University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 327

# HYDRAULIC MODEL STUDY OF THE SIPHON INTAKE TO THE BRASFIELD DAM HYDROELECTRIC FACILITY

by

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# I. INTRODUCTION

This report describes a hydraulic model study of the siphon intake and related approach flow regions for the Brasfield Dam Hydroelectric Project. The study was conducted for STS HydroPower Ltd, of Northbrook, Illinois. The proposed hydroelectric facility will consist of one 3 MW turbine/generator unit utilizing approximately 41 ft of head with a maximum discharge of 1000 cfs. The objectives of the study were as follows:

1. Make computer computations to predict characteristics of the water withdrawn from the reservoir by the intake using temperature and D.O. profiles supplied by STS HydroPower, Ltd., and the SELECT computer program developed by the U. S. Army Engineer Waterways Experiment Station.

2. Test initial design for intake vortices and reduce or eliminate any free surface vortices that occur with suitable anti–vortex devices. If dissolved oxygen (D.O.) requirements downstream of the hydroelectric project require that the intake be placed with as little submergence as possible in the reservoir, develop and test anti–vortex devices to reduce or eliminate any free–surface vortices that occur.

3. Evaluate the intake for any undesirable flow conditions that may occur and redesign the intake to eliminate these flow conditions. All flow improvement studies are to be made at discharges near the design discharge of 1000 cfs.

4. Measure headlosses in the intake–elbow–constriction section of the siphon intake.

NOTE: To avoid confusion, unless specifically noted otherwise, all measurements given in this report are in prototype units.

# II. Recommendations & Conclusions

1) Maximum headlosses for the cutoff intake and bend were found to be 0.7 ft.

2) The maximum velocity at the trash racks was found to be 1.16 fps.

3) To maximize the D.O. of the discharge from the Brasfield Hydroelectric facility intake, we recommend the prototype intake be positioned as close to the water surface as possible.

4) We recommend a 3 foot submergence of the cutoff intake and a 12 foot depth of the floating crib bottom plate.

5) We recommend a floating grid be constructed with 2 inch x 12 inch planks placed at 1 foot x 1 foot on center. This grid suppressed all surface vortices in the model study.

# III. SELECTIVE WITHDRAWAL MODELING

The dissolved oxygen (D.O.) concentration in the proposed Brasfield Dam siphon intake was estimated using the U.S. Army Corps of Engineer's selective withdrawal model, SELECT.

The temperature profile and D.O. profile used in the SELECT model were calculated using data provided by STS HydroPower. The data, given in Table 1, consisted of temperature and D.O. at 2 foot vertical intervals from five positions upstream of the proposed intake. At a given depth there are only slight variations in temperature and D.O. between sampling positions. Figure 1 shows the relative position of the five sampling positions with respect to the dam and the proposed intake. The temperature profile and the D.O. profile used in SELECT were computed by laterally averaging the profiles obtained at sampling positions 3, 4, and 5. Figure 2 shows the temperature and D.O. profiles used in the SELECT model.

## A. Modeling

SELECT "computes the withdrawal zone formed by a given release through or over a specified outlet structure for a known reservoir density stratification. The program also computes the quality characteristics of the release for user specified parameters treated as conservative substances" (Smith et al., 1987). In this case the specified parameter was dissolved oxygen concentration. SELECT computes the density stratification of the reservoir from the user supplied temperature profile.

SELECT uses a point sink potential flow solution to model withdrawal through side ports in a reservoir. The depth of the point sink in the model is usually specified as the depth of the centerline of the side port. However, for this project, the port is positioned horizontally (the intake is vertically inverted), 3 to 10 feet below the water surface, with a plate positioned horizontally 7 to 9 feet below the port (10 to 19 ft below the water surface). Figures 3 and 4 show the discrepancies in flow regimes between the computer model and the intake to be installed. A rough approximation would be to assume that the point sink depth is at mid-depth between the intake lip and the bottom plate. Thus, if the intake lip is at 3 ft depth, and the bottom plate is at 12 ft depth, the assumed point sink depth would be at (12+3)/2 = 7.5 ft.

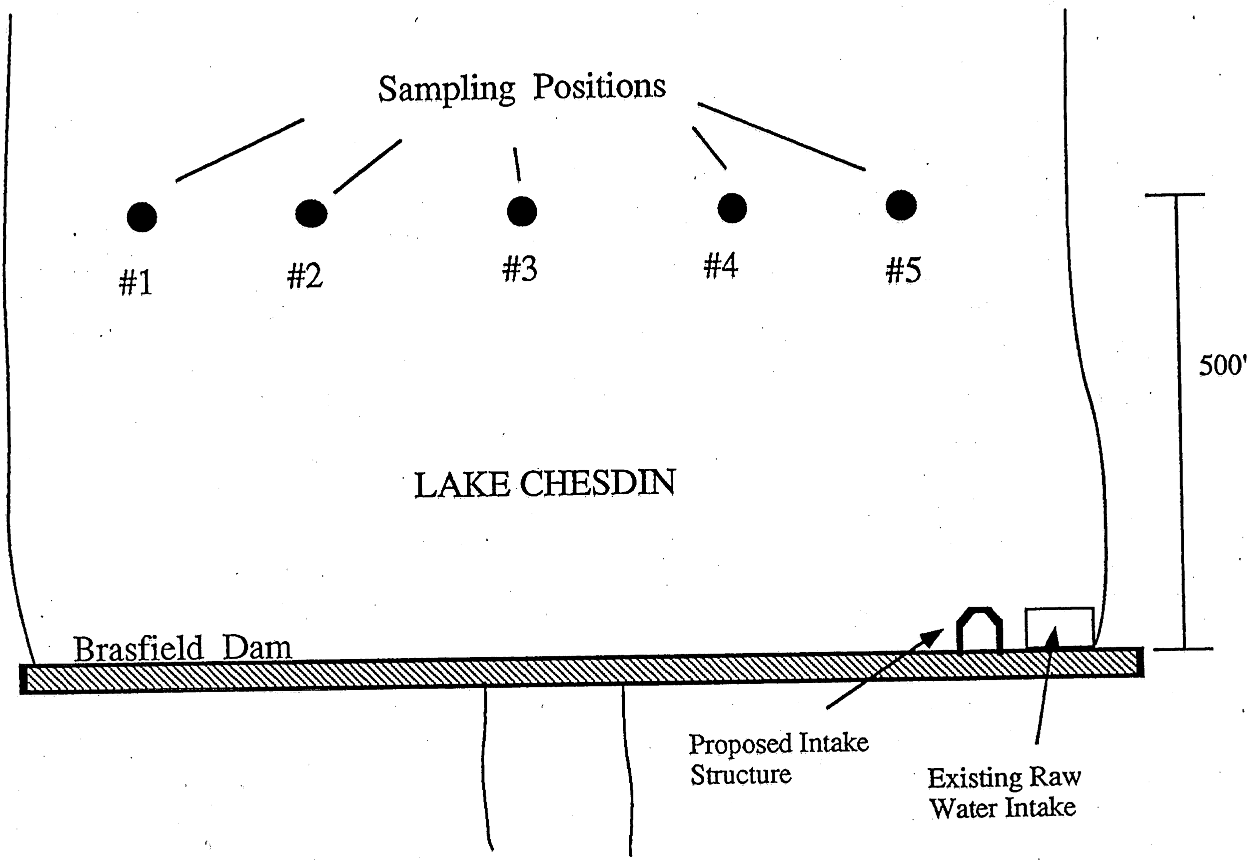


Figure 1 Sampling positions for D.O. analysis.

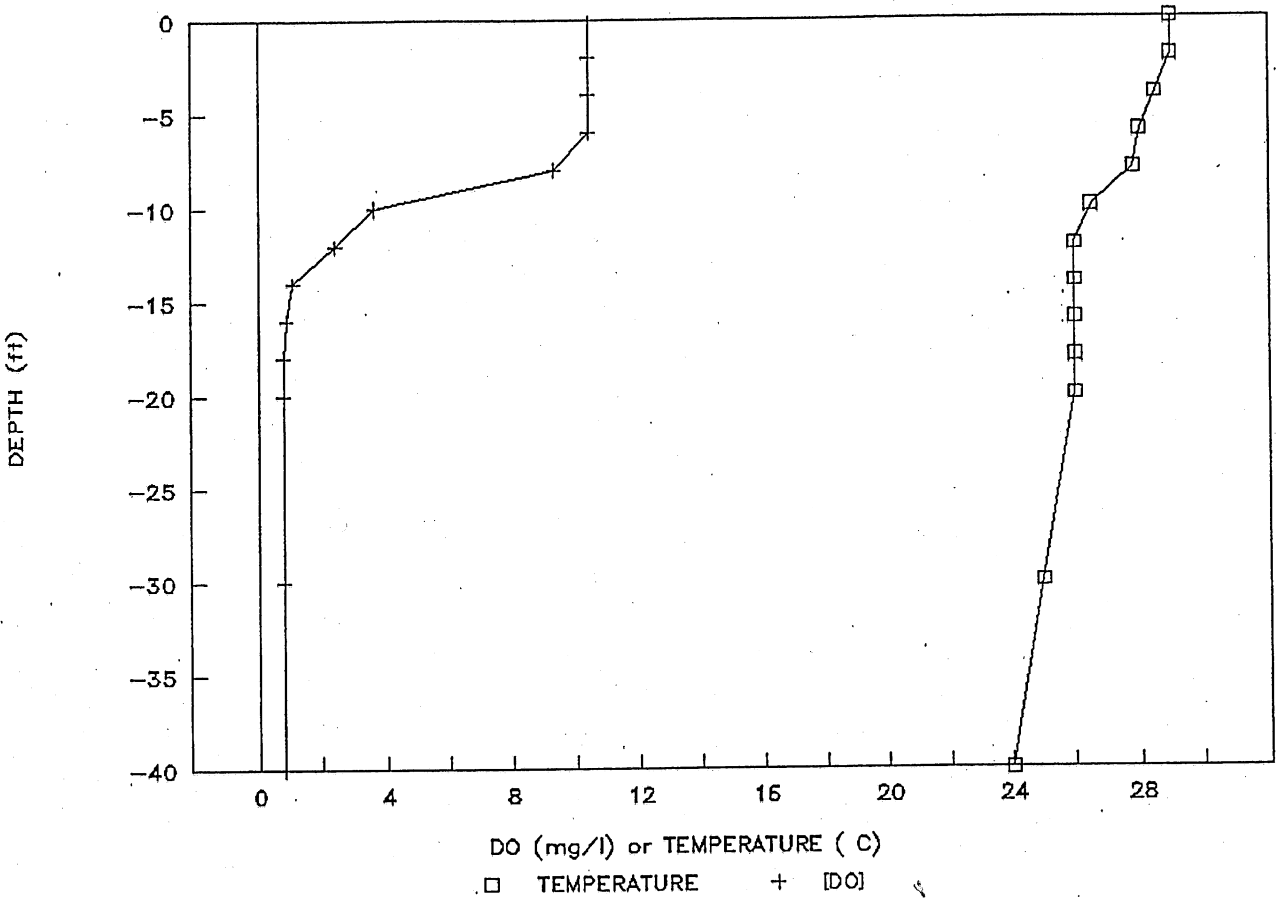


Figure 2 D.O. and temperature profiles supplied by STS HydroPower for Lake Chesdin.

