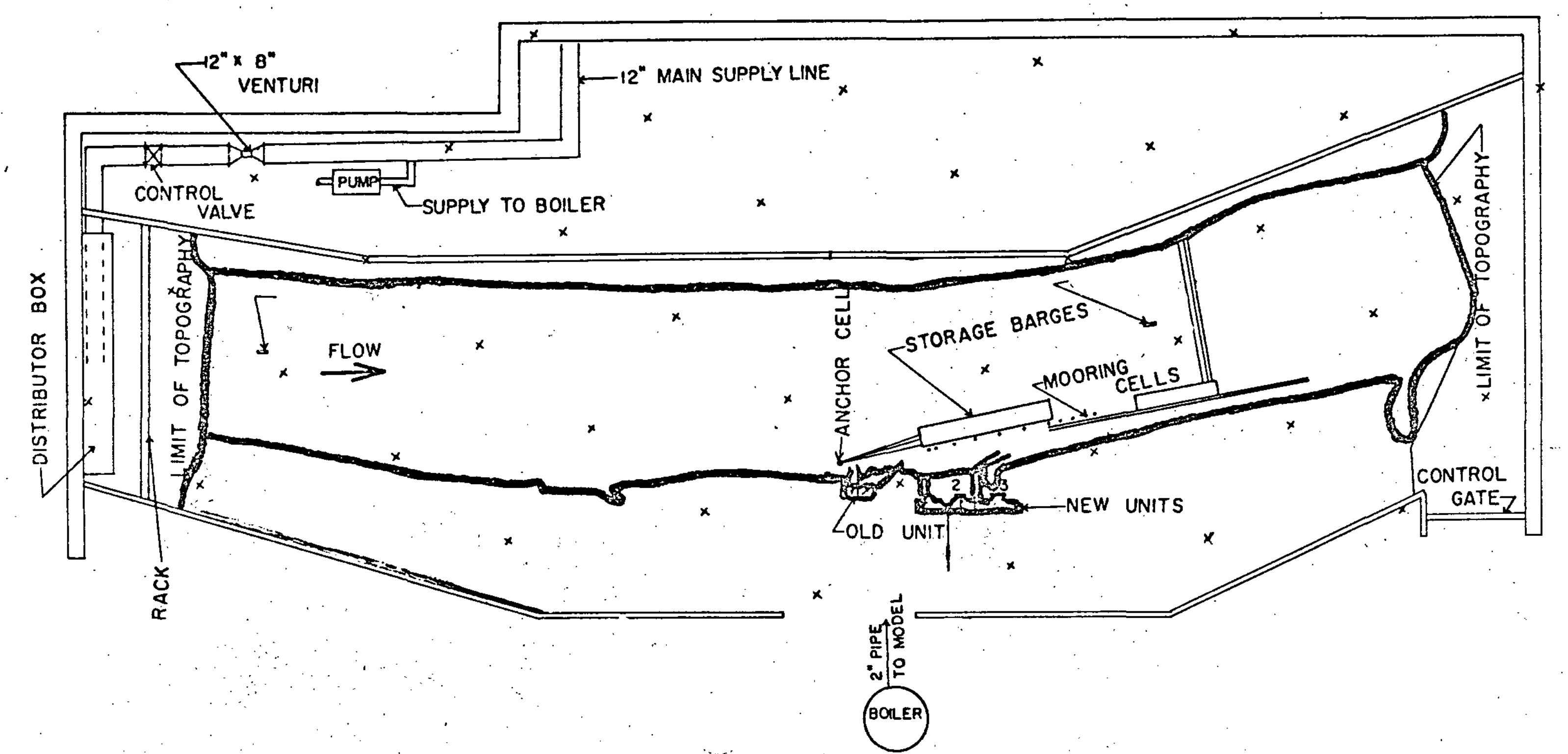


Photo 3



OVERALL MODEL LAYOUT

FIG. 1

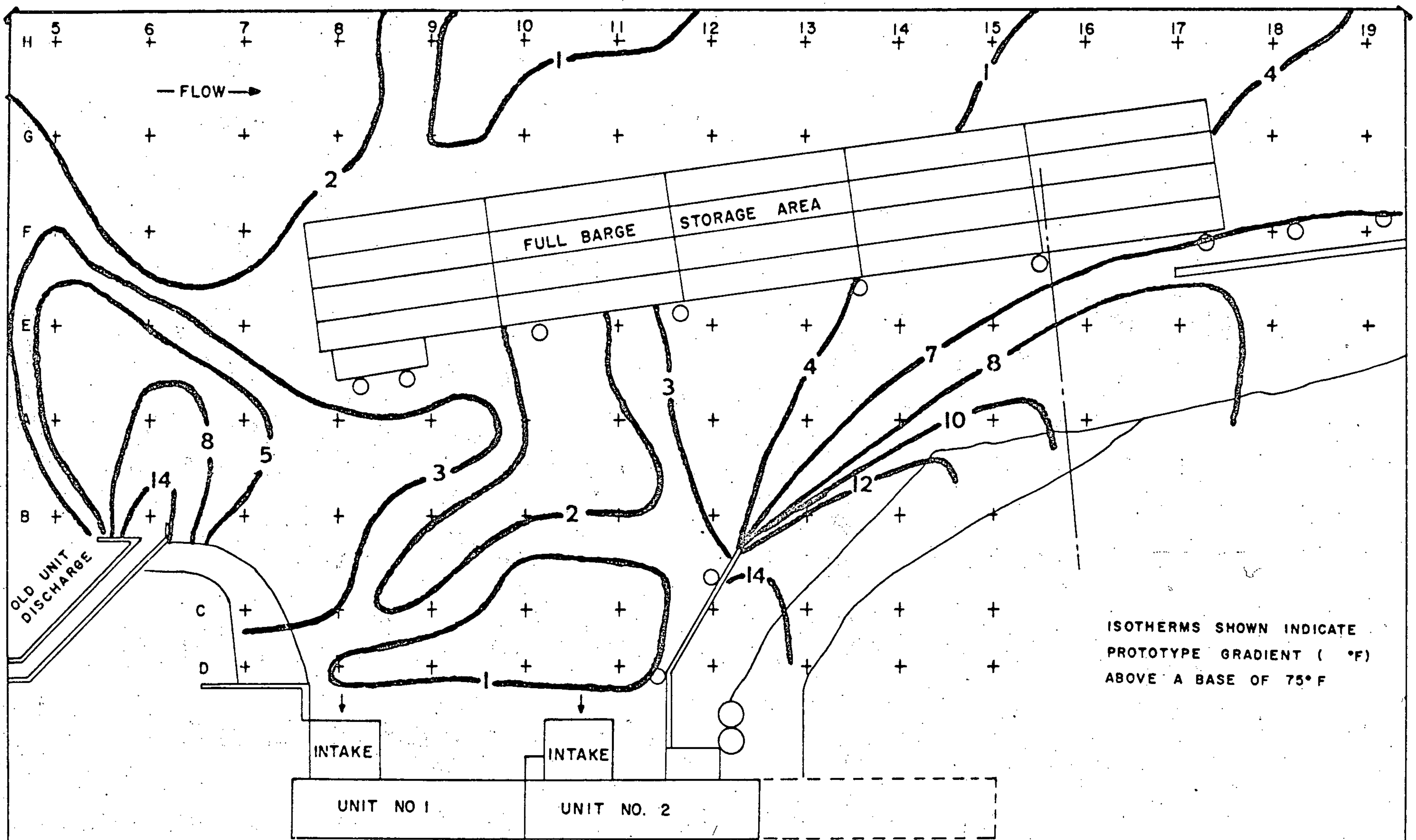
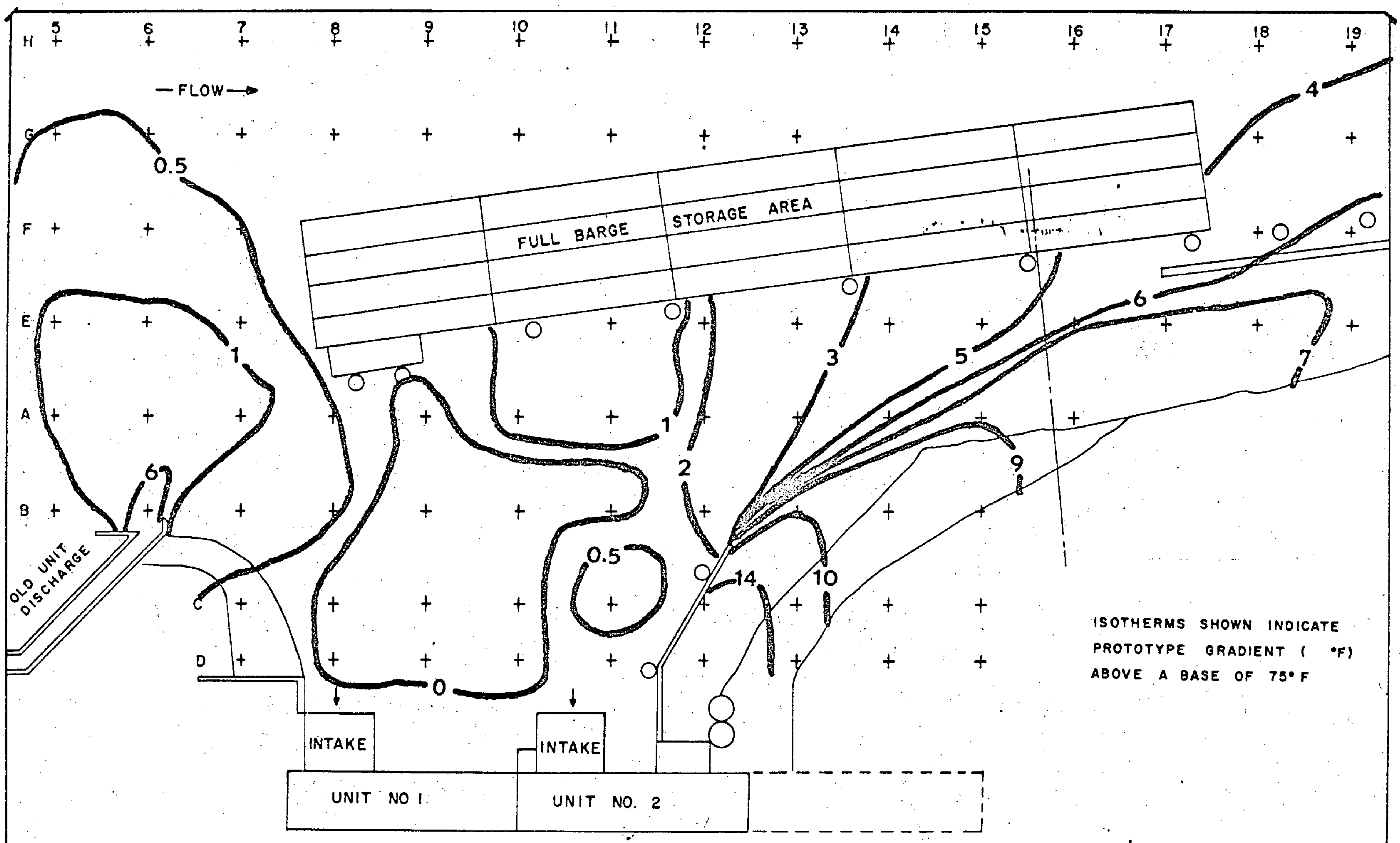
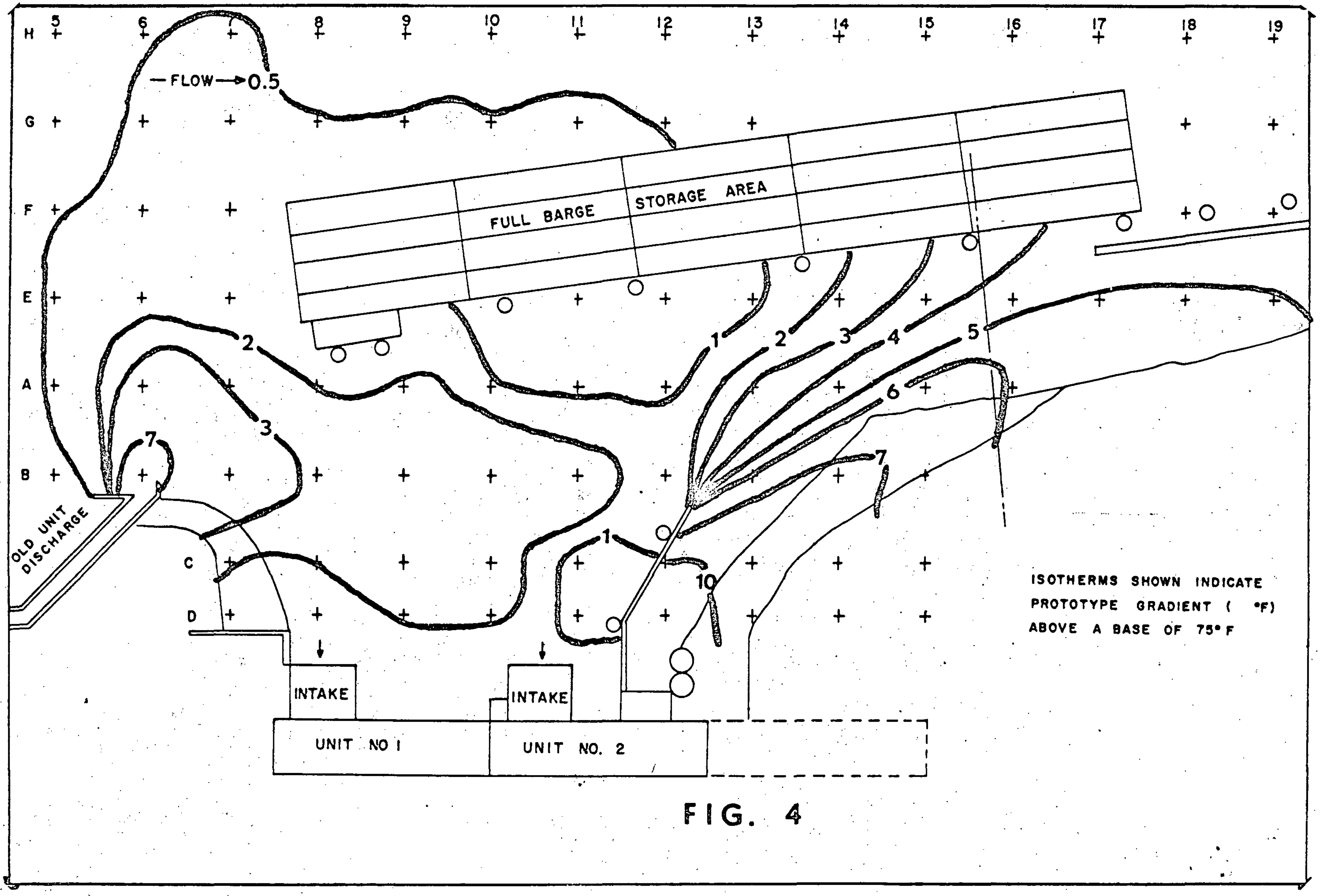

FLOW
FULL BARGE STORAGE AREA
OLD UNIT DISCHARGE
INTAKE
INTAKE
UNIT NO 1
