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# HUNGRY HORSE SELECTIVE WITHDRAWAL HYDRAULIC MODEL STUDY

August 1994


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16. ABSTRACT
An evaluation of two selective withdrawal concepts for application at Hungry Horse Dam was performed at the Bureau of Reclamation's Hydraulics Laboratory. A hydraulic model of a single power penstock intake and trashrack structure was constructed to study head losses and the potential for air-entraining vortex formation associated with the two different concepts. The two concepts were: (1) installation of bulkheads for the five bays inside of each existing trashrack structure (original design concept) and (2) the installation of a semi-cylindrical bulkhead which is also internal to the existing trashrack structures (a VE [value engineering] study team proposal). The results indicate that the VE proposal concept exhibits less head loss and weaker surface vortex action compared to the original design concept. The test data consisting of head loss versus discharge, head loss versus control gate submergence, and vortex observations for the two concepts are given.

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Denver, Colorado

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**UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION**

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Frontispiece. - Aerial photograph of Hungry Horse Dam and outlet works.

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## PURPOSE

This report presents the results of the Hungry Horse selective withdrawal hydraulic model study. The study was performed to evaluate the proposed selective withdrawal configurations and to provide operation and design information. Determination of additional head loss associated with the installation of the selective withdrawal system, evaluation of entrance loss coefficients, and evaluation of vortex formation potential for various operating configurations were conducted.

## APPLICATION

The information included in this report is intended to guide the selection of the best selective withdrawal configuration for the Hungry Horse power penstock intakes from a performance standpoint. This information may be used for the design of future selective withdrawal systems of this type.

## INTRODUCTION

Hungry Horse Dam is located on the south fork of the Flathead River, about 20 miles northeast of Kalispell, Montana. The Hungry Horse Project includes a reservoir, dam and appurtenant works, powerplant, and switchyard. The project provides power to the Pacific Northwest, a storage system for flood control, and contributes to irrigation as well as navigation. Figure 1 shows the general location of the Hungry Horse Project. Figure 3 shows Hungry Horse Dam plan, elevation, and maximum section.

Currently releases are not in conformance with Montana water quality standards for new projects (constructed after 1971) (Bureau of Reclamation, 1993). Release temperatures are lower than is acceptable for fish habitat. Thus, a method of retrofitting the power penstock intakes with selective withdrawal capability is under study. Selective withdrawal will be required during the period when the reservoir becomes stratified (June through September). Presently, during power generation periods, only cold water releases from the lower portion of the reservoir are possible. During power peaking operation, this cold water combines with the Flathead River (three miles downstream from the dam) temperatures, which exceed 15 °C. The result is thermal shock, causing excessive stress to aquatic life. The powerplant is presently operated to slowly increase powerplant discharges to reduce this thermal shock. Figure 2 illustrates the expected influence of selective withdrawal on river temperatures (Bureau of Reclamation, 1993).

The ability to withdraw water from various elevations in the reservoir will provide the necessary control to regulate the main stem temperature in the Flathead river to simulate natural conditions and provide for optimum fish growth efficiency.

A hydraulic model study was conducted to investigate the performance of two selective withdrawal concepts. The original selective withdrawal design concept consisted of internal bulkheading for each of the trashrack structures, creating adjustable submerged weirs in front of each intake. The weirs act to raise the intake elevation and force withdrawal from higher in the water column. This design allows for the withdrawal of water from within the epilimnion and thermocline regions, which contain higher temperature water.