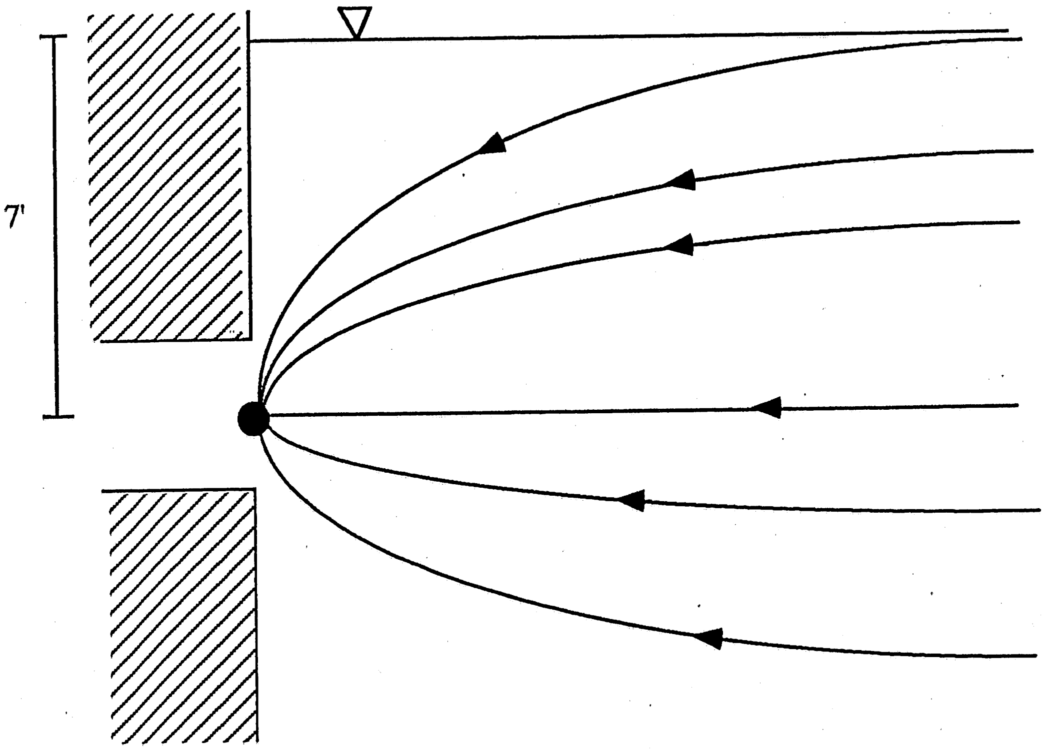


Figure 3 Flow regime of point sink for SELECT.

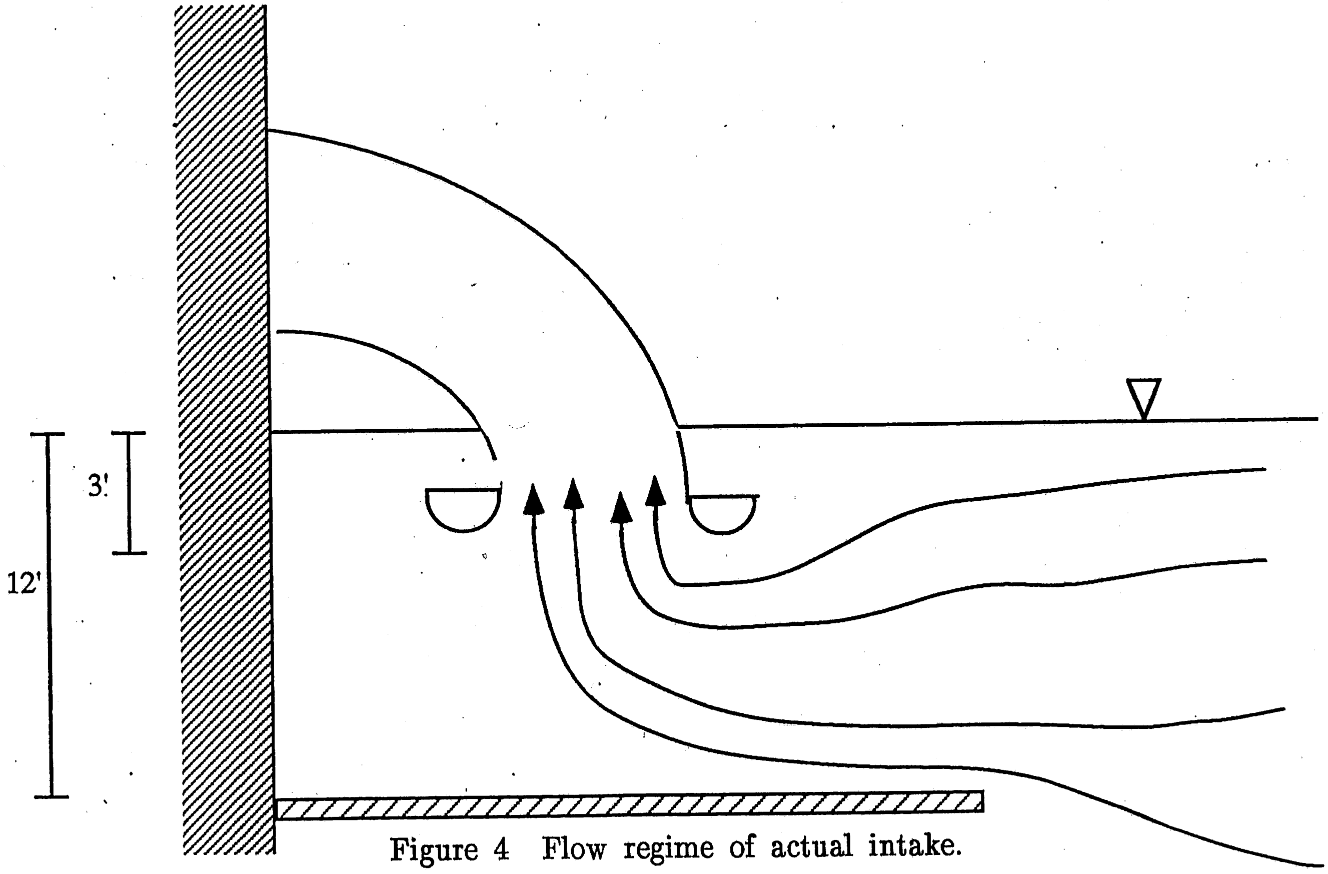


Figure 4 Flow regime of actual intake.

TABLE 1. STS SUPPLIED TEMPERATURE AND D.O. DATA

| | Position #1 | | Position #2 | | Position #3 | | Position #4 | | Position #5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Depth (ft) | Temp (°C) | D.O. (mg/l) | Temp (°C) | D.O. (mg/l) | Temp (°C) | D.O. (mg/l) | Temp (°C) | D.O. (mg/l) | Temp (°C) | D.O. (mg/l) |
| 2 | 29.5 | — | 29.0 | 10.9 | 29.0 | 10.4 | 29.0 | 10.3 | 29.0 | 10.6 |
| 4 | 29.0 | — | 29.0 | 10.8 | 29.0 | 10.4 | 28.5 | 10.3 | 28.0 | 10.6 |
| 6 | 28.5 | 7.4 | 28.5 | 10.6 | 28.0 | 9.6 | 18.0 | 10.3 | 28.0 | 11.2 |
| 8 | 28.5 | 5.4 | 27.5 | 6.9 | 28.0 | 8.8 | 27.5 | 9.7 | 28.0 | 9.4 |
| 10 | 27.0 | 2.4 | 26.5 | 3.6 | 26.5 | 3.8 | 26.5 | 4.0 | 26.5 | 3.7 |
| 12 | 27.0 | 2.2 | 26.0 | 2.5 | 26.0 | 1.6 | 26.0 | 2.6 | 26.0 | 3.0 |
| 14 | 26.0 | 1.5 | 26.0 | 1.0 | 26.0 | 1.0 | 26.0 | 0.8 | 26.0 | 1.4 |
| 16 | 26.5 | 1.3 | 26.0 | 1.10 | 26.0 | 0.9 | 26.0 | 0.8 | 26.0 | 0.9 |
| 18 | 26.0 | 1.3 | 26.0 | 1.0 | 26.0 | 0.9 | 26.0 | 0.8 | 26.0 | 0.8 |
| 20 | 26.0 | 1.3 | — | — | — | — | — | — | — | — |
| 22 | 26.0 | 1.3 | — | — | — | — | — | — | — | — |
| 30 | 26.0 | 1.0 | 26.0 | 1.0 | 25.0 | 0.8 | 25.0 | 0.8 | 25.0 | 0.8 |
| 40 | — | — | — | — | 24.0 | 0.8 | — | — | 24.0 | 0.7 |

## B. Results

The intake was modelled for point sink depths ranging from 4 feet to 18 feet and for flows ranging from 100 cfs to 1000 cfs. The results are summarized in Figure 5. For a given flow rate, the D.O. of the intake increases as the point sink is moved closer to the water surface. At lower flow rates the D.O. of the intake is more responsive to the depth of point sink. For higher flow rates, the sink draws from a wider vertical range of the reservoir; consequently, the D.O. of the intake is less responsive to the depth of the point sink.