UNIT NO. 2
ISOTHERMS SHOWN INDICATE PROTOTYPE GRADIENT (°F) ABOVE A BASE OF 75° F

FIG. 2



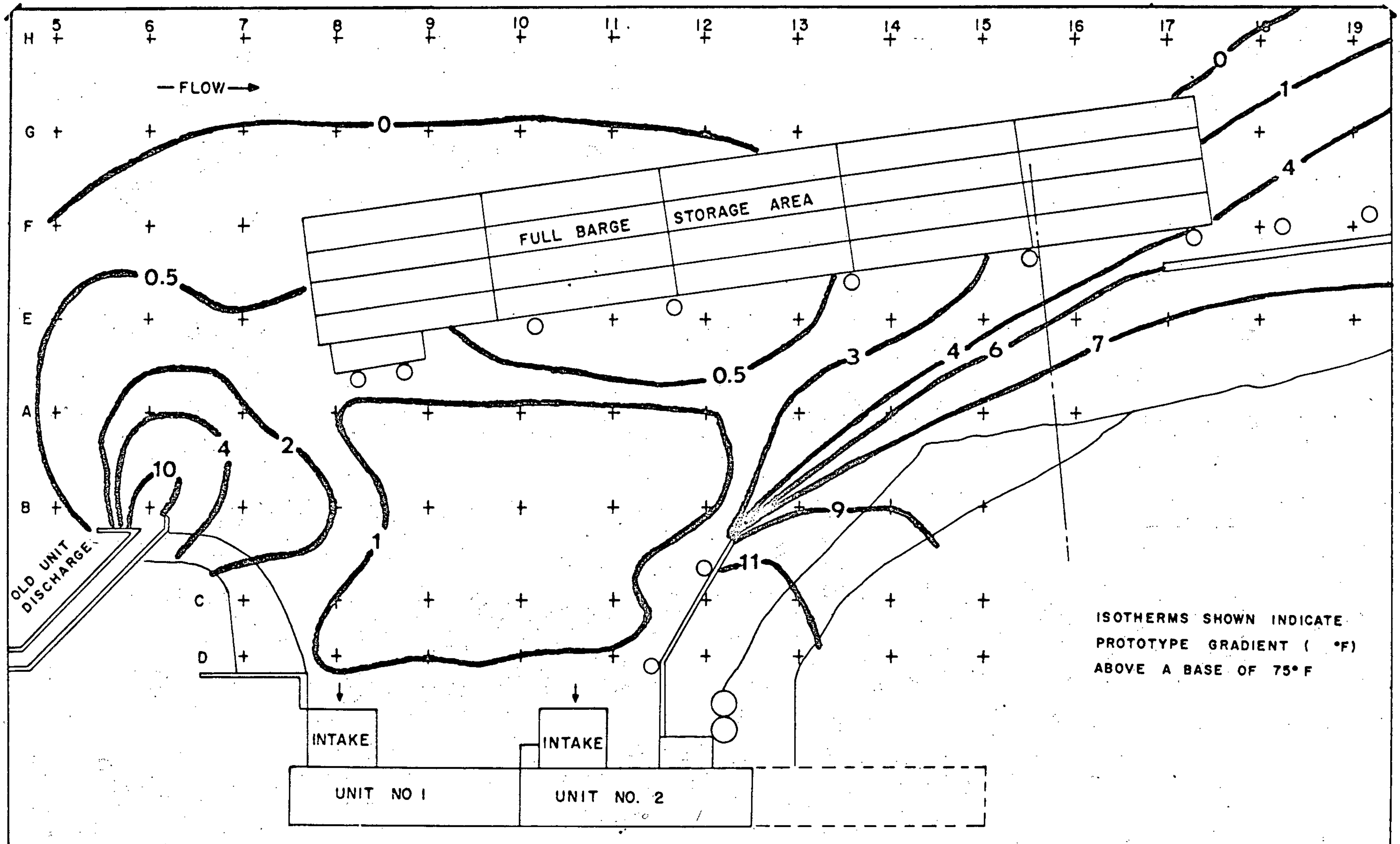
FLOW
FULL BARGE STORAGE AREA
OLD UNIT DISCHARGE
INTAKE
INTAKE
UNIT NO 1
UNIT NO. 2
ISOTHERMS SHOWN INDICATE PROTOTYPE GRADIENT (°F) ABOVE A BASE OF 75° F