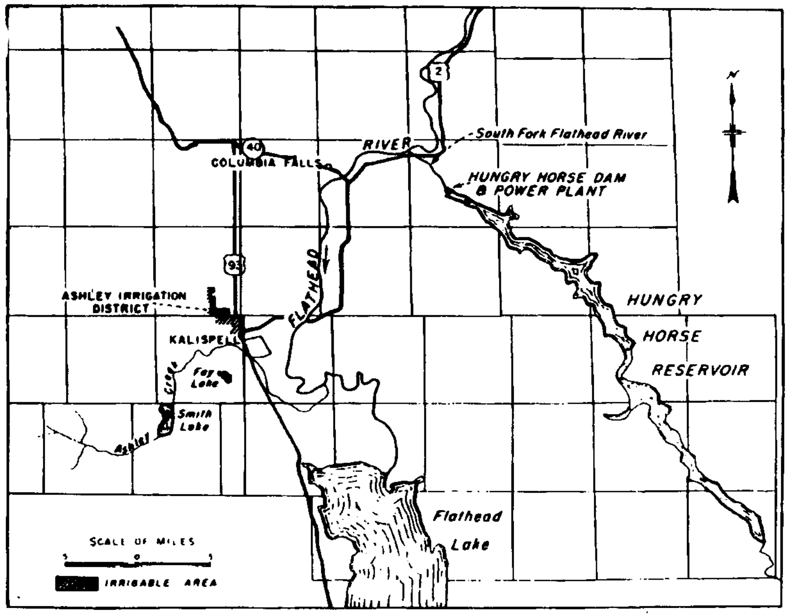
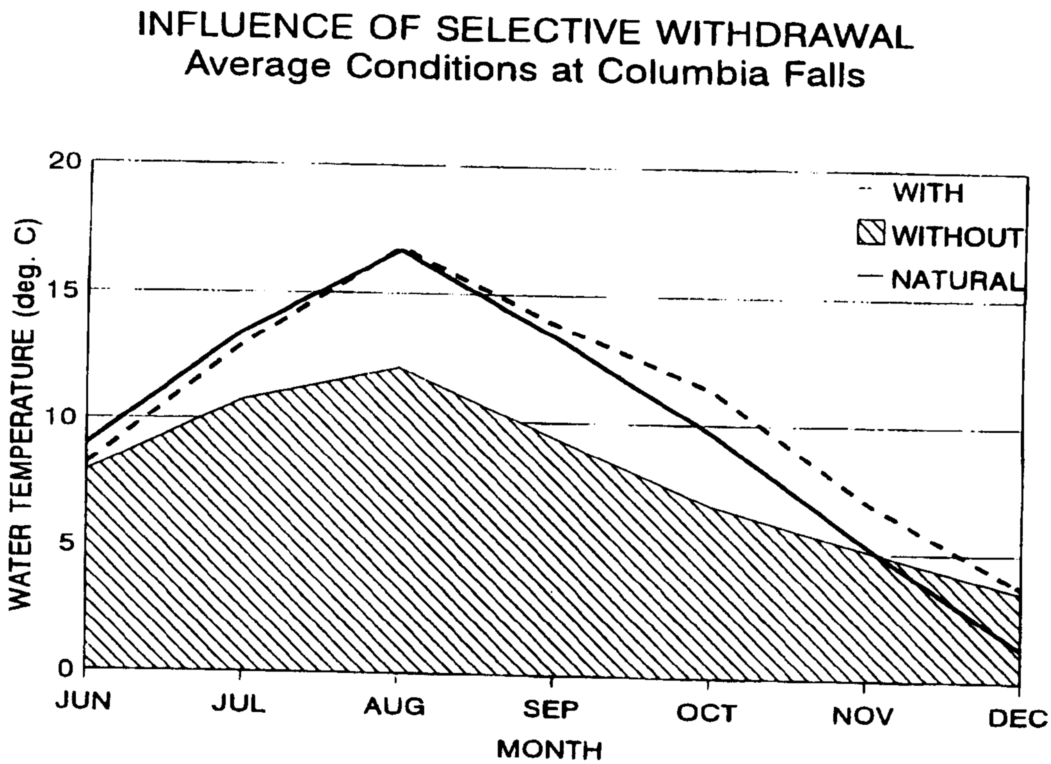
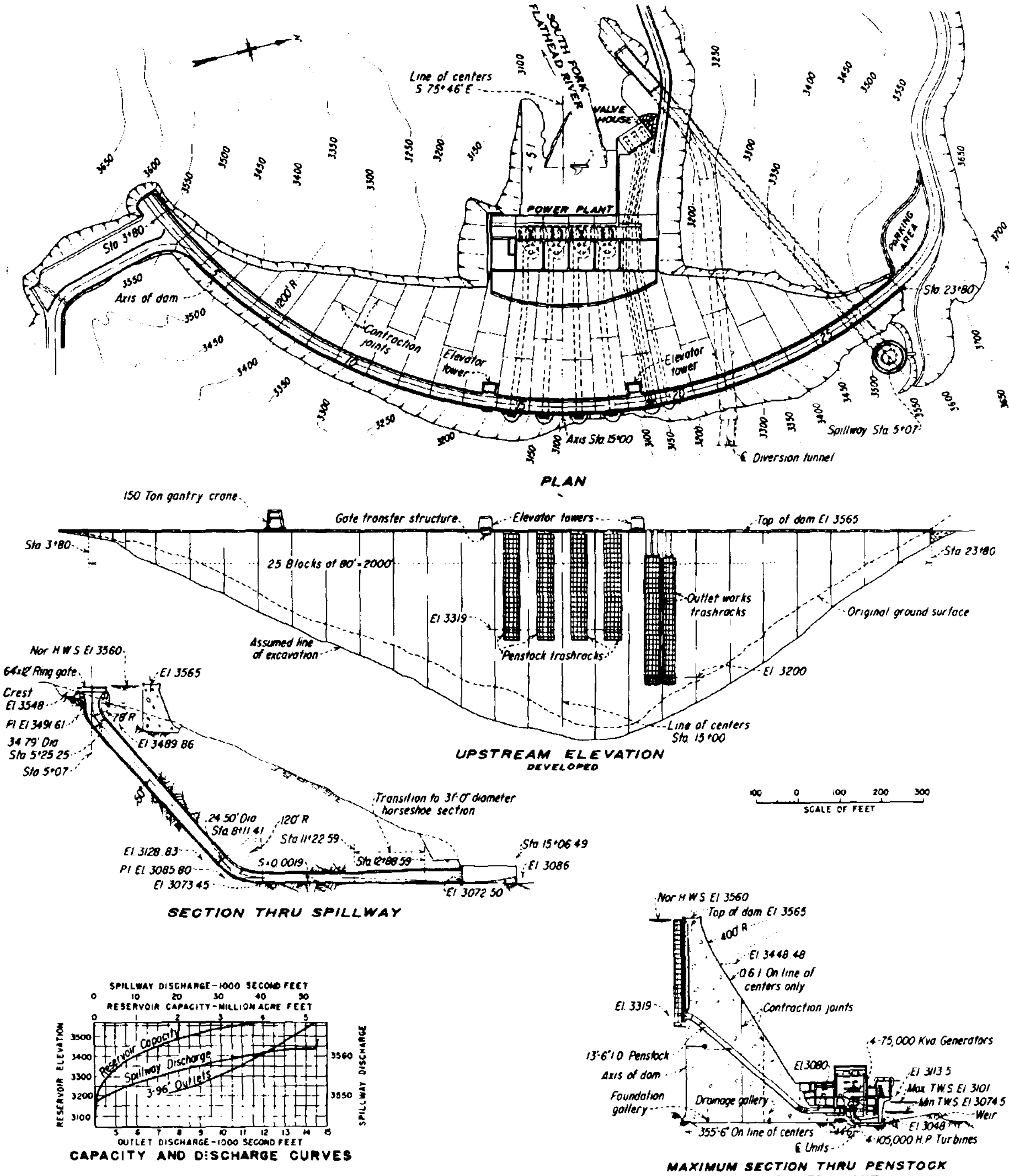



Figure 1. - Hungry Horse Project general location.




Data for the 1st of each month

Figure 2. - Influence of selective withdrawal on river temperature.