*The D.O. and temperature profiles given in Fig. 2 are about the worst possible scenario for a high D.O. in the withdrawn water.* Most of the time the withdrawn D.O. will be higher than that indicated in Figure 5. *There are times, however, when the hydroelectric facility will need to either a) pass water over the spillway to enhance tailwater D.O., b) back off on turbine discharge to increase intake D.O., or c) both.*

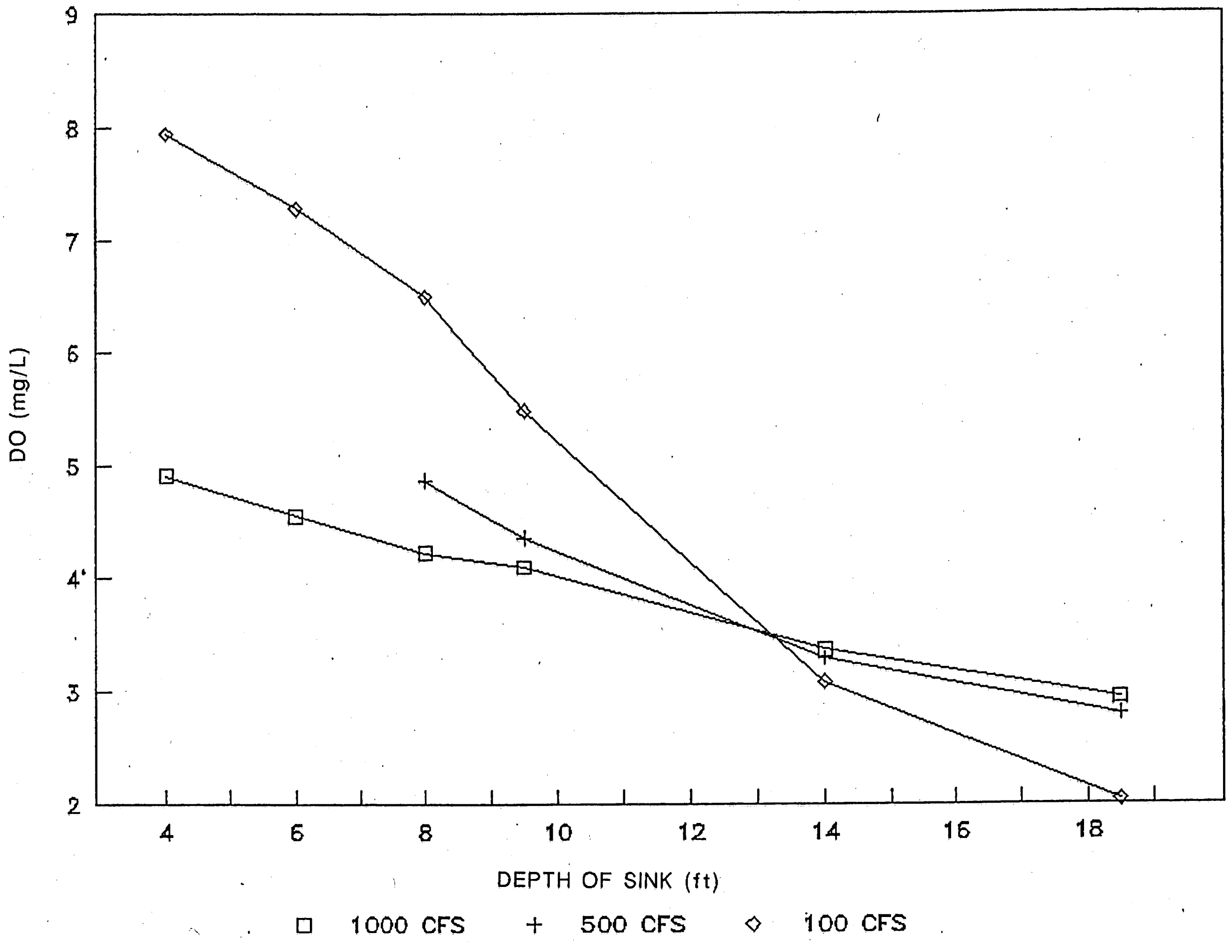


Figure 5 D.O. of intake computed with SELECT.

# IV. PHYSICAL MODEL DESIGN AND CONSTRUCTION

## A. Model Scale Selection

The intakes and upstream section were modeled with Froude scaling, which is based upon the ratio of inertial and gravity forces.

$$F_r = \frac{V_m}{\sqrt{gL_m}} = \frac{V_p}{\sqrt{gL_p}}$$

where
$Fr$ = Froude number,
$V_m$ = velocity in the model,
$V_p$ = prototype velocity, corresponding to $V_m$
$g$ = acceleration due to gravity
$L_m$ = a length in the model, and
$L_p$ = prototype length, corresponding to $L_m$.

In an undistorted model such as this, $L_m/L_p$ is a constant value equal to the model scale at every location. The model scale of the Brasfield Dam Hydroelectric Project is 1:24, meaning that 1 inch in the model corresponds to 2 ft in the prototype.

The size (or scale) of the model was determined such that other forces, such as friction, do not significantly alter the results, e.g. produce scale effects. The criteria to be used were reviewed by Lindblom (1987), who concluded the following:

1. To avoid viscous scale effects on intake vortices, the characteristic intake dimension (diameter) must be greater than 5 inches (Cambell 1983), and the radial Reynolds number ($Q/\nu S$), should be greater than $10^5$. Here, $Q$ is discharge (ft$^3$/sec), $\nu$ is kinematic viscosity of the water (ft$^2$/sec), and $S$ is intake submergence (ft). When no vortices are present, such as after modifications to the intake, the radial Reynolds number may be as low as $10^4$ (Cambell 1983). The radial Reynolds number for the Brasfield Dam model was between $8.5 \times 10^4$ and $2.8 \times 10^5$. The final submergence of 3 ft corresponds to a Reynolds number of $2.8 \times 10^5$.

2. To avoid scale effects due to surface tension, the Weber number, W $= \rho V^2 D/\sigma$, should be greater than 600 (Cambell, 1983). If there are no intake vortices, however, no scale effect due to surface tension has been observed at Weber numbers as low as 100 (Cambell, 1983). Here, $\rho$ = liquid density, V = velocity in the intake throat, D = throat diameter, and $\sigma$ = surface tension of the liquid. For the Brasfield Dam, the Weber number was approximately 630.

3. The Reynolds number in the approach flow should be greater than $10^4$ at all locations to avoid laminar flow and to properly simulate the approach flow. Here $Re = 4Vh/\nu$, where V = velocity, and h = depth, each taken at the same location. The Reynolds number was $1.6 \times 10^5$, 24" from the centerline of the intake (48 ft in the full scale). This was considered to be sufficient.

For a vertically inverted or horizontal intake such as at the Brasfield Dam, a Reynolds number criteria $Re = Q/\nu D > 7 \times 10^4$ (Stefan, 1985) should also be used to properly scale vortices that may occur. In the Brasfield Dam model, $Re = 9 \times 10^4$.

## B. Model Construction

Using a 1:24 scale meant that four bays of the Brasfield Dam could be included in the 12 ft by 13 ft basin constructed for the model. This is shown in Fig. 6, where the model outline is juxtaposed on a site plan. This basin size is sufficient if the flow is properly distributed around the outside of the model. Measurements were to be taken only in the region near the intake, with the remainder of the basin providing representative approach flows that adequately simulated the prototype.

A 12 ft x 13 ft x 30 inch basin was built to house the model. The floor and walls were of plywood and timber construction. Near the intake, the two side walls were constructed of plexiglas to aid in viewing the intake and surrounding area. Figure 7 shows the overall layout of the basin and model. Several other major reservoir features were included in the study. The existing raw water intake structure adjacent to the proposed intake siphon was included in the model. The morphology of the reservoir was estimated from reservoir plans supplied by STS. The bottom was constructed by attaching thin polypropylene sheets to a framework that closely simulated the contour.

The flow entering the basin was measured by a calibrated 3–inch orifice plate and manometer shown in Photo 1. Proper distribution of flow was accomplished by placing a diffuser pipe on the basin wall opposite the intake. Prior to the water entering the model, it would also pass through 4–inch guide vanes around the exterior of the tank.

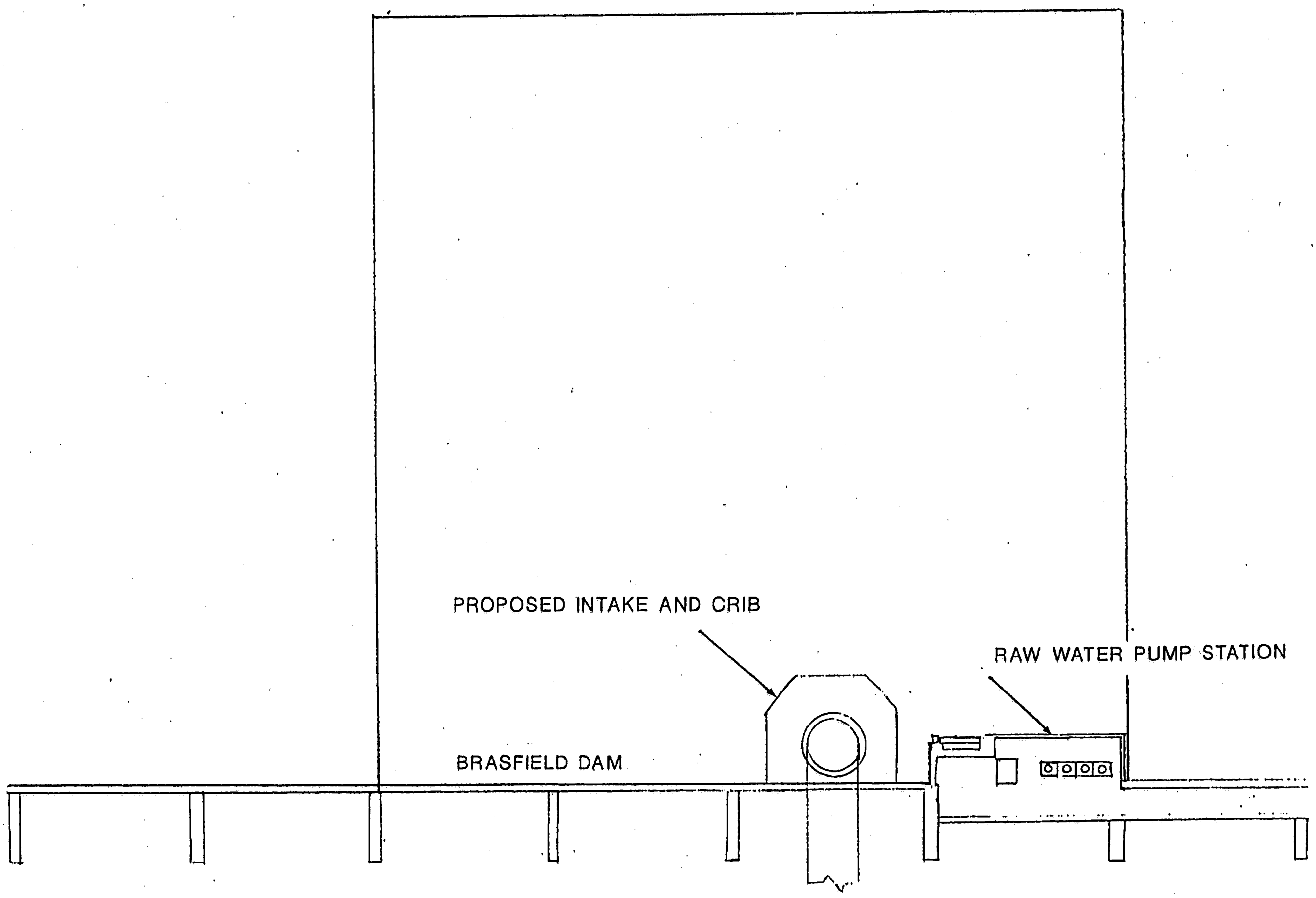


Figure 6 Model outline juxtaposed on site plan.