FIG. 3



5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
H
G
F
E
A
B
C
D
FLOW
0.5
FULL BARGE STORAGE AREA
2
3
7
1
2
3
4
5
6
7
1
10
OLD UNIT DISCHARGE
INTAKE
INTAKE
UNIT NO 1
UNIT NO. 2
ISOTHERMS SHOWN INDICATE PROTOTYPE GRADIENT (°F) ABOVE A BASE OF 75° F

FIG. 4



5
6
7
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9
10
11
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14
15
16
17
18
19
H
G
F
E
A
B
C
D
— FLOW —
0
1
4
0.5
FULL BARGE STORAGE AREA
0.5
3
4
6
7
2
4
10
1
9
11
OLD UNIT DISCHARGE
INTAKE
INTAKE
UNIT NO 1
UNIT NO. 2
ISOTHERMS SHOWN INDICATE
PROTOTYPE GRADIENT (°F)
ABOVE A BASE OF 75° F

FIG. 5

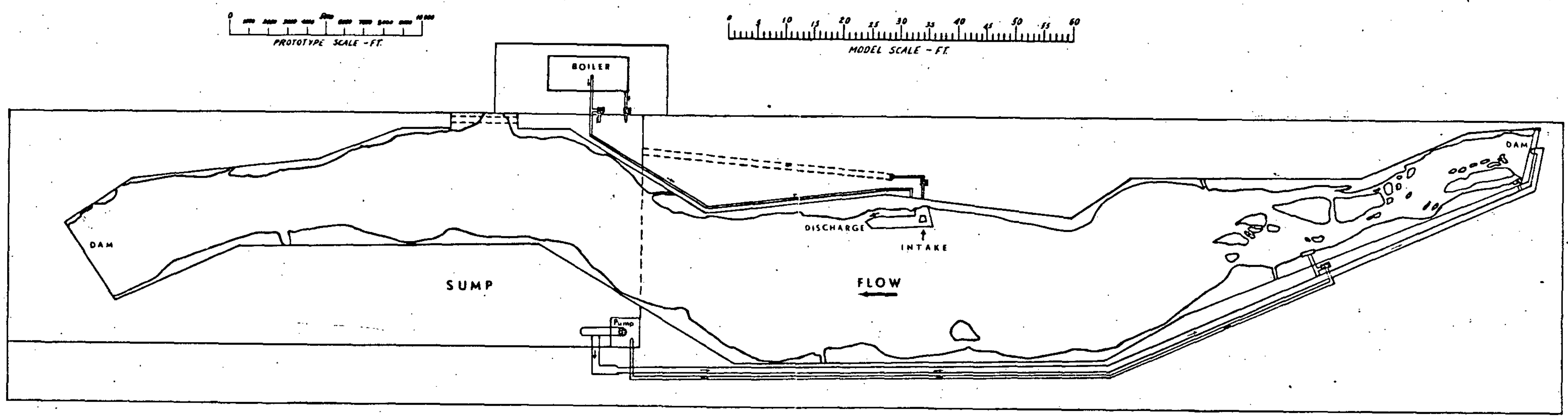
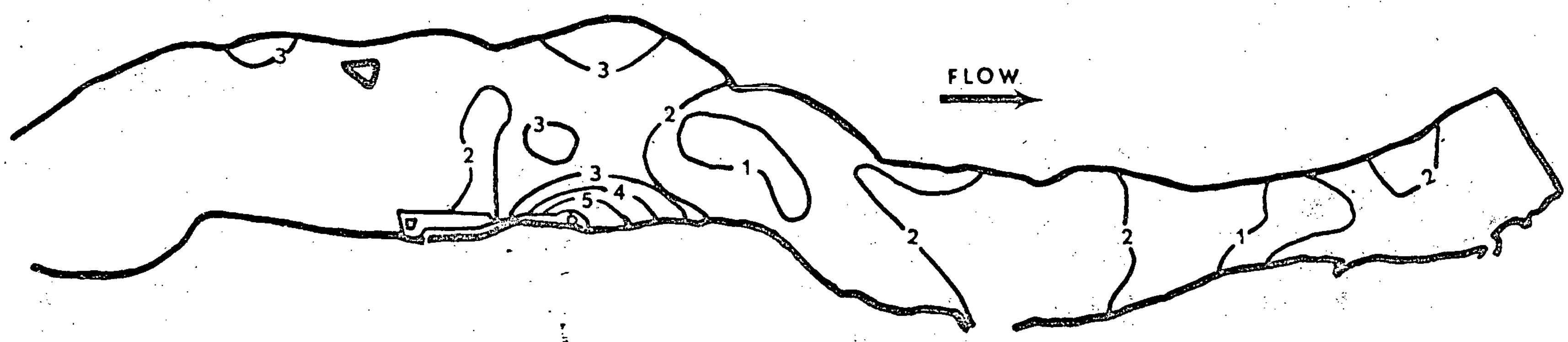

PROTOTYPE SCALE - FT.
0
10
20
25
30
35
40
45
50
55
60
MODEL SCALE - FT.
BOILER
DAM
DAM
SUMP
FLOW
DISCHARGE
INTAKE
PUMP

FIG. 6

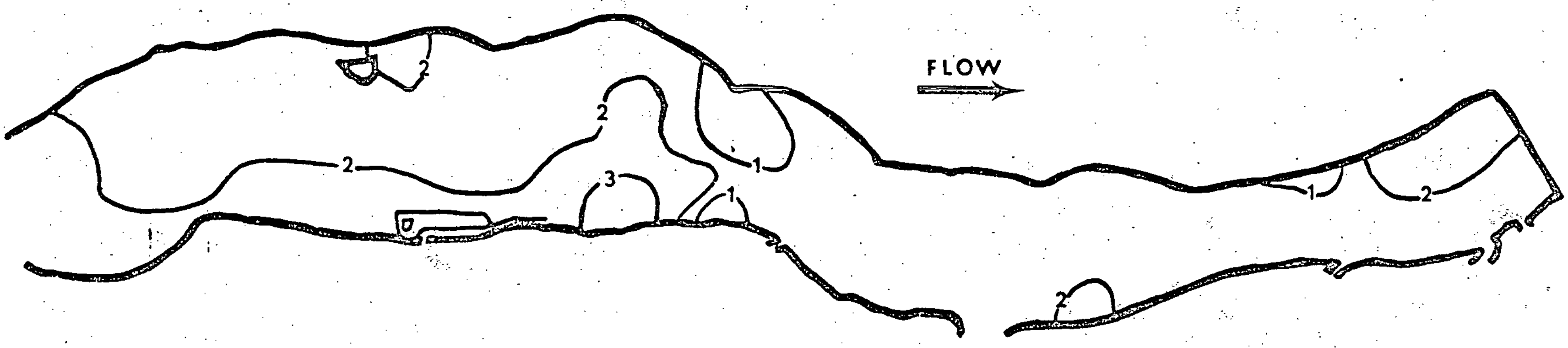


THURSDAY 6 P.M.

SURFACE

JET DISCHARGE		HYDRO PLANT FLOWS	
NUCLEAR PLANT FLOW	3350 cfs	PUMP STORAGE	0 cfs
NUCLEAR PLANT TEMP. RISE	8° F	DOWNSTREAM	12,770 cfs
RIVER FLOW	5000 cfs	UPSTREAM	8320 cfs

FIG. 7



THURSDAY 6 P.M.