Hungry Horse Dam and Powerplant, Plan and Sections

Figure 3. - Hungry Horse Dam: plan, elevation, and sections.

The design must provide the appropriate flexibility to handle fluctuating water surface elevations to maintain required submergence limits, consequently minimizing vortex action. The upper portion of the bulkheads must be movable for this purpose. In addition to the original design concept, a VE (value engineering) study team proposal was investigated. The VE proposal consisted of the installation of semi-cylindrical bulkheads internal to each existing trashrack structure as shown on figure 5.

## CONCLUSIONS

Based on the results of this study, the following may be concluded:

- The semi-cylindrical internal concept (VE proposal) performed equal to or better than the bay bulkhead concept (original concept) in all areas of this investigation.

- Head loss associated with the semi-cylindrical internal bulkhead concept will be about 1.5 ± 0.6 m (5.0 ± 2.0 ft) for maximum intake discharge passable under a minimum submergence of 6.1 m (20 ft). For the same conditions, head loss with the bay bulkhead concept will be about 2.0 ± 0.8 m (6.6 ± 2.6 ft).

- Head loss for the internal concept (VE proposal) will vary as the square of discharge ($Q^2$) and the inverse square of submergence ($1/s^2$).

- Head loss associated with both concepts consists primarily of entrance or form losses. Friction losses are considered negligible.

- Air entraining vortices will likely be encountered for operation at high discharge ($Q$ near maximum passable) in combination with low submergence (6.1 m or less). Frequent operation under these conditions may require vortex suppression devices.

- Air entraining vortices will not likely be encountered for discharges below 65 $m^3/s$ (2300 $ft^3/s$) with a minimum submergence of 6.1 m (20 ft).

- Based on model observations of vortex conditions, the recommended minimum submergence is 6.1 m (20 ft) for all discharges up to the maximum passable intake discharge of 87 $m^3/s$ (3070 $ft^3/s$).

- Based on model results, the semi-cylindrical internal bulkhead concept performance is the best of the two options tested for Hungry Horse Dam.

## SIMILITUDE

The hydraulic model of the Hungry Horse selective withdrawal concept must be geometrically and kinematically similar to the prototype to adequately predict prototype performance under specified operating conditions. Geometric similarity is achieved with the ratios of all geometric parameters between model and prototype being equal. This similarity is represented by the length ratio, $L_r = L_p/L_m$. Kinematic similarity exists when the ratios of velocity between model and prototype are equal. These geometric and kinematic ratios for a 1:18 scale Froude model are given as follows:

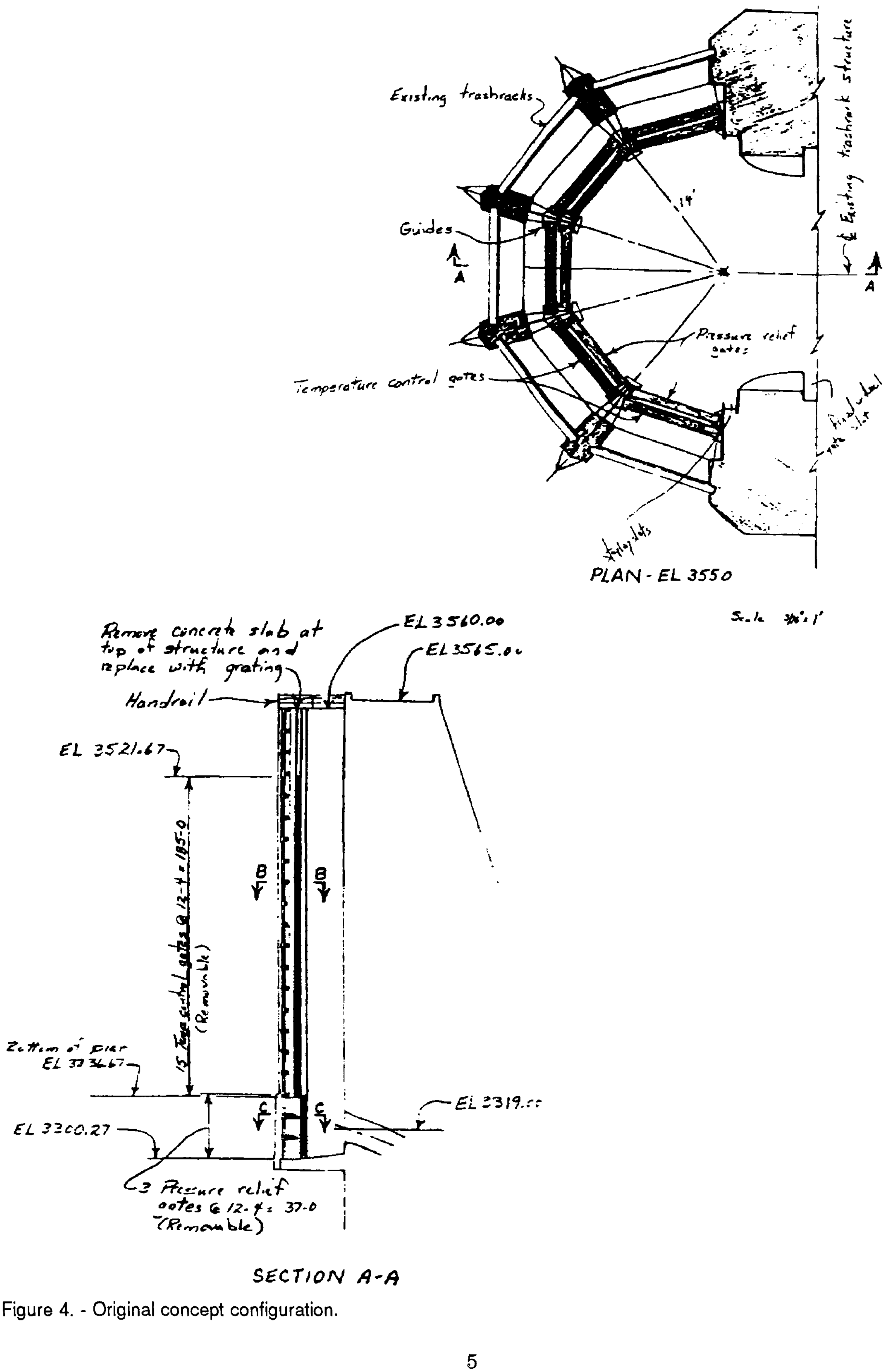



Figure 4. - Original concept configuration.