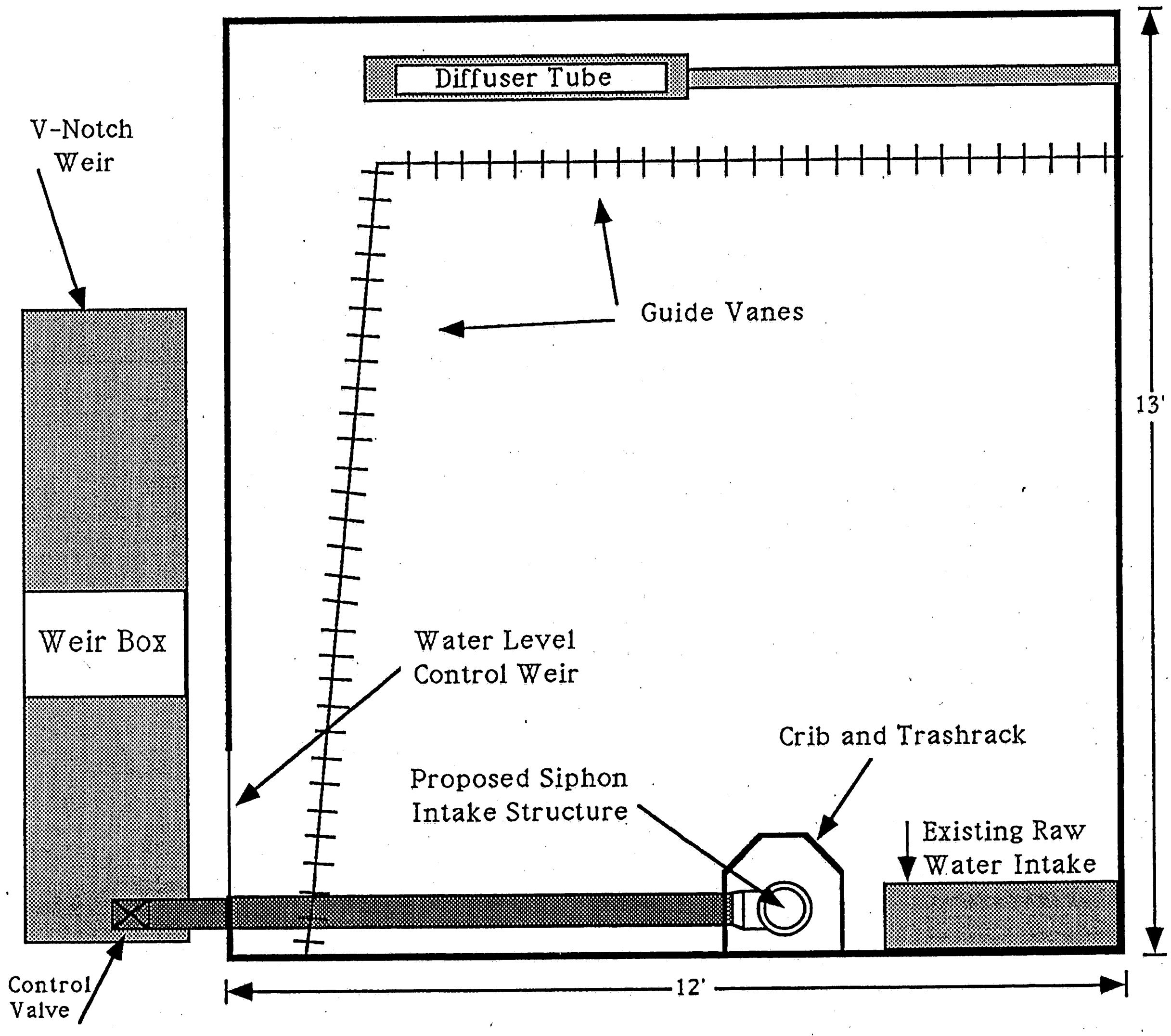


Figure 7 Overall layout of model study.

The intake and penstock were constructed at the 1:24 model scale according to drawings provided by STS HydroPower Ltd. The intake was fabricated in the SAFHL machine shop from clear plastic. The clear plastic is easy to work with and allows close tolerances in the construction of the model components. The intake and penstock system may be seen in Photo 2. The penstock had four pressure taps installed for headloss measurements and pitot cylinder access. Finally, a pressure tap was added at the highest point and attached to a vacuum system in order to prime the system, initiating discharge through the siphon.

Due to the configuration of the model and viewing area, an alteration to the initial design had to be made. The penstock needed to be rotated so it ran parallel, instead of perpendicular, to the face of the dam. Experience has shown that this alteration should have no significant effects on the flow characteristics in or approaching the intake, and created an accessible working and viewing area.

The elevation of the siphon intake was made to be adjustable because it was anticipated that the selective withdrawal study results may indicate that it is best to have the intake and horizontal plate as high as possible. The intake–penstock was installed so it could be adjusted in all directions, using an overhanging support and threaded rods. The intake is shown in Figure 8. Surrounding the intake is a floating crib, designed to support the trashracks, bottom plate, and any necessary anti–vortex device.

The outflow was controlled by a valve on the downstream end of the penstock tube. As the water exited the model, it entered a weir box, as shown in Photo 3. A v–notch weir and a point gage were placed in the weir box to measure discharge as shown in Photo 4. Water level control in the model basin was achieved by using inflow and outflow valves and a weir placed at a fixed elevation on the basin. Inflow discharge was set slightly higher than the intake (outflow) discharge. The small difference in discharge was passed over the weir, maintaining a very stable water surface elevation in the model.

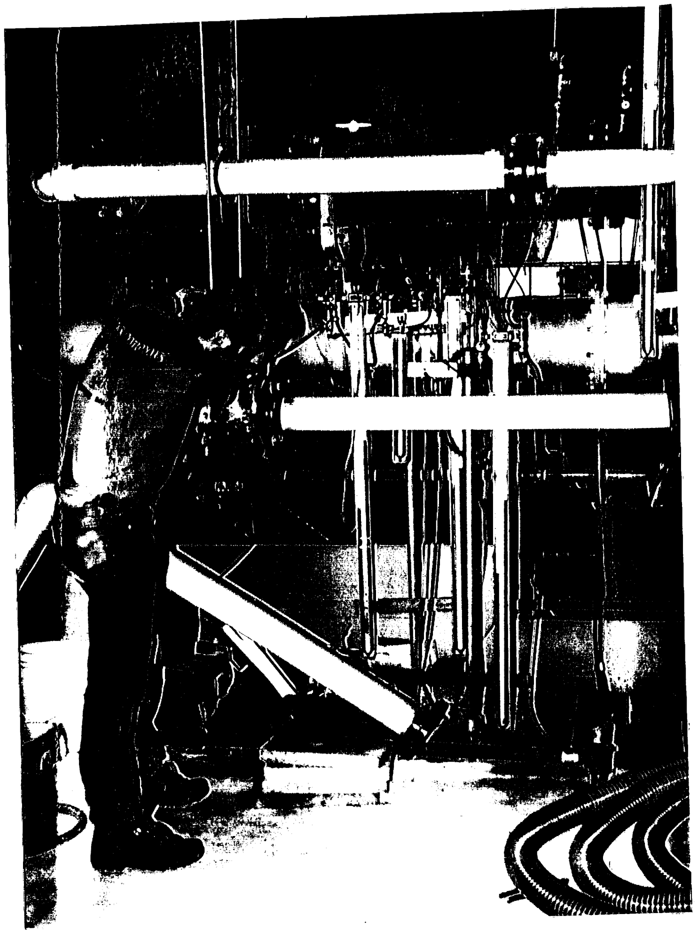


Photo 1 Inflow measurement system.

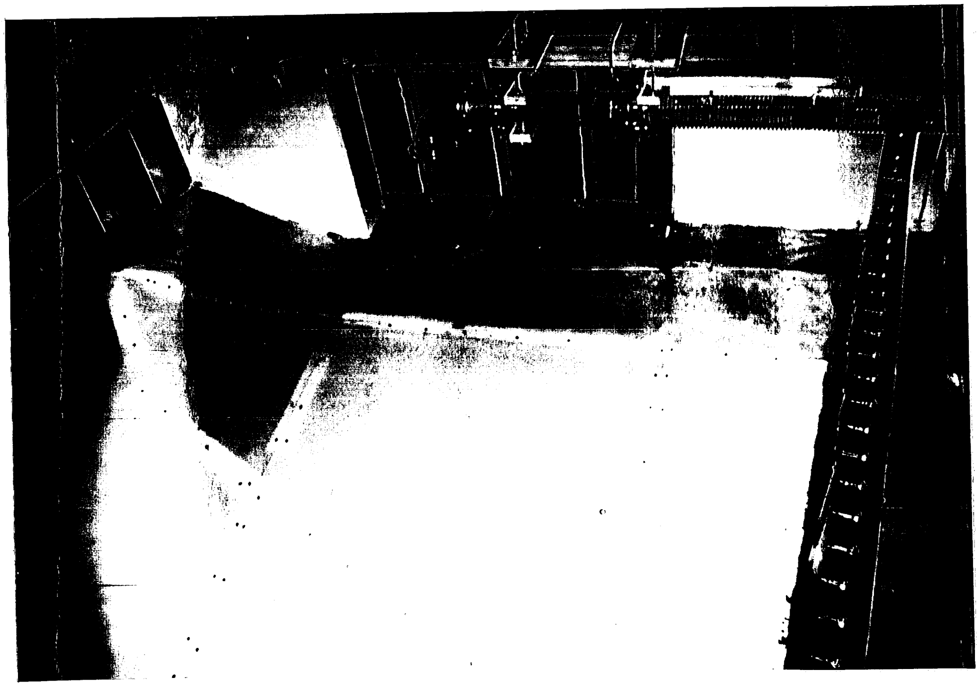


Photo 2 View of model showing intake and penstock system.