10 FT. DEPTH

JET DISCHARGE		HYDRO PLANT FLOWS		
NUCLEAR PLANT FLOW	3350 cfs	PUMP STORAGE	0	cfs
NUCLEAR PLANT TEMP. RISE	8° F	DOWNSTREAM	12,770	cfs
RIVER FLOW	5000 cfs	UPSTREAM	8320	cfs

FIG. 8

SUNDAY 6 A.M.

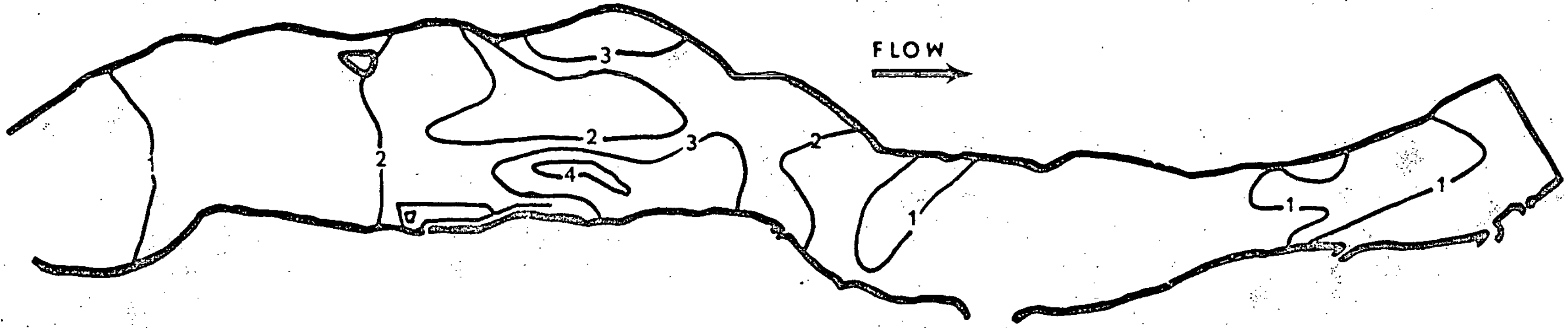
SURFACE

JET DISCHARGE

NUCLEAR PLANT FLOW	3350 cfs	PUMP STORAGE	17,180 cfs P
NUCLEAR PLANT TEMP. RISE	8° F	DOWNSTREAM	0 cfs
RIVER FLOW	5000 cfs	UPSTREAM	0 cfs

HYDRO PLANT FLOWS

FIG. 9



SUNDAY 6 A.M.

10 FT. DEPTH

JET DISCHARGE		HYDRO PLANT FLOWS	
NUCLEAR PLANT FLOW	3350 cfs	PUMP STORAGE	17,180 cfs P
NUCLEAR PLANT TEMP. RISE	8° F	DOWNSTREAM	0 cfs
RIVER FLOW	5000 cfs	UPSTREAM	0 cfs

FIG. 10

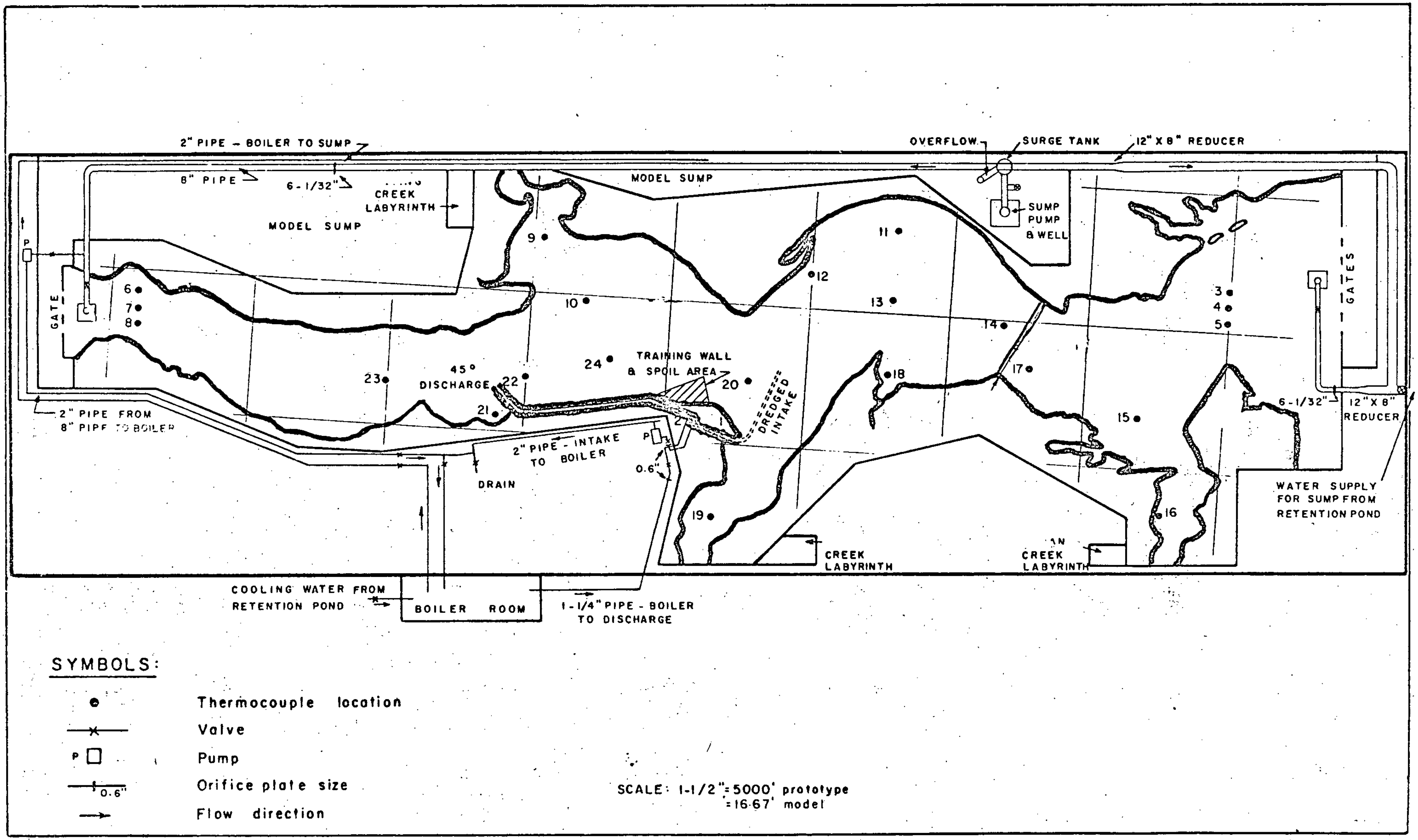

2" PIPE – BOILER TO SUMP
8" PIPE
6-1/32"
CREEK
LABYRINTH
MODEL SUMP
MODEL SUMP
OVERFLOW
SURGE TANK
12" X 8" REDUCER
SUMP
PUMP
& WELL
GATE
GATES
P
6
7
8
9
10
11
12
13
14
3
4
5
TRAINING WALL
& SPOIL AREA
24
45°
DISCHARGE
22
23
21
20
DREDGED
INTAKE
18
17
15
16
19
2" PIPE FROM
8" PIPE TO BOILER
2" PIPE – INTAKE
TO BOILER
DRAIN
0.6"
6-1/32"
12" X 8"
REDUCER
WATER SUPPLY
FOR SUMP FROM
RETENTION POND
CREEK
LABYRINTH
CREEK
LABYRINTH
COOLING WATER FROM
RETENTION POND
BOILER ROOM
1-1/4" PIPE - BOILER
TO DISCHARGE
SYMBOLS:
Thermocouple location
Valve
Pump
Orifice plate size
0.6"
Flow direction
SCALE: 1-1/2" = 5000' prototype
= 16.67' model