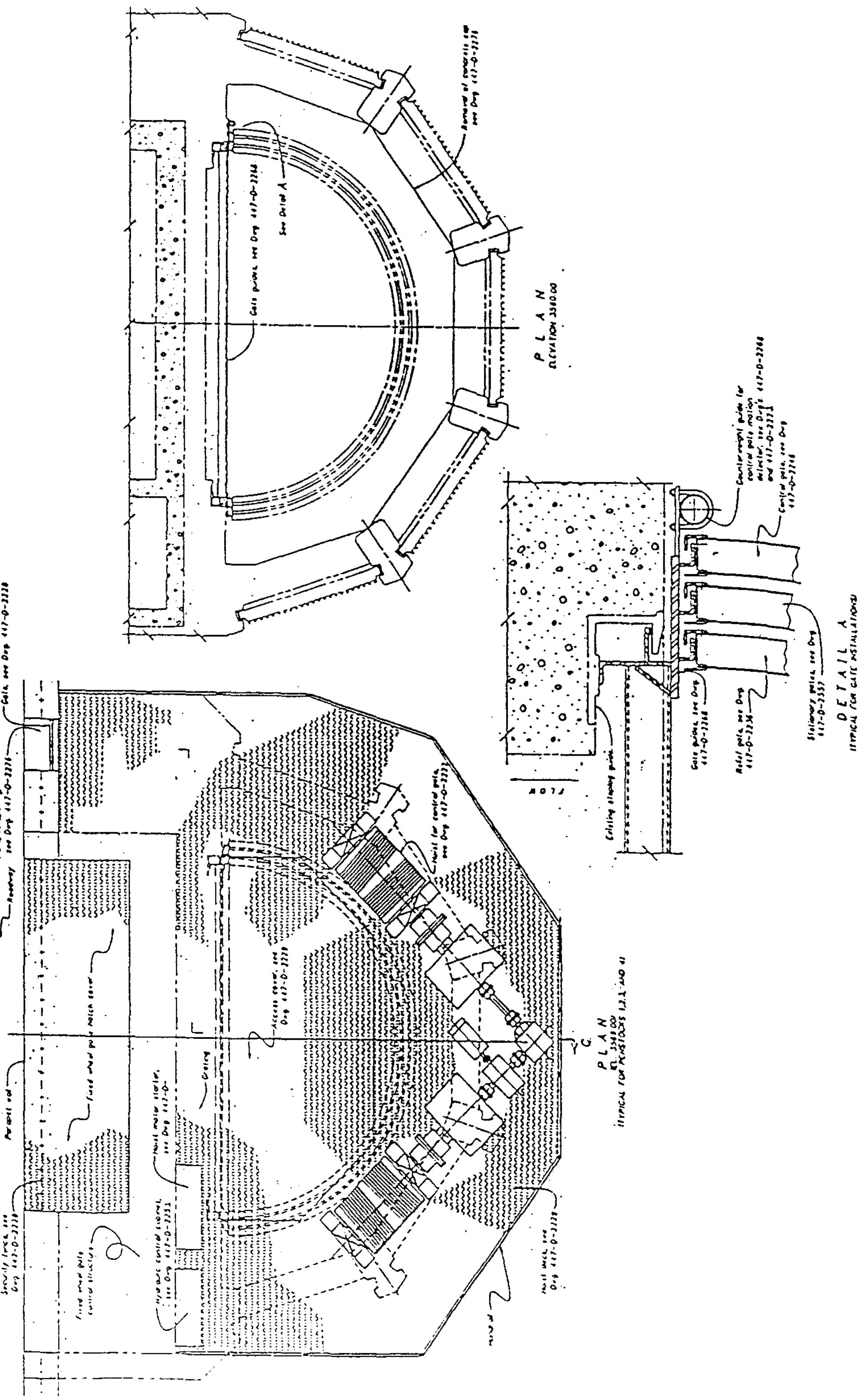



Figure 5a. - Conceptual layout: VE proposal concept (plan).