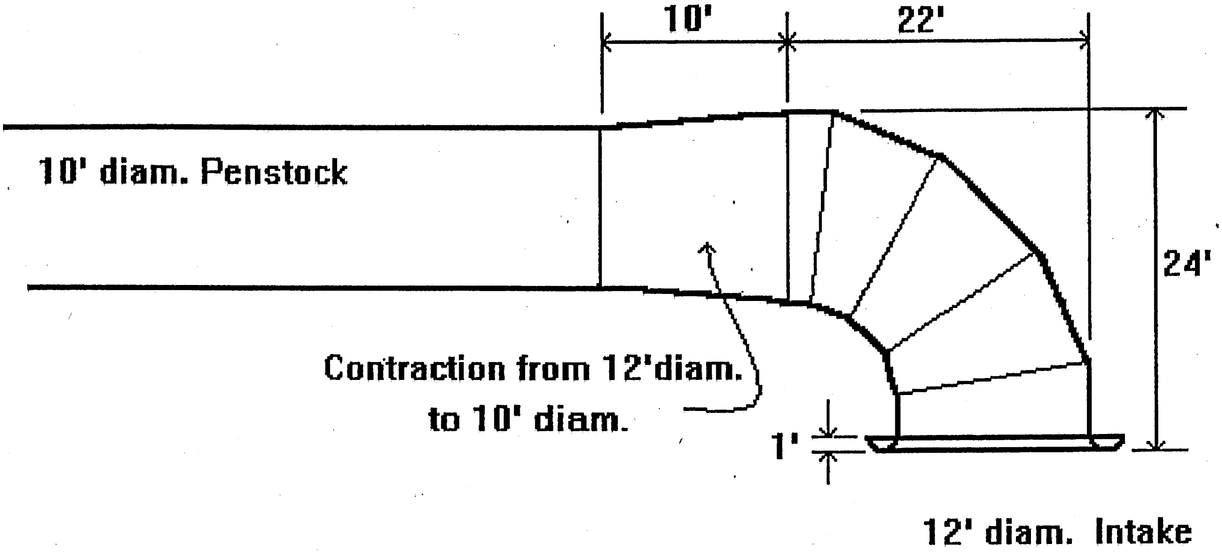


Figure 8 Non–cutoff intake design.

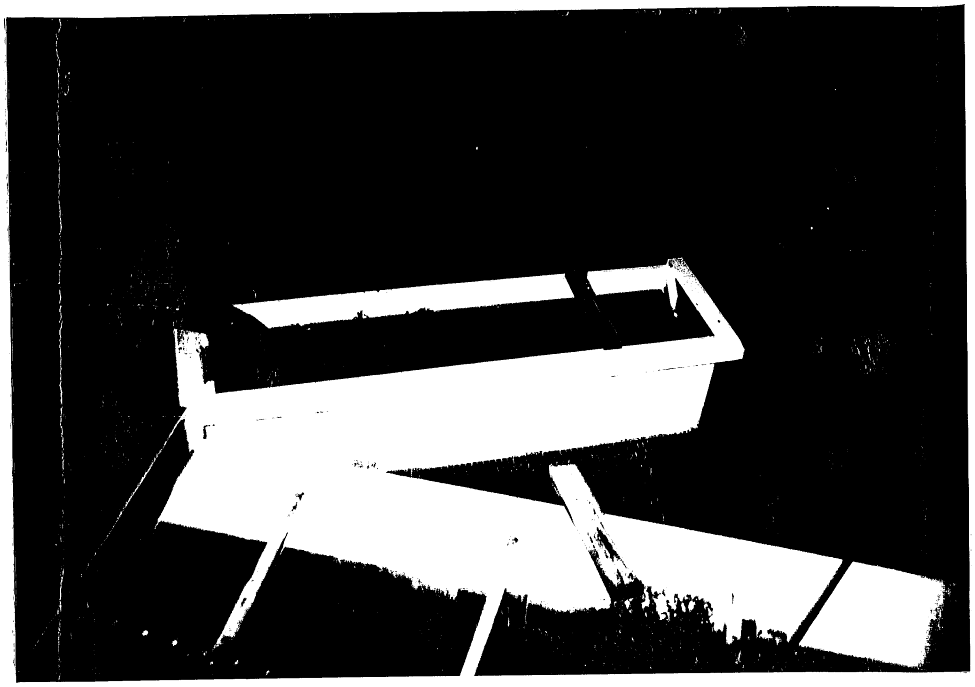


Photo 3 Model guide vanes and weir box.

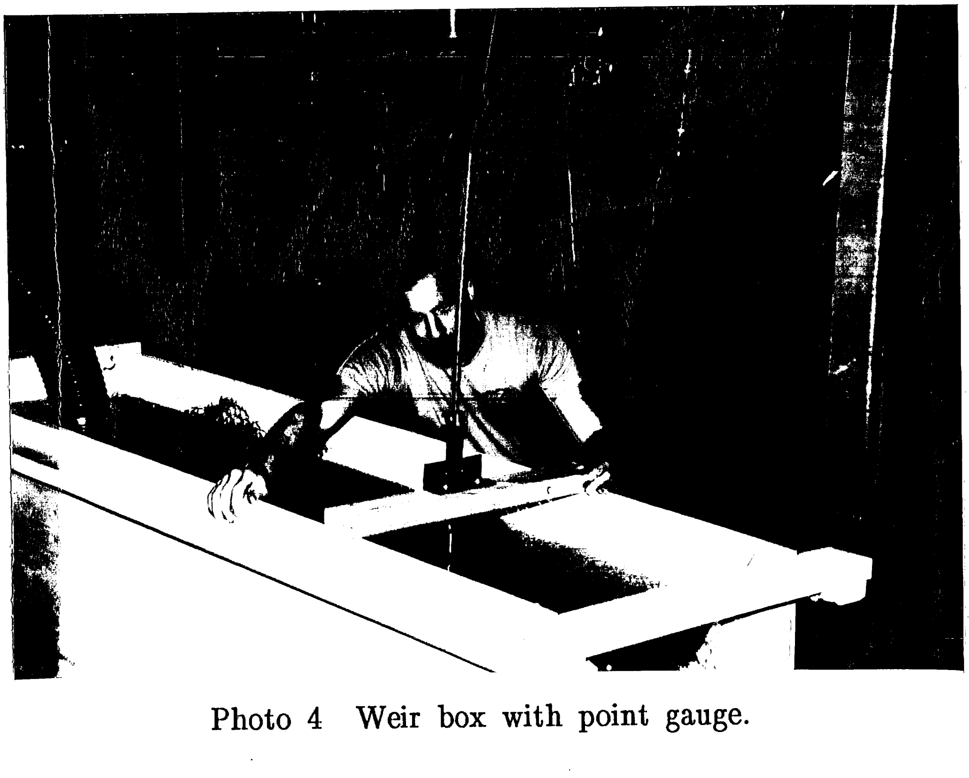


Photo 4 Weir box with point gauge.

# V. FLOW IMPROVEMENT STUDY

## A. Vortices Present

The flow improvement study was run for a variety of flow conditions. The foremost parameter varied was the depth of the intake. Also varied were the depth of the bottom plate and primary direction of the approach flow. The results of the selective withdrawal modeling indicated that it was desirable to keep the intake as close to the surface as possible. The combinations of intake depths and plate depths selected for testing are shown in Table 2.

For each test run, several aspects of the flow were studied and documented; first without the vortex suppression grid, and then with the grid in place. (The vortex suppression grid is described in Section B–Vortex Mitigation.) At the prototype design flow rate of 1000 cfs, observations were made on any potential flow problems such as separation zones, surface waves, and vortices. Comments and data from each test run were recorded on separate data sheets. A sample data sheet is given in Fig. 9.

To study the approach flow patterns, dye was released from subsurface areas surrounding the inlet. Dye was also used to accent the visualization of floor vortices and vortices forming along the dam face. Photo 5 shows a floor vortex.

Quantitative vortex formation data was taken by measuring the time vortices present during a given testing period. Times were recorded for each of the following three degrees of surface vortex formations:

1) Surface swirl: general random swirl, no dye–core vortices present.

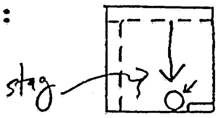
2) Small dye core: dye core vortices less than 0.4 feet (prototype) from water surface to vortex tip.

3) Large dye core: dye core vortices greater than 0.4 feet (prototype) from water surface to vortex tip.

A fourth degree of vortex formation, "air bubble vortex" was recorded by the number of occurrences per test period, since each occurrence was very short lived (less than one second) and difficult to time. Air bubble vortices occurred when the tip of the vortex extended sufficiently close to the bottom of the intake to allow air bubbles to be pulled through the intake. An example is shown in Photo 6.

DATA SHEET
STS Hydropower
Brasfield Dam Syphon Intake Model

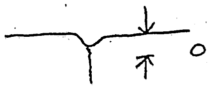
Date: 1-24-92
Time: 11:10 Am
Recorded by: DA
Inflow manometer reading, Δh, cm: 15.3+15.4=30.7 cm  cfs: 1200
Syphon discharge, weir point gauge reading, ft: 1.626 ft.  cfs: 1165
Water surface point gauge reading, ft: 1.827
Water Temp, °C: 2°C
Depth of bell mouth (inches below WS): 4½"
Depth of plate (inches below WS): 9½"
Headloss, manometer Δh:
Primary direction of approach flow:
(show with arrows)

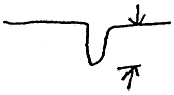


Photos: #2: 14-24

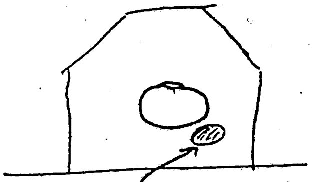
Observations/Comments:

total time 15:00 min
dye core time 2:21
trash 0:18


0 to 0.5 cm w/ dye core


0.5 to 2.0 cm w/ dye core

continued swirl
surface



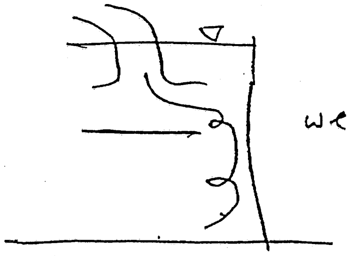


Figure 9 Sample data sheet for observation of flow improvement study.