FIG. 11

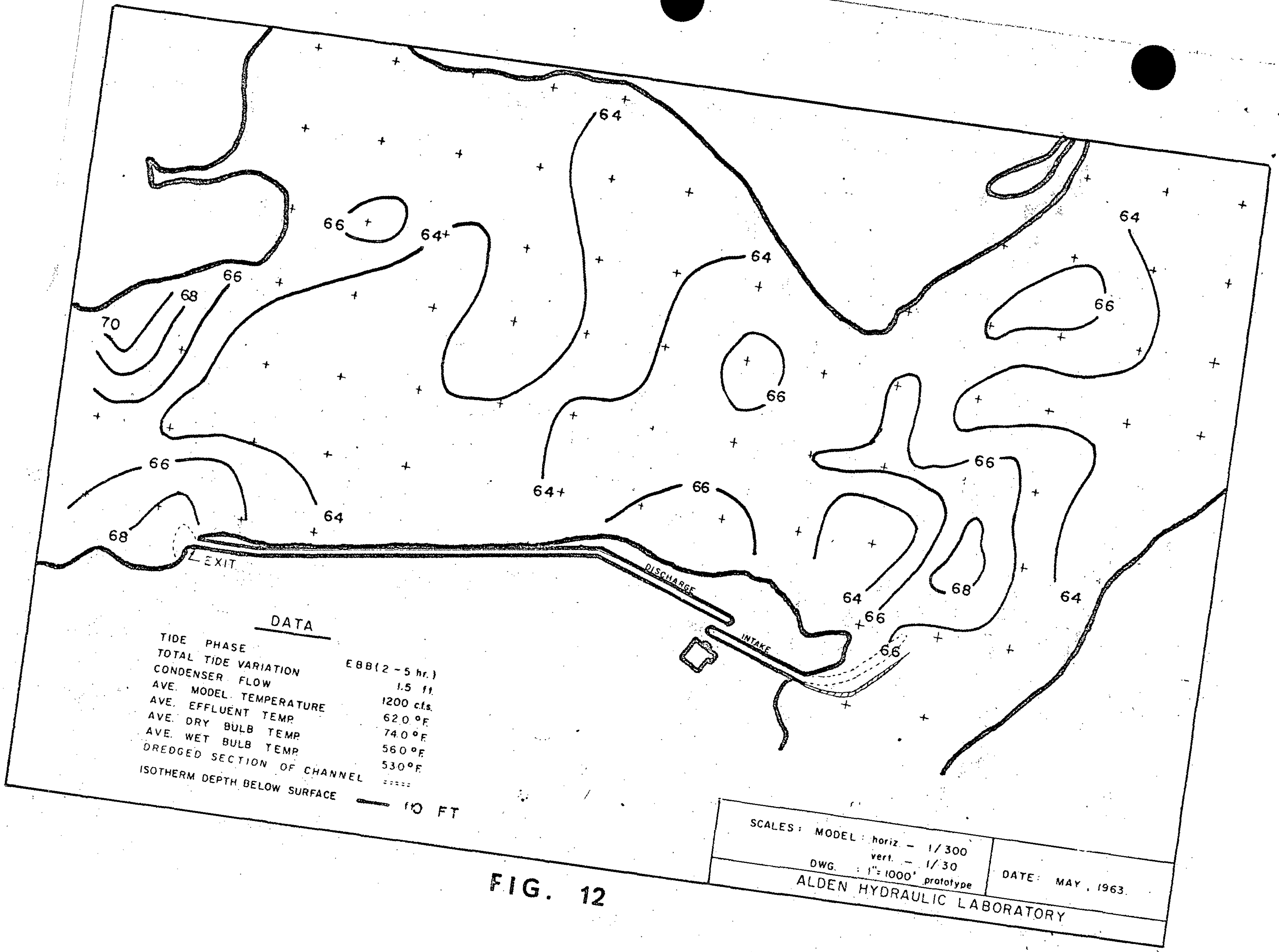
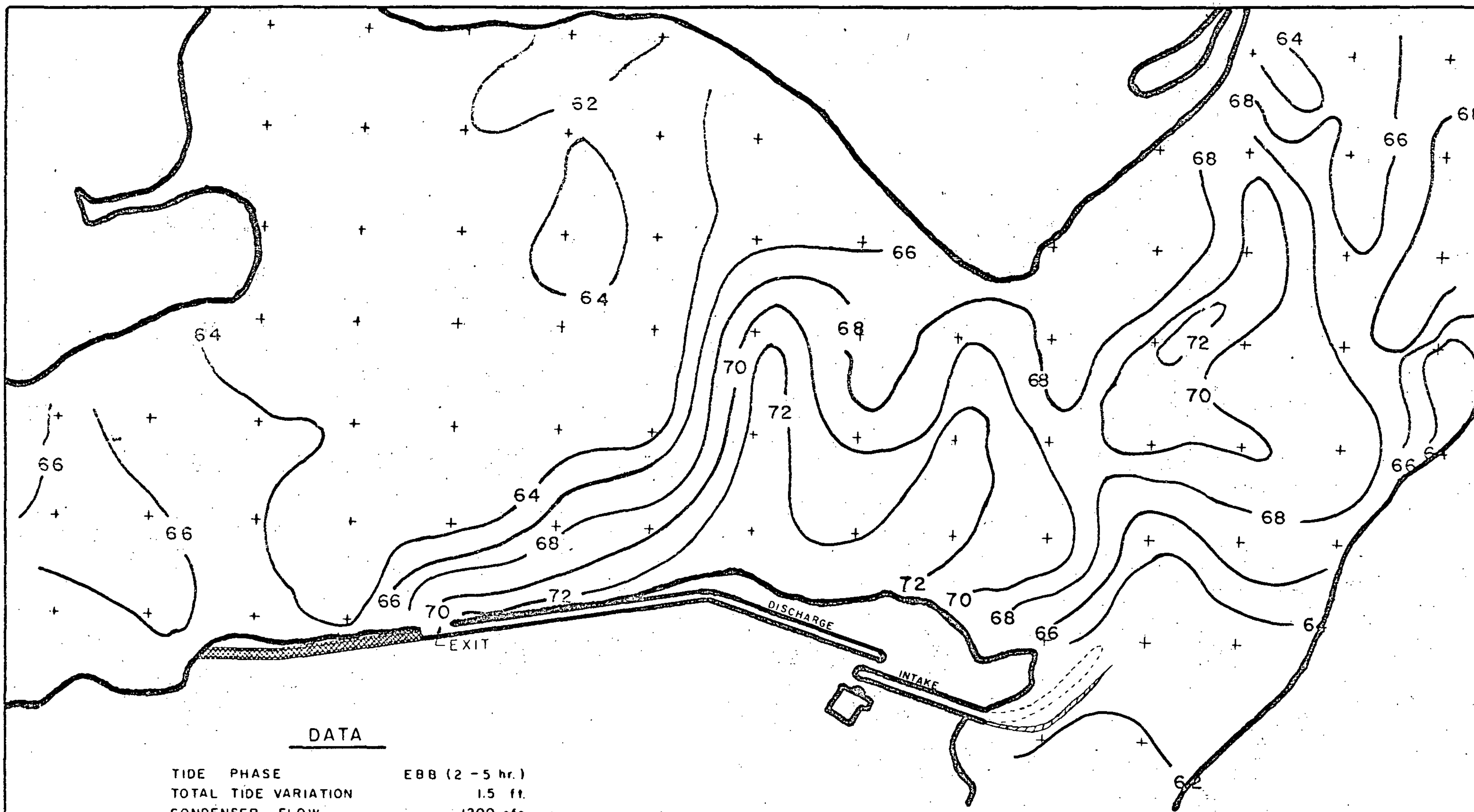

70
68
66
64
EXIT
DISCHARGE
INTAKE
DATA
TIDE PHASE EBB (2 - 5 hr.)
TOTAL TIDE VARIATION 1.5 ft.
CONDENSER FLOW 1200 c.f.s.
AVE. MODEL TEMPERATURE 62.0 °F
AVE. EFFLUENT TEMP. 74.0 °F
AVE. DRY BULB TEMP. 56.0 °F
AVE. WET BULB TEMP. 53.0 °F
DREDGED SECTION OF CHANNEL
ISOTHERM DEPTH BELOW SURFACE 10 FT
SCALES: MODEL: horiz. - 1/300
vert. - 1/30
DWG. : 1" = 1000' prototype
DATE: MAY, 1963.
ALDEN HYDRAULIC LABORATORY