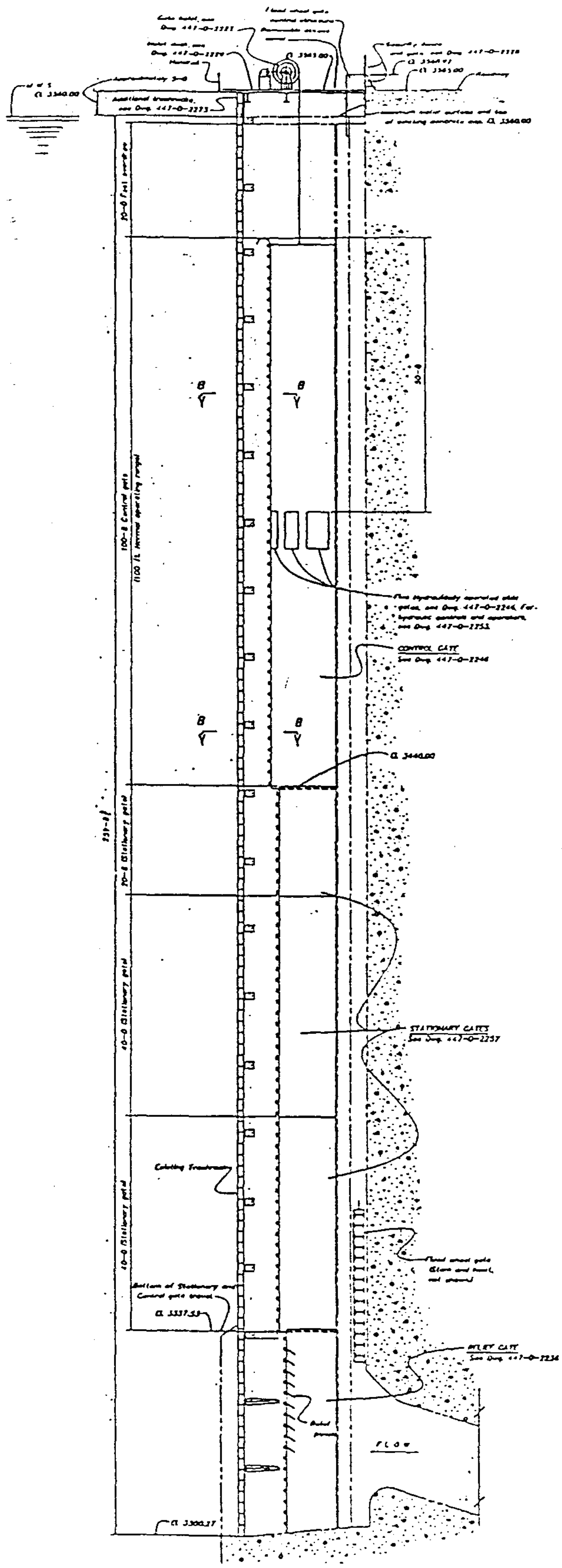


Figure 5b. - Conceptual layout: VE proposal concept (elevation).

**Geometric**

$L_r = L_p/L_m = 18$

$A_r = L_r^2 = 324$

$V_r = L_r^3 = 5{,}832$

where:

$A_r$ = area ratio

$V_r$ = volume ratio

**Kinematic**

$t_r = L_r^{1/2} = 4.2$

$v_r = L_r^{1/2} = 4.2$

$a_r = 1.0$

$Q_r = L_r^{5/2} = 1{,}374$

where:

$t_r$ = time ratio

$v_r$ = velocity ratio

$a_r$ = acceleration ratio

$Q_r$ = discharge ratio

## PHYSICAL MODEL

The physical model is a 1:18 scale model of a single power penstock intake and trashrack structure. The scale was selected as the minimum required to adequately model surface vortex formation. Previous studies have shown that viscous effects can be considered negligible for Reynolds numbers greater than $1.5 \times 10^5$ (Hecker, 1981). Because this flow is gravity driven, kinematic similarity was achieved by application of Froude law similitude.

## TEST SETUP

An existing model head box was modified to include a single power penstock intake and trashrack structure for the Hungry Horse hydraulic model study. A piezometer ring was employed to measure static pressure in the discharge pipe. This pressure was directly compared to the static pressure in the head box by means of a differential pressure transducer. The laboratory flow control and Venturi bank measurement system were used to deliver the desired flows to the model. A hook gage and stilling well were used to monitor reservoir water surface elevations. Model flow conditions were set by establishing a constant discharge into the model and then regulating the valve located on the penstock outlet pipe to adjust the reservoir water surface elevation.

## MODEL TESTS

### Theory

Application of Bernoulli's equation along a streamline is required to determine head loss associated with the selective withdrawal system. This equation is given as:

$$z_1 + P_1/\gamma + v_1^2/2g = z_2 + P_2/\gamma + v_2^2/2g + h_L$$

where:

$z_1$ = reservoir EL, m (ft)

$z_2$ = piezometer ring EL, m (ft)

$v_1$ = velocity in the far field of the intake at reservoir EL, m/s (ft/s)

$v_2$ = velocity at piezometer ring location, m/s (ft/s)

$P_1/\gamma$ = pressure head at reservoir EL, m (ft)

$P_2/\gamma$ = pressure head at piezometer ring location, m (ft)

$h_L$ = total head loss, m (ft)

$g$ = gravitational acceleration, m/s$^2$ (ft/s$^2$)

Solving for $h_L$ in the above equation, assuming $v_1$ and $P_1/\gamma$ are zero, gives:

$$h_L = (z_1 - z_2) - P_2/\gamma - v_2^2/2g, \text{ m (ft)}$$

The entrance loss coefficient, $K$, can then be described as the proportionality constant between head loss, $h_L$, and velocity head referenced to a point within the structure along a streamline, $v^2/2g$, as:

$$h_L \propto v^2/2g \;\Rightarrow\; K = h_L/(v^2/2g)$$

### Head Loss Versus Discharge

The initial test data obtained consisted of baseline tests with no selective withdrawal structure in the model. This arrangement was required to determine baseline characteristics of the model. Additional head loss incurred by each selective withdrawal concept was determined by subtracting the baseline head loss data from the total head loss data obtained for each of the selective withdrawal concepts investigated. For each concept, head losses were determined for flows up to the maximum passable power penstock discharge.

## Vortex Formation

Flow surface observations were conducted at the same time as the head loss versus discharge data were being acquired. The location and qualitative strength of vortices were noted. Video tape was used to document these results.

## Head Loss Versus Submergence

Head loss was measured in the same manner as the previously acquired head loss versus discharge data. The desired bulkhead submergence was set for each point in question and the reservoir elevation was maintained at the maximum. The discharge was then varied to obtain head loss data for the various discharges of interest to be investigated.

## Velocity Profiles

Near field velocity profiles were measured under steady state conditions using a Marsh-McBirney electromagnetic velocity meter. These measurements were conducted at the maximum reservoir elevation and the discharge of 65 $m^3/s$ (2300 $ft^3/s$) at a selective withdrawal gate submergence of 6.1 m (20 ft). The velocity meter was positioned vertically at the desired distance away from the trashrack structure. Measurements were taken at 1.8-m (5.9-ft) increments of depth. The results obtained from this portion of the study, although limited in applicability to actual field conditions, are indicative of the order of magnitude which can be expected for near field velocities in the prototype. Some variation in these profiles will be realized under stratified conditions and multiple unit operation.