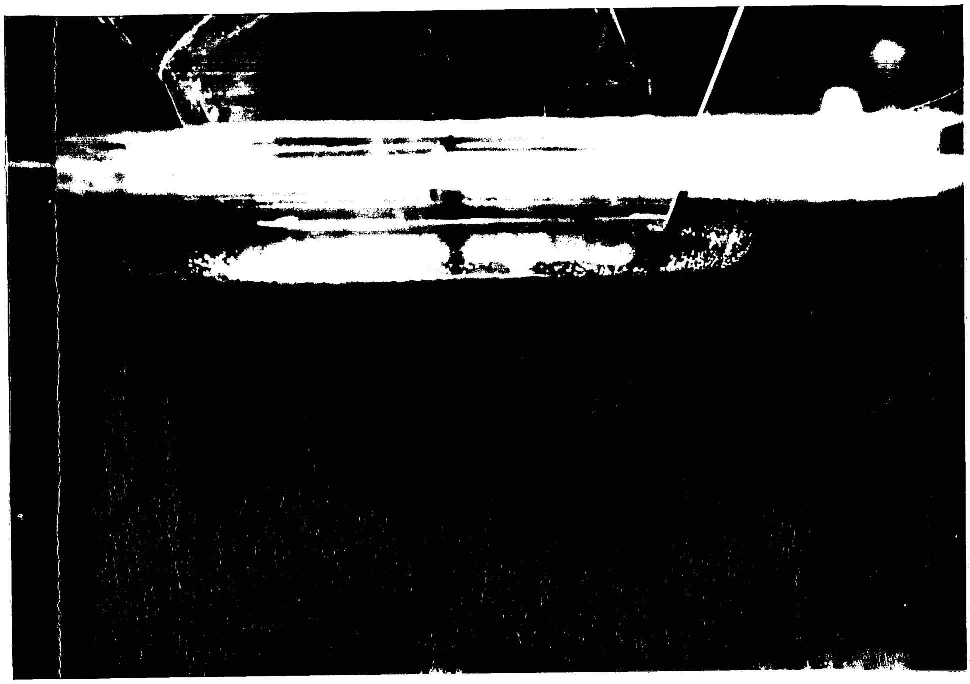


Photo 5 Floor vortex.

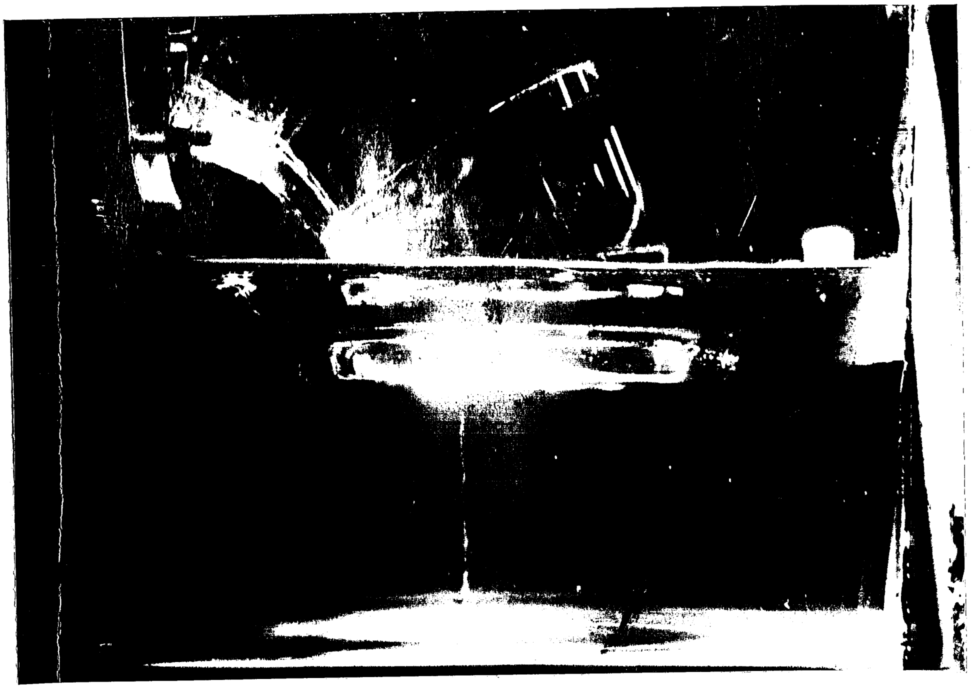


Photo 6 Air bubble vortex.

For all test runs, surface vortices were present without the grid in place. Table 2 summarizes the quantitative vortex formation data. The predominant areas of vortex formation are shown in Figure 10. Floor vortices were also present in all test runs. The strength of the floor vortices ranged from a mild haphazard swirl to a well defined swirl, sucking debris, such as leaves, from the bottom of the model through the intake. If the floor vortices entering the intake are strong, they may carry through to the turbine and affect performance.

TABLE 2 Qualitative Vortex Formation Measurement Summary without Grid in Place

| Test Run No. | Prototype Flowrate (cfs) | Prototype Intake Depth (ft) | Prototype Plate Depth (ft) | Small Dye Core (% time) | Large Dye Core (% time) | Air Bubble Vortex (#/5 min) |
|---|---|---|---|---|---|---|
| Non–cutoff Intake | | | | | | |
| 1 | 1165 | 9.0 | 19.0 | 16 | 2 | 0 |
| 2 | 1150 | 7.0 | 17.0 | 59 | 26 | 2 |
| 3 | 1130 | 5.0 | 15.0 | 74 | 29 | 5 |
| 4 | 1175 | 3.0 | 13.0 | 82 | 35 | 12 |
| Cutoff Intake | | | | | | |
| 5 | 1060 | 3.0 | 12.0 | 54 | 33 | 4 |
| 6[a] | 1060 | 3.0 | 12.0 | 69 | 37 | 10 |
| 7[b] | 1060 | 3.0 | 12.0 | 49 | 15 | 11 |

[a] Altered approach flow; approach flow parallel to dam.
[b] Altered approach flow; approach flow normal to dam.

## B. Vortex Mitigation

A grid was placed inside of the floating crib in an attempt to suppress surface vortex formation. The grid is shown in Fig. 11. The prototype dimensions would be 1 ft in depth with 1 ft x 1 ft on center spacing. The actual grid could be constructed from 2 inch x12 inch planks.

*All surface vortices listed in Table 2 were eliminated by the floating grid for each test run as long as the top of the grid was placed at or slightly below the water surface.* When the top of the grid was submerged to a depth of 2 ft (prototype), small dye core vortices were observed above the grid but did not carry through the grid.

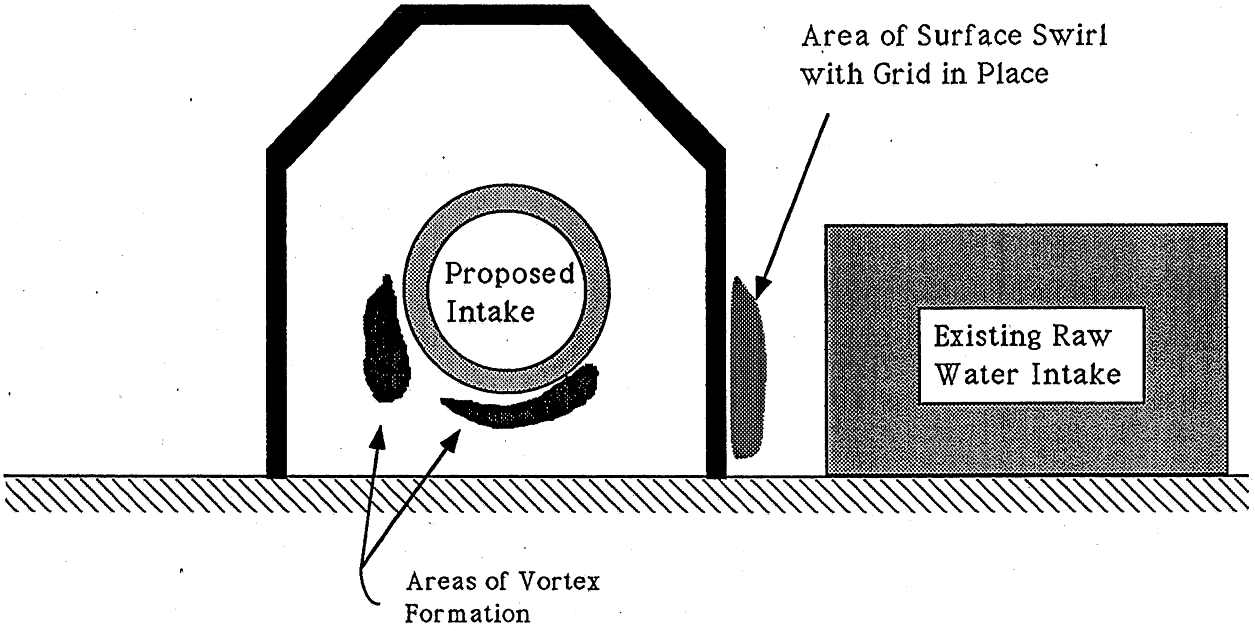
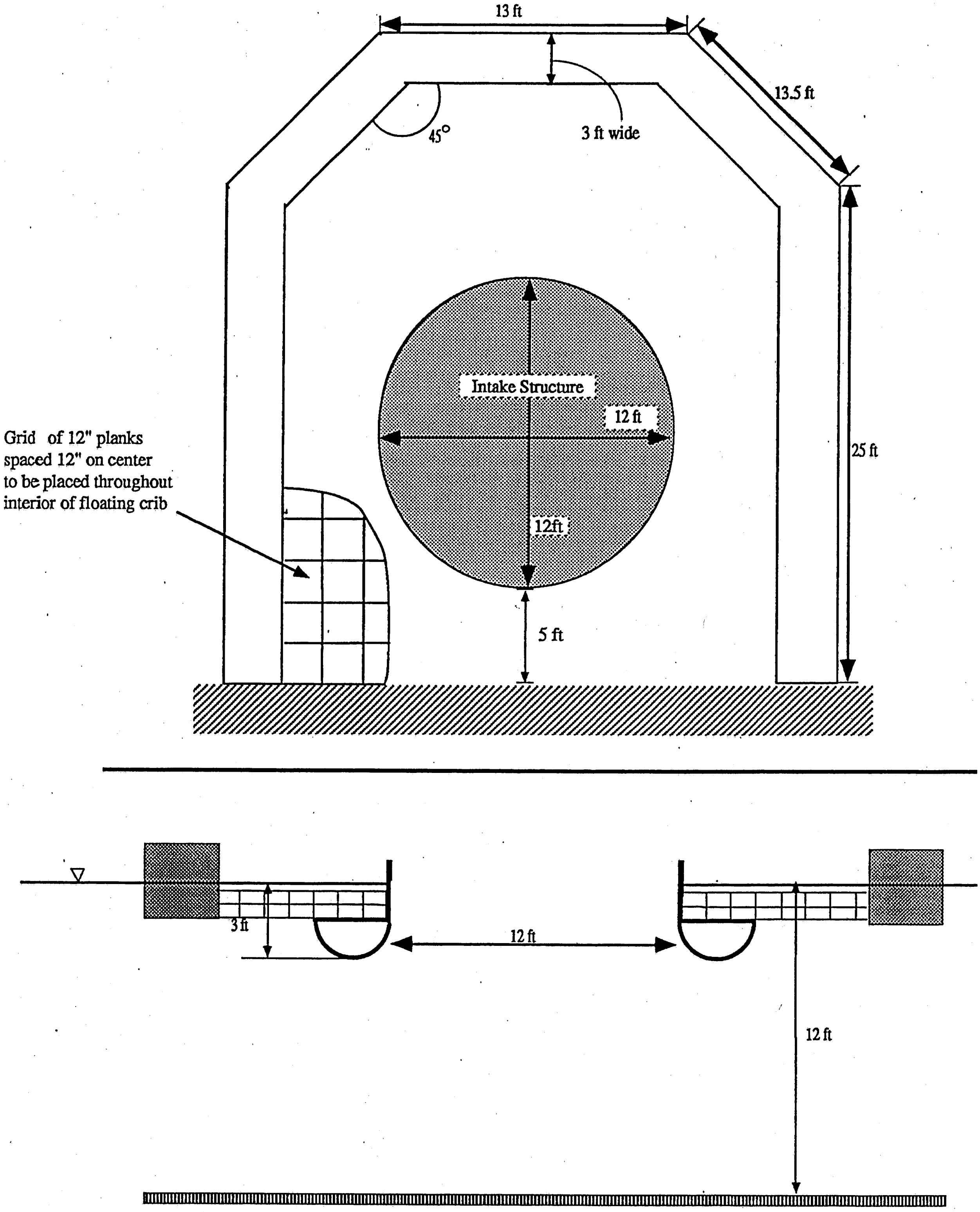