FIG. 12



DATA

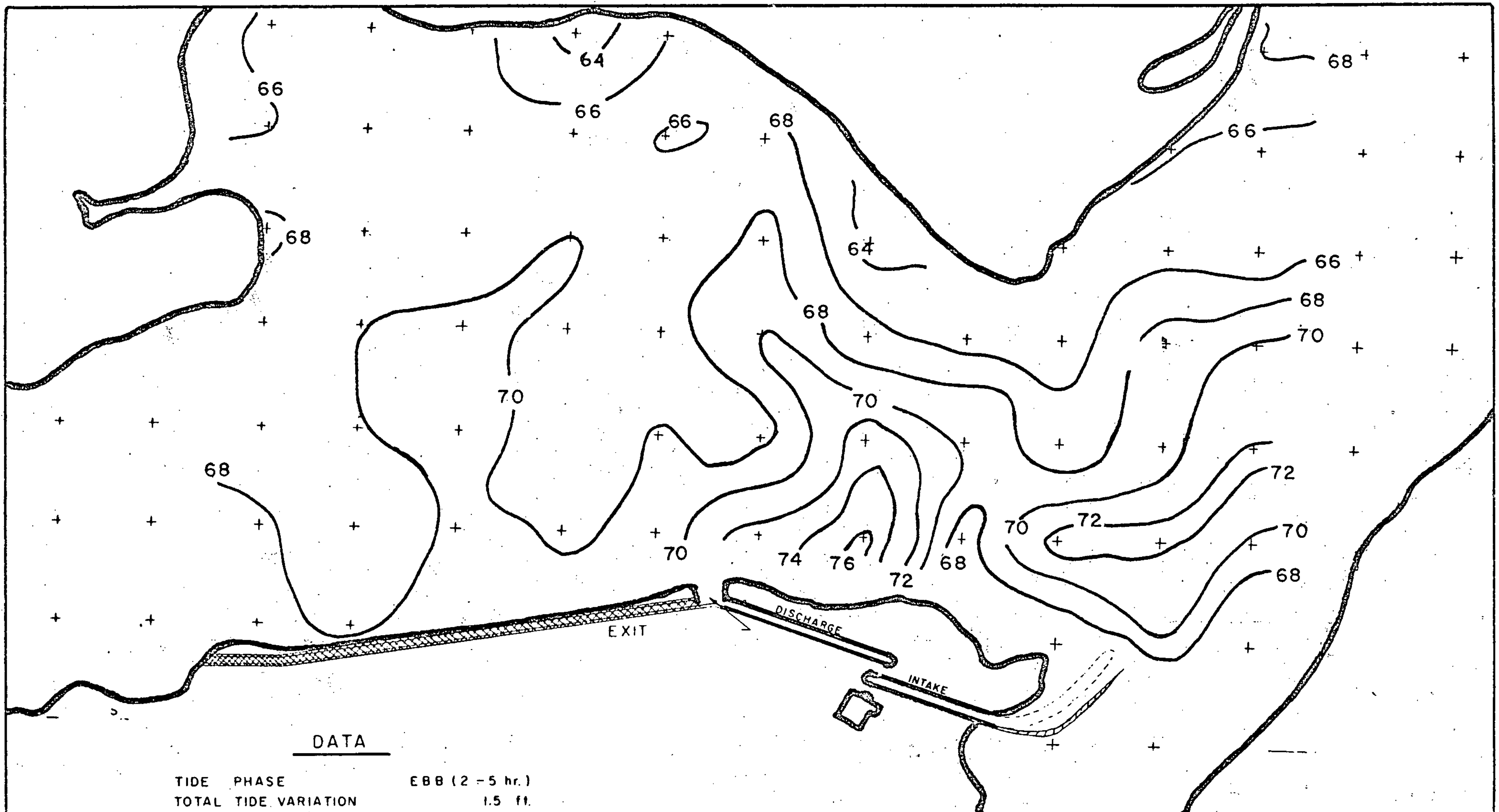
TIDE PHASE	EBB (2 - 5 hr.)
TOTAL TIDE VARIATION	1.5 ft.
CONDENSER FLOW	1200 c.f.s.
AVE. MODEL TEMPERATURE	62.0 °F.
AVE. EFFLUENT TEMP.	75.1 °F.
AVE. DRY BULB TEMP.	55.5 °F.
AVE. WET BULB TEMP.	53.2 °F.
DREDGED SECTION OF CHANNEL	:::::
ISOTHERM DEPTH BELOW SURFACE	0 FT ft.

SCALES: MODEL: horiz. – 1/300
vert. – 1/30
DWG. : 1" = 1000' prototype

DATE: MAY, 1963.

ALDEN HYDRAULIC LABORATORY

FIG. 13



DATA

TIDE PHASE	EBB (2 - 5 hr.)
TOTAL TIDE VARIATION	1.5 ft.
CONDENSER FLOW	1200 c.f.s.
AVE. MODEL TEMPERATURE	64.0 °F.
AVE. EFFLUENT TEMP.	76.4 °F.
AVE. DRY BULB TEMP.	61.0 °F.
AVE. WET BULB TEMP.	57.8 °F.
DREDGED SECTION OF CHANNEL ____ ::::	0 FT
ISOTHERM DEPTH BELOW SURFACE	ft.

SCALES: MODEL: horiz - 1/300 vert. - 1/30 DWG. : 1" = 1000' prototype	DATE: MAY, 1963.
ALDEN HYDRAULIC LABORATORY	

FIG. 14

MODEL STUDIES OF RECIRCULATION IN POWER PLANTS

L. J. Hooper, Director
Alden Hydraulic Laboratory
Worcester Polytechnic Institute
Worcester, Massachusetts

Presented at

WASHINGTON STATE UNIVERSITY, PULLMAN, WASHINGTON

October 29-30, 1959

MODEL STUDIES OF RECIRCULATION IN POWER PLANTS

L. J. Hooper, Director
Alden Hydraulic Laboratory
Worcester Polytechnic Institute
Worcester, Massachusetts

The factors to be taken into account in the design of the model for this type of work have been described in a previous paper. In brief, the effects may be summarized by pointing out that inasmuch as the problem is associated with low flow in the river, it follows that the depth and velocity in the field will both probably be small. These facts lead to large physical models in order to keep the flow conditions in the model above laminar. This naturally leads further to distorted models for economic reasons. We have always used heated water in our model studies to provide the effect of the heating by condensers in the power plant since this duplicated the density conditions as well as all of the other properties of the water. Furthermore, it allows the analysis of the performance of the model to be made by the heat balance.

Model experience

It is proposed in the following paper to describe some of the difficulties that have been experienced with model testing of re-circulation of condenser cooling water in power plants and to discuss further some of the types of results that can be obtained from such studies.

The greatest problem that was encountered in this type of model study is the establishing of standard conditions for test or even maintaining control of all of the conditions that affect the heat balance in the model. All models of this type at the Alden Hydraulic Laboratory have been constructed outdoors because of their size. It was quickly found that the sun and the wind both had a tremendous effect on the heat radiated into and out of the model. When time is not pressing and the work can be done in the summertine, it is usually best to wait until late in the afternoon when the sun is low and there is no heat coming in; the breeze that has stirred during the day has died away and the evening flow of air has not commenced. This naturally means that there will be a large number of days when the model will be fired up but the weather conditions will not become satisfactory and the model will be shut down to wait for a favorable situation.

The best possible solution is a model located indoors or completely covered in. This may add considerable to the expense, but it is definitely desirable to provide for covering in the model. It not only makes the work go faster, but it also provides better control so that the results are apt to be more accurate.

Where work must continue into colder weather with an outdoor model, it has been found desirable to provide two boilers so that the river water could be heated as well as the circulating water. Although some study was given to heating both the river water and the condenser flow, with one boiler, it seemed to produce a very complex arrangement of controls with a good possibility of interaction. For this reason, the simpler method of using two boilers was adopted. In the first case, there was found a condemned 100 hp boiler which was vented to the atmosphere so that it worked under no steam pressure. For the second boiler, a simple insulated box with expanded metal tubes and an oil burner was used to provide the necessary heating effect. This made it possible to control the temperature coming into the model as well as the temperature rise provided by the condensers and made the operation of the model considerably simpler.

Most of these models for studying re-circulation are difficult to operate because of the pondage effects. Naturally the bed of the river is large compared to the flow and the very low velocities make control difficult. Work with these models have also indicated that it is very desirable to take much more temperature data than one would at first think necessary. It is obvious that the river temperature, the condenser inlet temperature, the condenser discharge temperature and the river discharge temperature will all be necessary in making the heat balance. It will quickly be found in experience that many more readings can be taken of the surface temperature in order to arrive at an average figure of surface temperature of the pool surface to be used in computing the heat transfer coefficient "U". Further, readings may also be desirable at various spots along the bottom so that the temperature profile can also be estimated.

On one of the model studies, there was made available a multipoint recording resistance thermometer which took temperatures in twelve different locations in succession. The calibration of the instrument was modified in order to make the temperature range of the model extend across the full scale of the instrument. This was found very desirable in controlling the model, inasmuch as variations in flow and temperature became apparent more quickly and it was found valuable thereafter in providing information that was needed in the analysis of the results.

TEST RESULTS

All of these re-circulating water studies have the effects of density and consequent stratification to a greater or less degree. Unfortunately, the density effect is not the only one acting, but there are also the velocity effects which can modify the pattern of flow considerably. It is obvious that where there is a deep pool the density effects will predominate, but where the depths are shallow, the flow and velocity effects may be the dominant factor in establishing the pattern.

One of the interesting facts found on an early model was the pattern of flow at the intake to a proposed steam power plant. In this case, the tests were being made with approximately 50% re-circulation and there was a pool, although quite shallow. As will be noted in Figure 1, the relatively cool water coming from upstream, was on the left bank of the river and the re-circulating water returning to the intake was also on the left and convex bank of the river. Whereas one might have expected that each of these flow would have gone into the nearest intakes, the reverse was found to be true. As will be seen in Figure 1, the hot water flowed beyond the center line of the intake and entered the upstream entrance, whereas the cold water flowed underneath and beyond the centerline of the intake and for the most part, entered the downstream intake opening. The temperature of the incoming water of each section of the intake was recorded throughout the tests and differences between the two intakes as great as 10 were found. It was not known whether this would constitute a problem in the operation of the plant, so that steps were taken to mix this flow should it be necessary in the field. Although a means was found of doing this, it proved to be more difficult than anticipated. The corrective work consisted of a wall extending out into the stream and this was not put in until actual experience with the plant indicated its need. So far as is known, no trouble has been experienced with the variation in temperature between the cooling water to the two units and the wall to provide mixing has not been installed.