# RESULTS

The following results were obtained from the 1:18 scale physical model of the single power penstock intake and trashrack structure:

## Head Loss Versus Discharge

Baseline head loss conditions for the hydraulic model were evaluated over a discharge range of 0 to 87 $m^3/s$ (0 to 3070 $ft^3/s$), where 87 $m^3/s$ is the maximum discharge passable for a single power penstock unit. Baseline conditions consist of those for which no bulkheads are installed. The evaluation of baseline conditions provides for determination of head loss associated with each of the configurations and a basis for comparison of the two concepts investigated. Baseline head loss results were subtracted from all selective withdrawal test results to obtain the additional head loss for each of the concepts.

Tests of head loss as a function of discharge were conducted for both design options at submergences of 6.1 m (20 ft) and 12.2 m (40 ft). Submergence is the depth of water above the top of the selective withdrawal bulkheads. In addition to this testing, head loss as a function of discharge was determined with the bottom relief gate removed. The relief gate is the lowest section of the bulkhead structure within the water column. This section will likely be removed to reduce head loss during periods when the reservoir is isothermal.

Figures 6 and 7 represent the data and statistical curve fits for all head loss tests. The curve producing the lowest head losses over the discharge range in question is the baseline curve. The next lowest curve represents the removed relief gate configuration. The remaining order

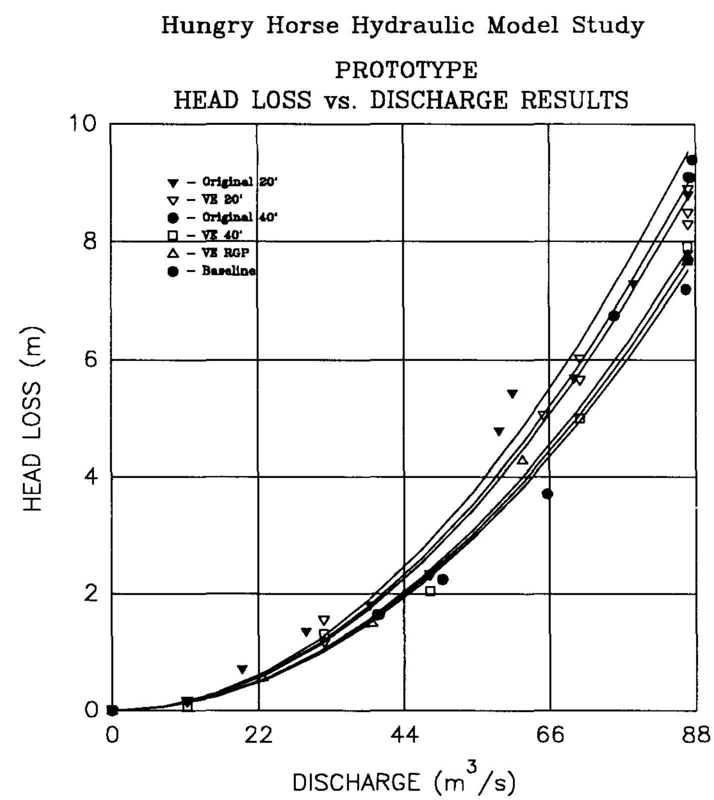



Figure 6. - Baseline and configuration data (SI/metric).

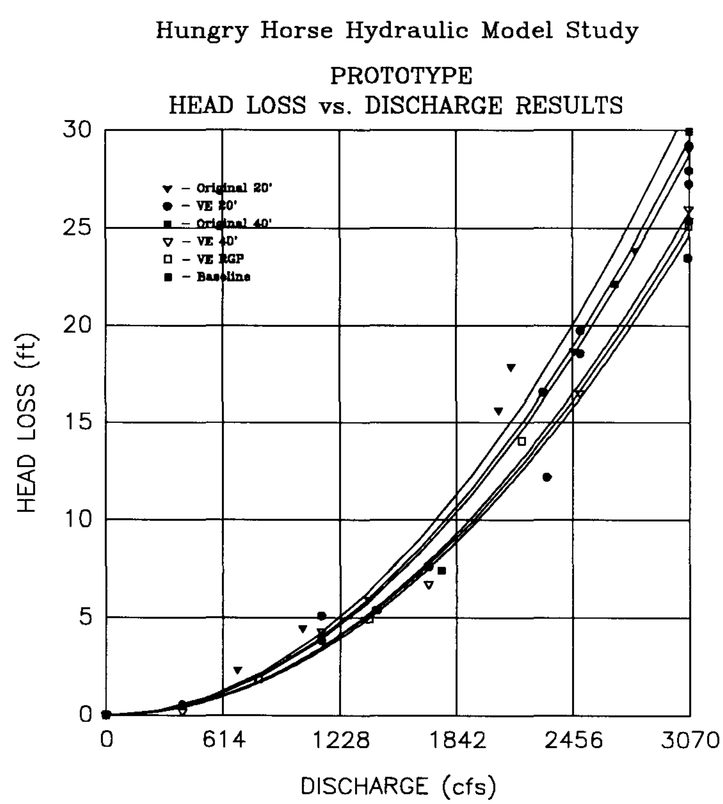



Figure 7. - Baseline and configuration data (in-lb).

from lowest to highest is: the semi-cylindrical bulkhead at 12.2 m (40 ft) submergence, the bay bulkhead concept at 12.2 m (40 ft) submergence, the semi-cylindrical bulkhead at 6.1 m (20 ft) submergence, and the bay bulkhead at 6.1 m (20 ft) submergence. The additional head loss or entrance loss attributed to each selective withdrawal concept is determined by subtracting the baseline relationship from the head loss data for that concept (figs. 8 and 9).