Figure 10 Predominant areas of vortex formation.



Grid of 12" planks spaced 12" on center to be placed throughout interior of floating crib

Figure 11 Plan and section view of floating crib and anti–vortex grid.

The area between the proposed intake crib and the existing water intake structure, as shown in Figure 10, exhibited some potentially problematic behavior during test runs with the intake set above a prototype depth of 7 feet and with the grid in place. Although no surface vortices or dye–cores were observed in that area, substantial surface swirl was observed.

Because the floating grid was so successful and is relatively simple and inexpensive to construct, no other anti–vortex devices were tested. *The submergence of the intake may be placed at a 3 ft depth, as long as the floating grid is in place.*

The bottom plate of the floating crib will cause a strong floor vortex that is pulled into the intake if there is insufficient clearance between the plate and the intake lip. This was investigated at clearance distances of 7 ft, 8 ft, 9 ft and 10 ft, through the use of dye released on the bottom plate. At seven feet of clearance, a strong floor vortex was apparent. At 8 ft clearance, the floor vortex strength was diminished, but still believed to be a potential flow problem. At 9 ft clearance, a floor vortex was present, but any difference in strength between 9 ft and 10 ft of clearance was difficult to distinguish. Therefore, *9 feet of clearance is recommended between the intake lip and the bottom plate of the floating crib. If the intake submergence is three feet, the bottom plate should be placed at a 12 foot depth.*

## C. Approach Velocity

Velocities near the trash rack were measured at seven locations approximately 2 feet outside the crib. At each location, a Marsh McBirney electromagnetic current meter, Model 511, was used to measure the normal and parallel components of the horizontal velocity at each of three vertical positions: 4 feet below the water surface, 8 feet below the water surface, and 12 feet below the water surface. The maximum velocity and angle of approach were then calculated. The results are summarized in Figure 12. The maximum approach velocity measured was 1.16 ft per second.

Additionally, velocity profiles extending from the water surface to the model floor were taken approximately 12 feet in front of position #4 in Figure 12. The velocity profile is given in Figure 13. The purpose was to determine the selective withdrawal from the various depths that would take place with no stratification in the reservoir. This may be interpolated to give some indication of the selective withdrawal that would occur with stratification.

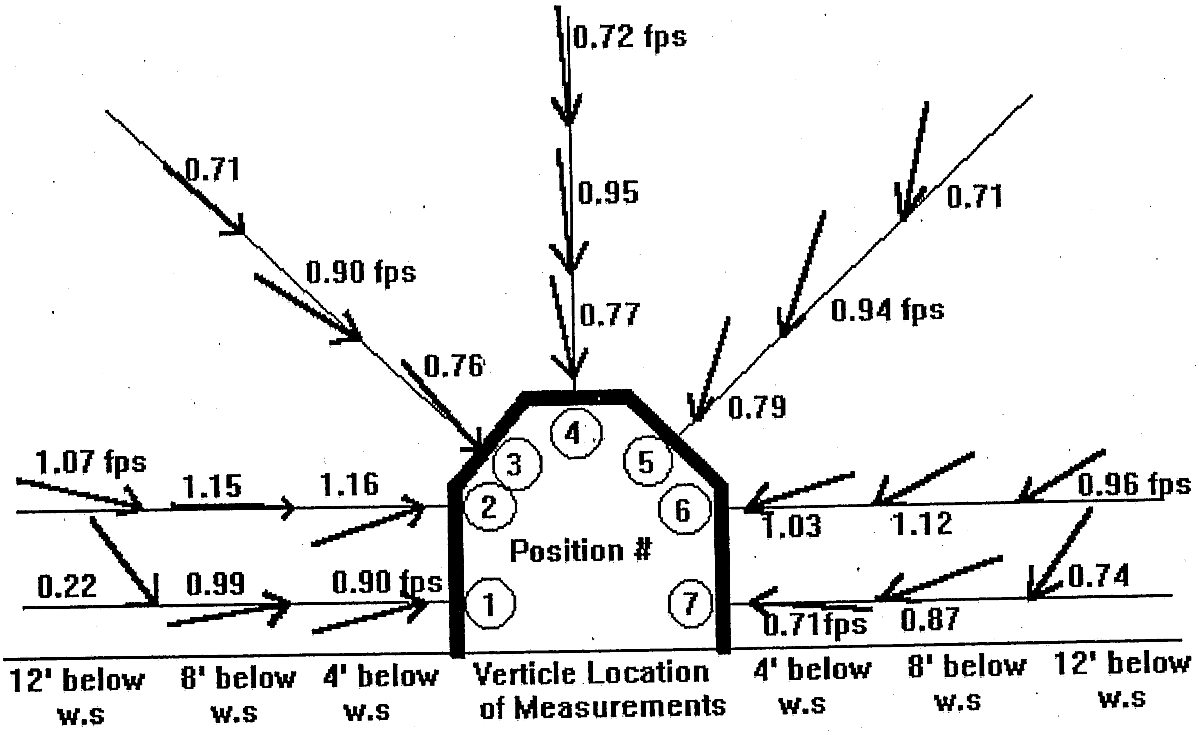


Figure 12 Prototype approach velocities 2 feet outside of crib.

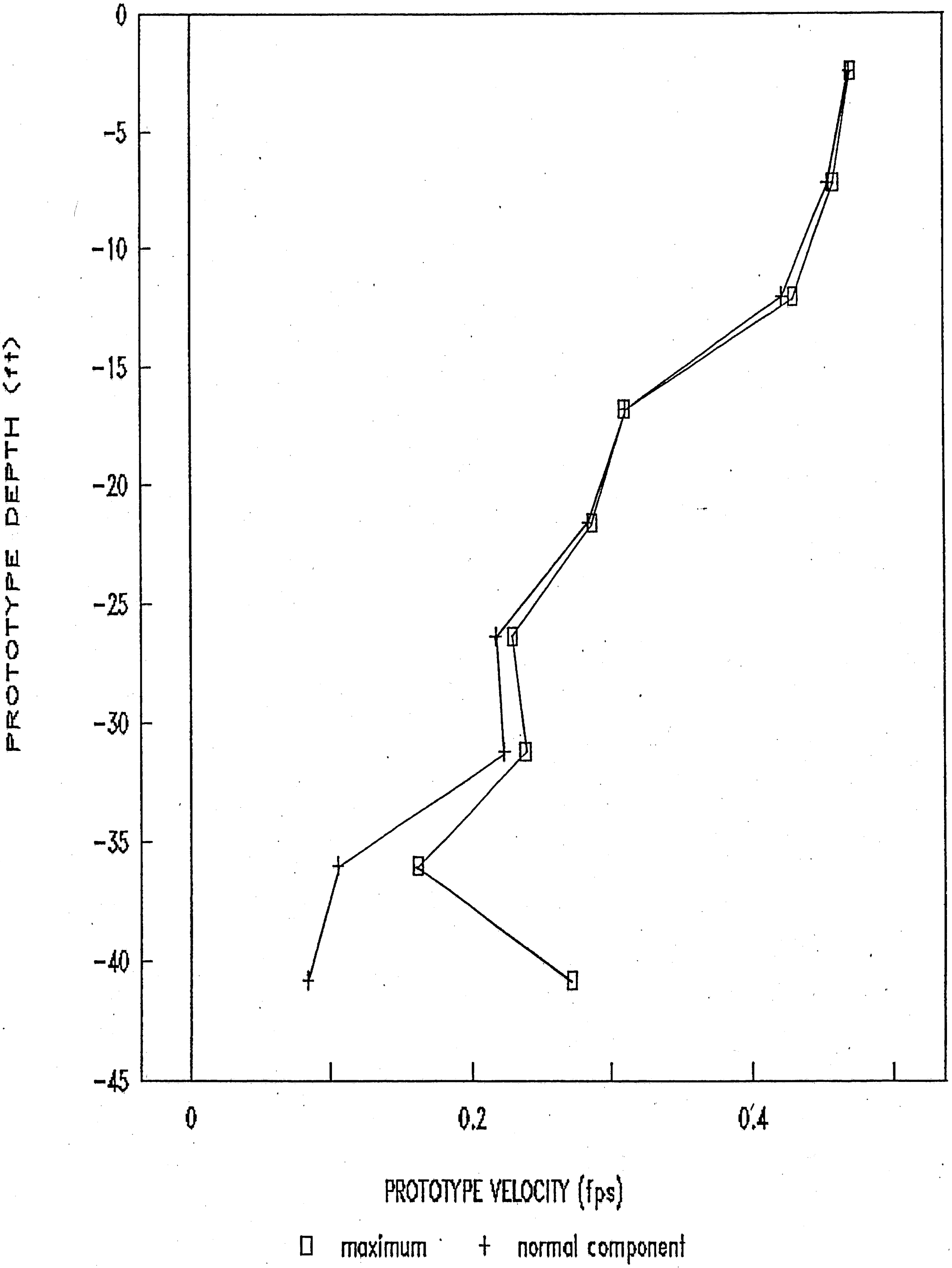


Figure 13 Velocity profile 12 ft in front of the crib.