Another effect that may be a little surprising is the matter of discharging the discharge, where possible, parallel to a bank of the river. The velocity along the bank will present a lower pressure than is present in the main stream, so that the moving stream will be held on contact with the bank until its kinetic energy is dissipated (Figure 2). Reference to Figure 3 will show the relative increase in cooling area of the pool at a given river flow that could be secured by taking advantage of this velocity effect. Naturally the effect is easier to maintain on the concave bank of the stream than on the convex, but it will work in both cases.

An interesting indication of the interplay between velocity and density effects, is seen in Figure 4, which shows the velocity patterns at river discharges of 1500 and 600 cfs, with a condenser re-circulating flow of 800 cfs. This pattern was found in a river where the depths were varying between a minimum of approximately 5 feet to a maximum of about 15 feet, so that the pool effects were becoming more prominent as the river discharge decreased. It will be noted that at 1500 cfs the surface water flow pattern is showing signs of instability with areas where the water is apparently sinking or stagnant rather than flowing. On the other hand, the bottom flow for this condition is completely definite and stable as is shown by dye indications. At 600 cfs, however, the reverse is true. It will be seen by this time that the surface flow is completely stable, whereas the bottom flow has now the unstable characteristics that were seen before in the surface flow. Needless to say, when a model is being operated in a transition range of this sort, it is much more difficult to secure consistent heat data.

As an indication of the type of result that is normally found from this study, there is included the test result of one of the model studies, Figure 4. This is for a river where there is a considerable pool effect at the low river discharges. It will be seen that the model indicates a temperature rise of 16 degrees at the intake due to re-circulation when the river flow drops to 500 cfs. The condenser flow for this condition was taken at 800 cfs, with a 14 degrees Fahrenheit rise. At 800 cfs the temperature rise at the intake is still 9.3 degrees, and even at 1500 cfs, which is nearly twice the cooling water flow to the condensers, it is found that there is re-circulation causing a temperature rise of 3.7 degrees.

From this model curve, there is predicted immediately below it, another curve which indicates the expected temperature rise in the field. Experience has indicated that the minimum heat transfer obtained in the model for conditions of little heat transfer to the air, is 3 BTU per square foot per degree F. per hour. Experience in the field, however, indicates a minimum value of 6 or 7 BTU per degree, per square foot, per hour. The predicted curve, therefore, reflects the difference of 3 and 6 in the heat transfer coefficient. Beyond this, the use of a distorted model results in a smaller area, in proportion to the volume of water, than will be found in the field. Even further, in this particular model, more area of the pool will be affected by higher temperatures than was represented in the model. In predicting the field result, therefore, a heat balance calculation was made at several discharges by a method of arithmetic integration to evaluate properly the increased area and the increased heat transfer coefficient that will be found in the field. As shown in the curve, this amounted to 4.5 degrees at the low flow. The modification of temperature was only 1.4 degrees at a discharge of 1500 cfs. In the latter case, the increased velocity of the stream prevented the warm water from traveling very far upstream so that the modification of area as between the model and the field was very small.

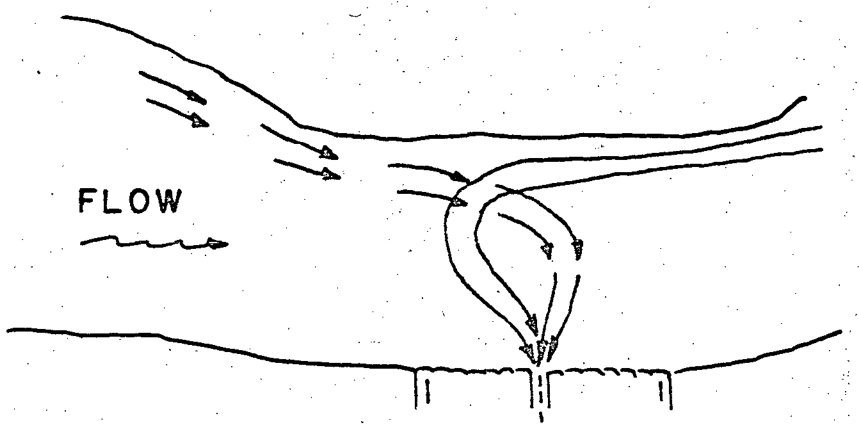
There is an interesting possibility in the re-circulation problem of using a heat storage effect of a pool to tide over the period of worst operating conditions during the day. Briefly the highest daily temperature comes between 12 and 6 o'clock in the afternoon; the humidity and a lack of wind are apt to go along with this high temperature as it is the maximum peak load due to air condition. On the other hand, after 6 o'clock the temperatures drop as a rule, and during the night a modest breeze may spring up to give a much better operating condition. Obviously, if the pool is large enough, there can be an averaging effect between the night operating conditions and those found during the worst part of the day. Unfortunately, in none of the models that we have tested, has this pondage effect been adequate to be of any economic interest.

The possibility of reducing load and dropping the pool temperature was studied on one of the projects. It was assumed that reduced load on the plant would be maintained until noontime and then full load would be carried from noon until 6 o'clock. In this study, it was found that only four degree-hours of storage could be secured by operating the plant at 50% load for six hours in advance of the desired maximum load condition. The re-circulating time in the pool was three hours and the study showed again that most of the benefit obtainable was secured in one re-circulating period.

However, where a steam plant is located on a deep pool and where density stratification is possible, it should be entirely feasible to secure considerable benefit from storage effects.

There is one further item that is shown from the studies made at the Alden Hydraulic Laboratory, concerning the re-circulating problem of a steam power plant located on a river. This is the fact that the power plant should preferably be located on the outside or concave bank of the bend. In the first place, this will be effective in bringing the deepest water to the intake of the power plant and at the same time minimizing any trouble that may occur from silting. As the depth of the pool increases, the location on a concave bank is still important since to secure the maximum benefit of stratification, the intake must be located as deep as possible and with very low velocity of inflow if the stratification is not to be disturbed.

In conclusion, it is felt that some of the results found from tests indicate that the model test of a steam power plant to determine the factors of temperature, re-circulation, time, silting and stratification at steam power plant inlets may well be of value in indicating the design of such intakes. With the increasing size of steam power plants, the problem of securing adequate supplies of cooling water is becoming more serious. In some locations, there is a further complication that States are beginning to talk of considering heat in a stream under the same category as acid, and other industrial wastes; in other words, an undesirable pollution. In one instance, it is known that a committee on legislation is toying with the idea of considering that any single steam power plant must not raise the total temperature of the river water by more than 2 degrees. It is obvious that if such thinking is expressed in the regulation of steam power plants, there are many plants now in operation which will find themselves in difficulty during severe warm weather operating conditions.

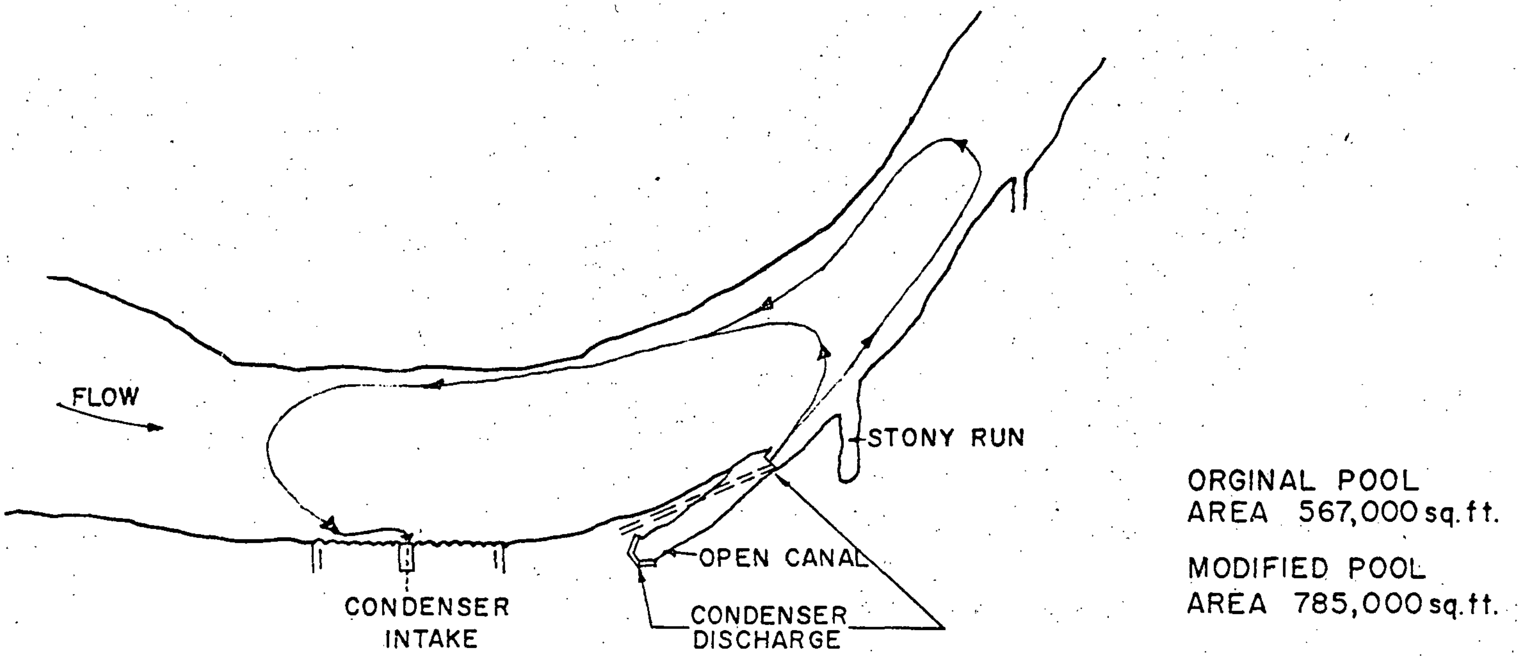


PATTERN OF FLOW AT INTAKE
WITH 50% RECIRCULATION

ALDEN HYDRAULIC LABORATORY
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASS.