Head loss varies with the square of discharge, as expected for entrance losses. These results indicate that the semi-cylindrical concept produces improved performance over the bay bulkhead concept. At the maximum passable discharge of 87 $m^3/s$, the bay bulkhead concept produced a head loss of about 2.0 ± 0.8 m (6.6 ± 2.6 ft) at a submergence of 6.1 m (20 ft). The semi-cylindrical concept produced about 1.5 ± 0.6 m (5.0 ± 2.0 ft) under the same submergence and discharge. Results for higher submergences reflect the same trend as those above. The semi-cylindrical concept produced less head loss than the bay bulkhead concept. For both concepts, head loss decreased sharply as submergence increased.

These results were also used to determine entrance loss coefficients for the submergences of 6.1 and 12.2 m. The entrance loss coefficient was determined by dividing the measured head loss by the velocity head within the structure, along a streamline. Thus, the estimated entrance loss coefficients produced by the bay bulkhead concept are 5.2 and 3.1 for submergences of 6.1 m and 12.2 m, respectively. The semi-cylindrical concept produced entrance loss coefficients of 4.4 and 1.2 for submergences of 6.1 m and 12.2 m, respectively.

Measurement uncertainties consisting of random errors associated with the reported head loss data were determined by error analysis. The fractional uncertainty associated with all head loss results was determined by computing the standard deviation of the mean (which is the uncertainty associated with the measurement result) and dividing this value by the statistical mean (Taylor, 1982). The highest fractional uncertainty obtained was then taken as the fractional uncertainty for all head loss results. Thus, a conservative estimate of the uncertainty associated with the head loss results is reported as ±0.4. Although this uncertainty appears excessive, the scale of the model influences the uncertainty in each of the measurements because, as expected, all uncertainties scale with the results.

### Vortex Formation Potential

Flow visualization techniques were employed to determine the surface vortex formation characteristics associated with the installation of the proposed selective withdrawal structures. Although vortex strengths were not directly measured, a qualitative evaluation was conducted to determine acceptable conditions. Vortex observations were made for both concept configurations at submergences of 6.1 m (20 ft) and 12.2 m (40 ft) at maximum reservoir elevation (1085 m [3560 ft]) and a maximum passable discharge of 87 $m^3/s$ (3070 $ft^3/s$). The absence of a visible surface dimple inside the trashrack structure for both concept configurations indicated no significant vortex action is expected at a submergence of 12.2 m (40 ft). However, when the submergence was reduced to a control gate crest depth of 6.1 m (20 ft), substantial vortex action was observed at the surface just inside of the fixed wheel gate slot.

Figure 10 represents the two oppositely rotating vortices present at this location. The location of these vortices was the same for both concept configurations. The vortices are generated by flow separation from the trashrack structure at the fixed wheel gate slots.

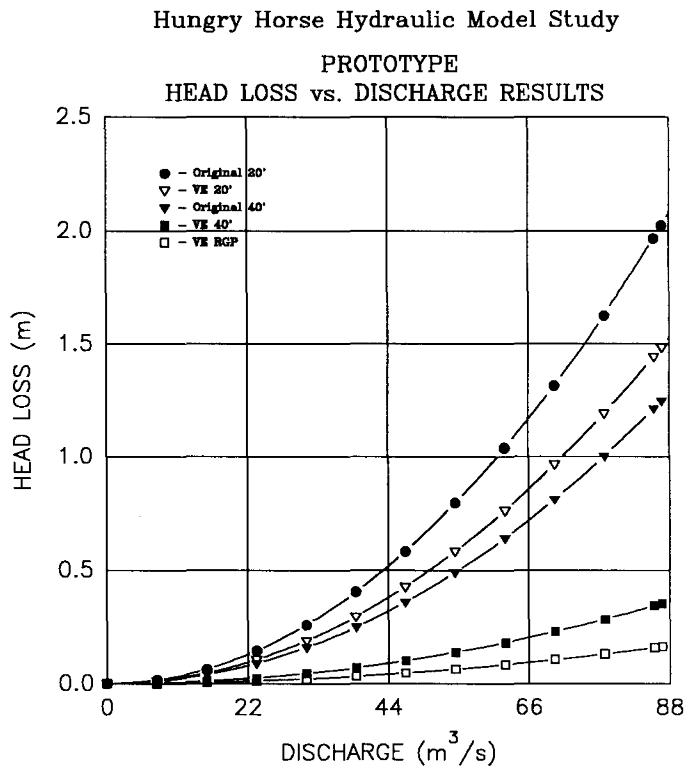



Figure 8. - Head loss attributed to the selective withdrawal bulkheads as computed from the best fit regression analysis of model head loss data (SI/metric).

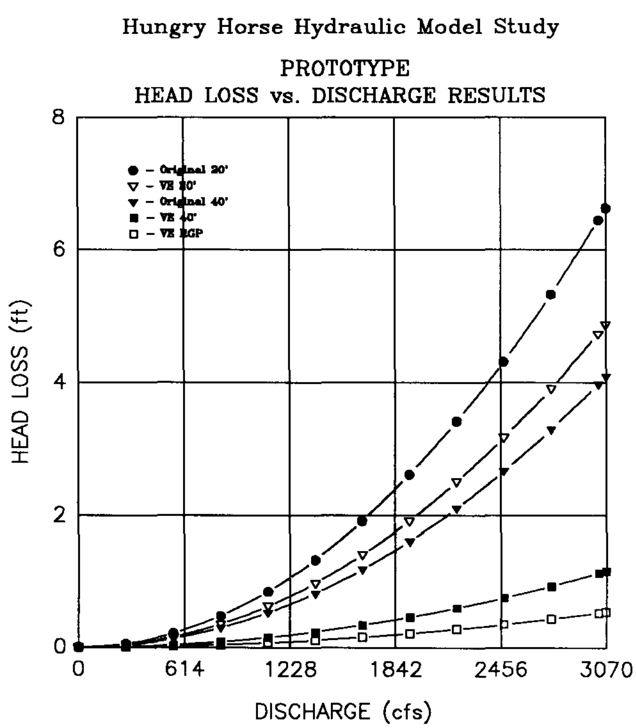



Figure 9. - Head loss attributed to the selective withdrawal bulkheads as computed from the best fit regression analysis of model head loss data (in-lb).