# VI. Documentation of Recommended Design

The testing performed in the flow improvement study concluded that with the grid in place, the prototype intake could be placed three feet below the surface of the water without the formation of surface vortices. The relatively shallow submergence is good from a dissolved oxygen concentration perspective; however, it presents other problems in the startup and operation of the siphon. With the bottom of the intake at 3 feet below the water surface, and the five–segment bend in the 12 foot diameter intake, the top of the bend would be approximately 21 feet above the water surface. This approaches the limits of available vacuum pumps needed to initially prime the penstock and bend. Additionally, while vapor pressure is theoretically obtained at approximately 33 feet of water, our experience has shown problems begin to occur in the range of 15 to 16 feet of vacuum suction. We therefore tested the "cutoff" model intake shown in Photos 7 and 8, corresponding to a height of 14 feet above the water surface in the prototype. Dimensions of the cutoff intake are given in Fig. 14.

The "cutoff" intake was run through the same tests as the non–cutoff intake described in Section V. *At an intake depth of three feet and a plate depth of 12 feet, the cutoff intake without the grid in place exhibited somewhat similar surface vortex formations as the non–cutoff intake without the grid.* Table 2 summarizes the quantitative data. *With the grid in place, no surface vortices were observed.* As with the non–cutoff intake, minor floor and bottom plate vortices were present in the cutoff intake study.

Headloss measurements for the intake and bend were conducted for the design flow rate of 1000 cfs. Water surface elevation was measured at a point away from the intake and connected to one side of a U–tube manometer. Four pressure taps connected with a manifold were placed on the penstock, 4 diameters downstream from the constriction, and connected to the other side of the U–tube manometer. The manometer was filled with meriam yellow indicating fluid, with a specific gravity of 1.20, to provide a sufficiently large deflection in the manometer for accurate pressure measurement.

Beginning with Bernoulli's equation:

$$z_1 + \frac{P_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + h_L$$

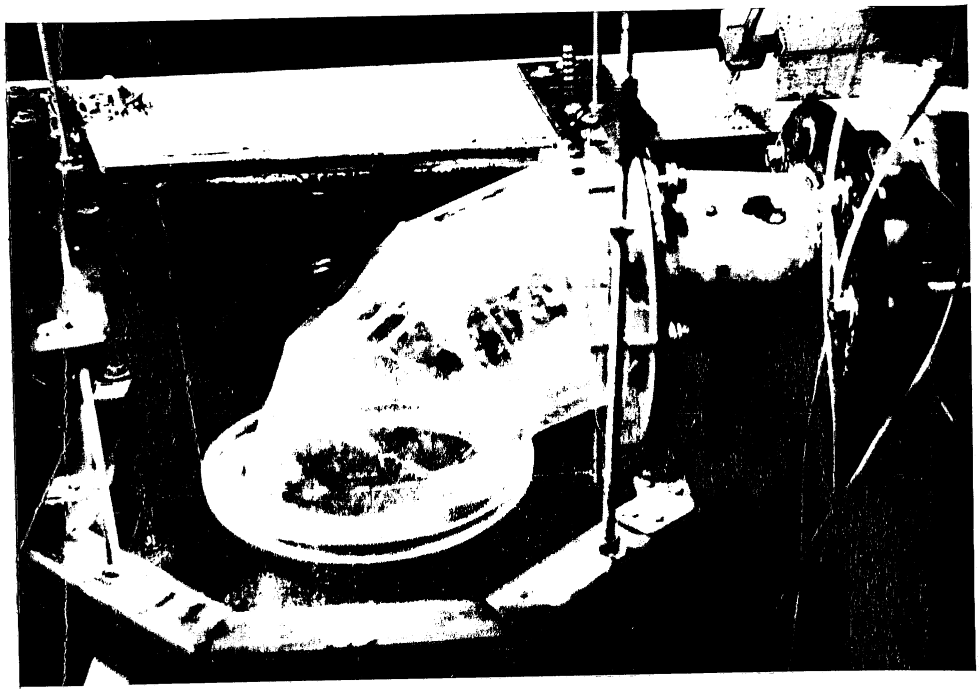


Photo 7 Cutoff intake.

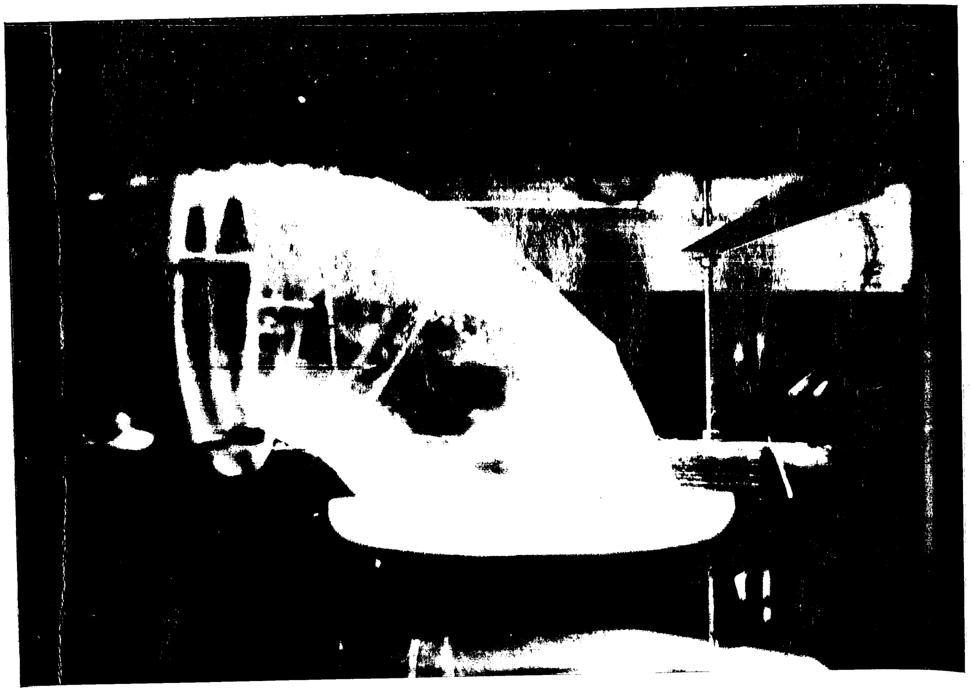


Photo 8 Cutoff intake.

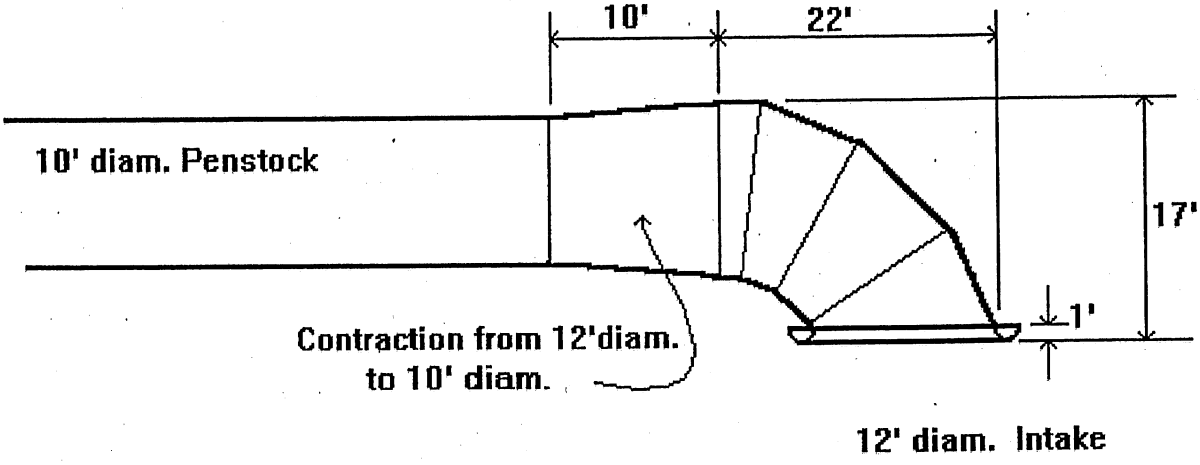


Figure 14 Recommended cutoff intake design.

where

$z_1$ = elevation of water surface
$P_1$ = atmospheric pressure
$\alpha_1$ = kinetic energy correction factor for velocity of water surface
$V_1$ = velocity of water surface
$z_2$ = elevation of penstock
$P_2$ = pressure in penstock
$\alpha_2$ = kinetic energy correction factor for velocity in penstock
$V_2$ = velocity in penstock
$\gamma$ = specific weight of water
$g$ = gravity
$h_L$ = headloss through intake and bend

assuming $V_1 = 0$:

$$\Delta h = \Delta h_m(S - 1.0) = z_1 + \frac{P_1}{\gamma} - (z_2 + \frac{P_2}{\gamma}) = \alpha_2 \frac{V_2^2}{2g} + h_L$$

or

$$h_L = \Delta h - \alpha_2 \frac{V_2^2}{2g}$$

where

$\Delta h$ = differential head reading in water units
$\Delta h_m$ = head difference across differential manometer with indicator fluid and water
$S$ = specific gravity of indicating fluid.

We assumed $\alpha_2 = 1$. This is a conservative assumption since $\alpha_2$ will actually be greater than 1. The actual headloss will be less than or equal to the calculated headloss.

$$h_{L_{actual}} \leq \Delta h - \frac{V_2^2}{2g}$$

The headloss through the intake and bend was calculated to be 0.7 ft.

Finally, the cutoff intake was tested under a variety of approach flow conditions in an effort to find a worst–case approach pattern. Initially all the vanes started on the open position, giving an all–directional flow pattern corresponding to the distribution of the flow when there is no flow over the spillway. When the side wall guide vanes were closed, the flow would correspond to the expected distribution of the flow when there is a significant discharge over the spillway.

The third condition permitted flow only to enter from the most downstream 2 ft of the side guide vanes (48 ft prototype). While this condition did not represent the flow distribution expected in the field, it was chosen for flow evaluation to further analyze the intake susceptibility to vortex formation.

*Without the grid in place, the flow from the extreme left of the intake looking upstream produced long lasting air core vortices* (approx. 2 to 4 seconds). The flow from upstream showed little change from the normal flow conditions. *With the grid in place, no surface vortices were observed either from the extreme left approach or from the upstream approach.*

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