Fig. 1

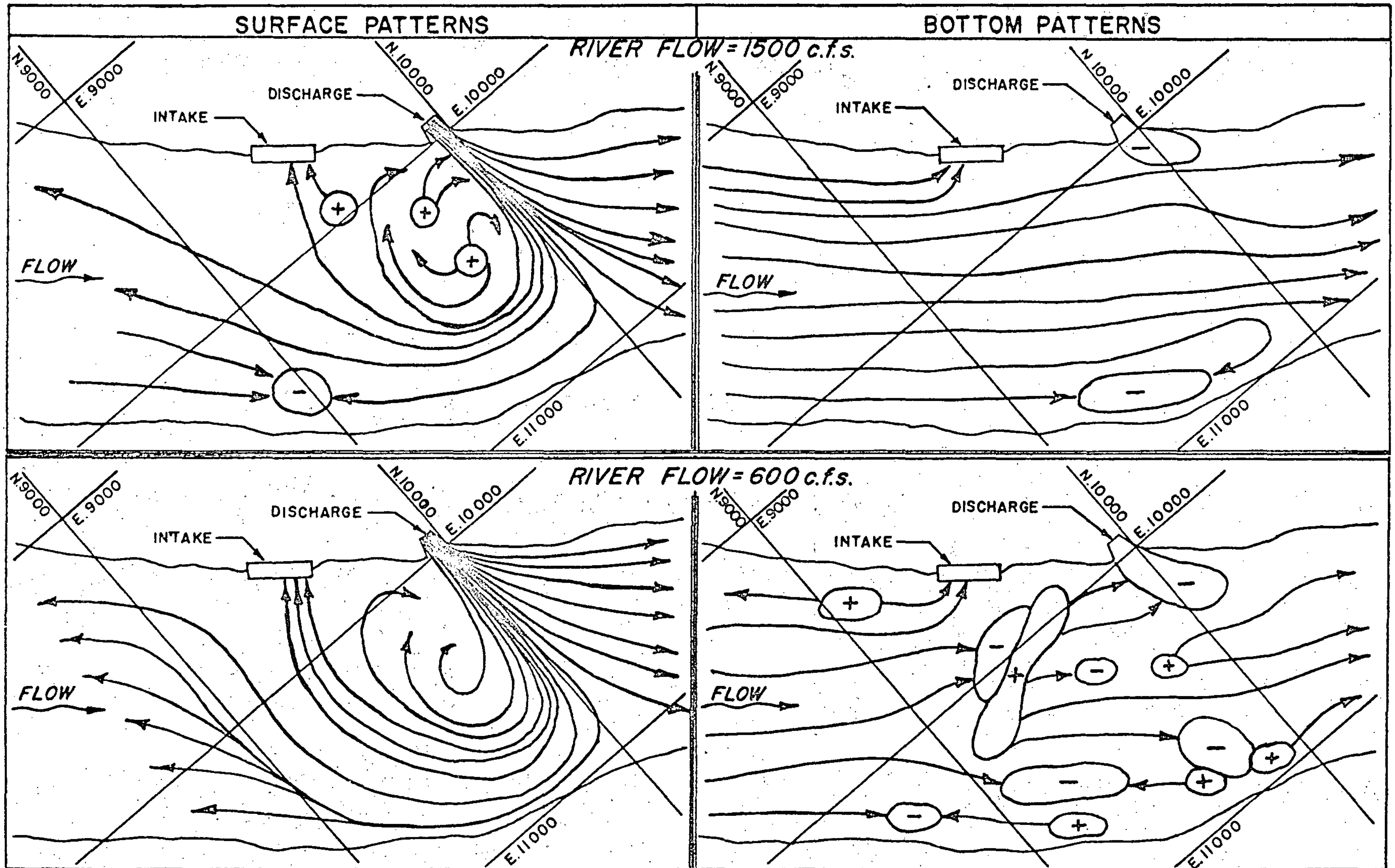
FIGURE 2. Effect of Condenser Flow Directed Along River Bank.



COMPARISION OF COOLING POOL AREAS

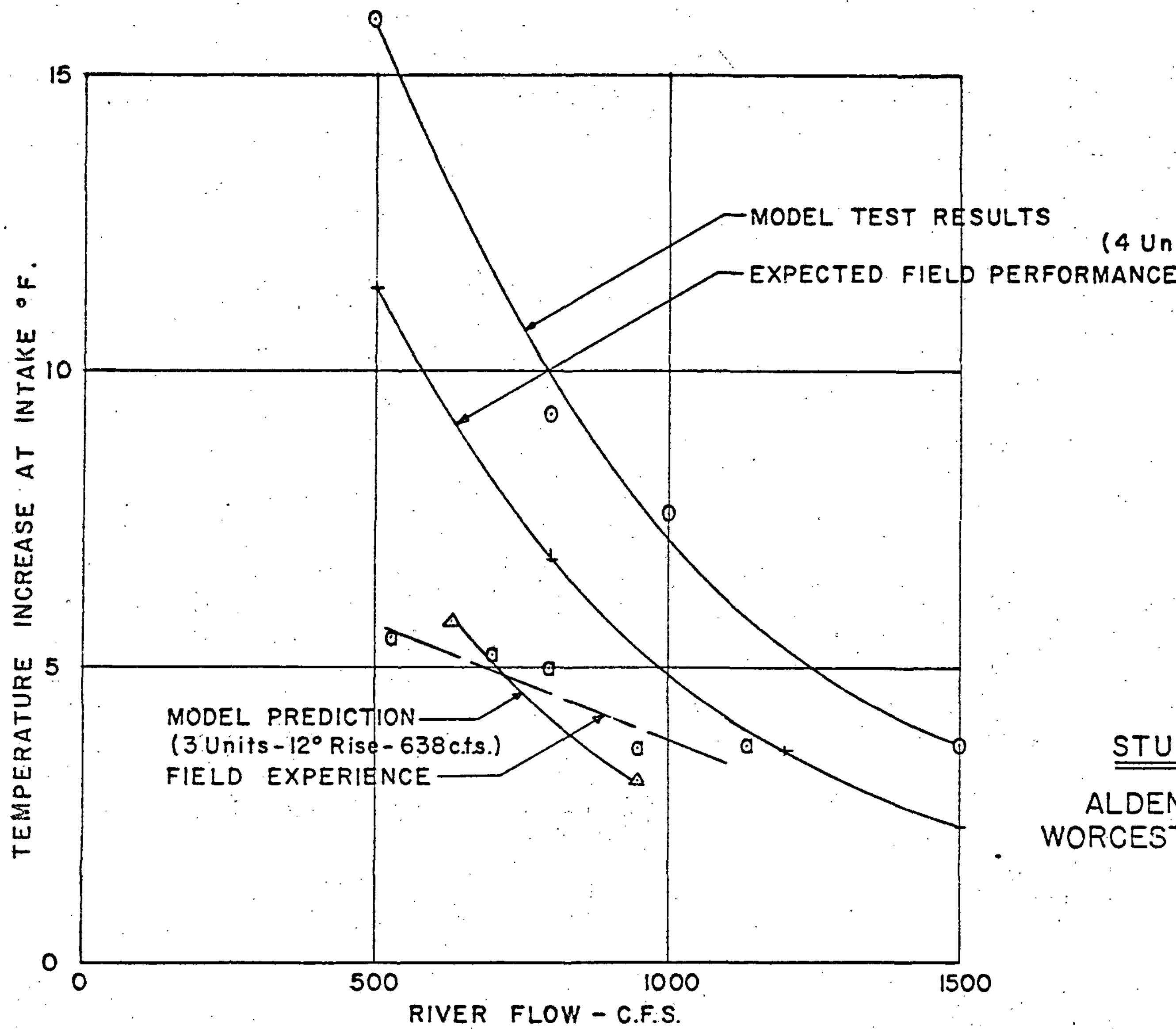
ALDEN HYDRAULIC LABORATORY
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASS.

FIGURE 3



THE GENERAL PATTERN OF SURFACE AND BOTTOM STREAMLINE FOR DIFFERENT RIVER FLOWS WITH A CONDENSER FLOW OF 804 c.f.s.

Fig. 4



STUDY OF RECIRCULATION

ALDEN HYDRAULIC LABORATORY
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASS.

FIGURE 5