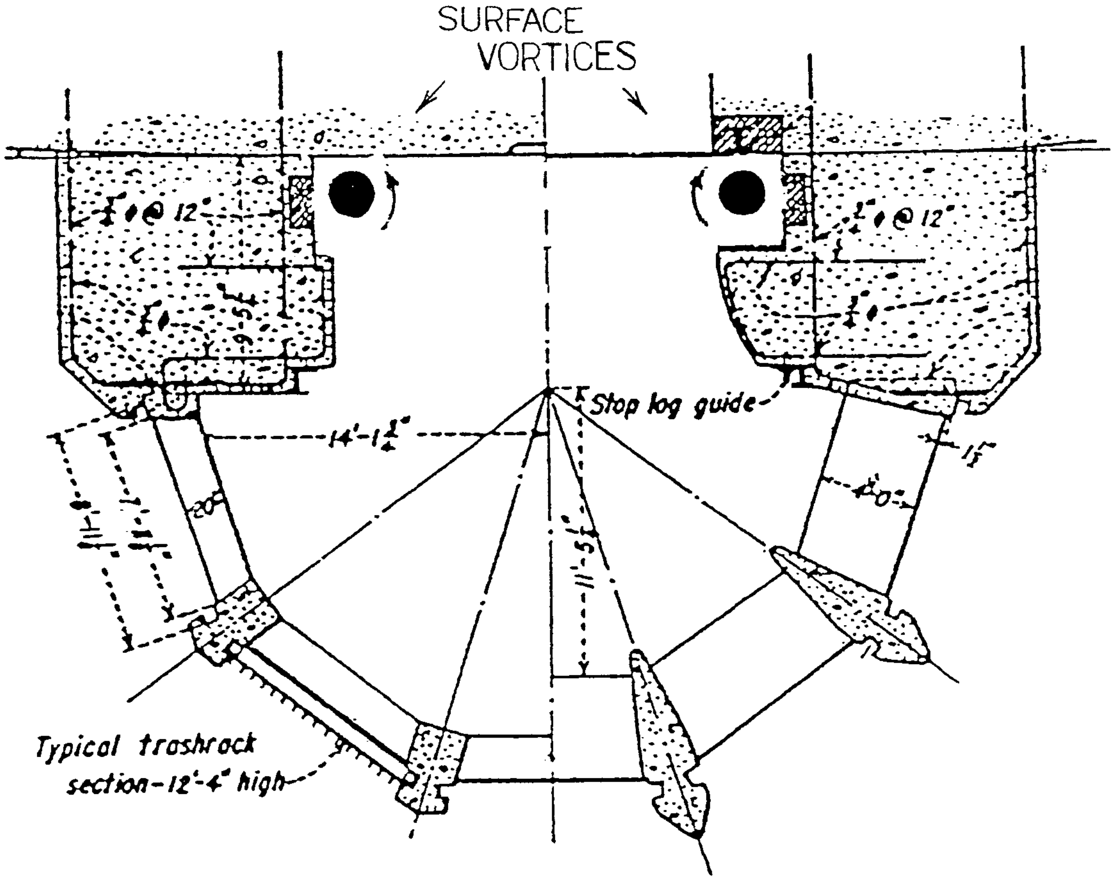



Figure 10. - Plan view of existing structure: relative size, location, and direction of surface vortices observed.

The strength was indicated by the fact that intermittent air-entrainment was observed in the model as bubbles being pulled down below the surface. It is important to note that a continuous air core down to the intake was not present under any of the conditions studied. A discernible difference existed in the frequency of intermittent air-entrainment between the two concepts. The semi-cylindrical concept exhibited slightly less air-entrainment compared to the bay bulkhead concept. This difference probably occurred because of the difference in entrance geometry of the concepts, the semi-cylindrical concept being more favorable. Vortex conditions that are air-entraining in the model are expected to be somewhat stronger in the prototype, which can result in air-entrainment to the turbines and rough turbine operation. A literature review of previous work done in the area of modeling surface vortices revealed that surface vortex strength may be determined qualitatively as follows (Hecker, 1981):

Type 1 - surface swirl.

Type 2 - surface dimple with coherent swirl.

Type 3 - dye core from surface to intake with coherent swirl.

Type 4 - vortex pulling.

Type 5 - vortex pulling air bubbles to intake.

Type 6 - full air core to intake.

Type 5 vortices typically represent unfavorable vortex conditions with regard to turbine operation. However, type 5 vortices can often be controlled by adding various rack or lattice-type vortex suppression devices (should this suppression be necessary). An important result of these observations is that type 5 vortices were observed in the model only for tests at the maximum passable discharge of 87 $m^3/s$ and a submergence of 12.2 m (20 ft) for the maximum reservoir elevation of 1085 m (3560 ft). Type 5 vortices were not present at the discharge of 65 $m^3/s$ (2300 $ft^3/s$) corresponding with the maximum reservoir elevation of 1085 m (3560 ft) for a submergence of 6.1 m (20 ft). This result indicates that for probable operating conditions, vortex strengths of type 5 will not likely be encountered in the prototype.

Based on the head loss versus discharge results and vortex observations, the VE proposal concept was chosen as the best alternative. Thus, for the remainder of testing, the emphasis shifted to documenting the performance of the semi-cylindrical concept in greater detail.

### Head Loss Versus Submergence: VE Proposal Concept

An understanding of the head loss versus submergence relationship was required to determine the effects of submergence on power generation for various operating configurations. Thus, additional head loss versus submergence curves were developed for the discharges tested over a reservoir draw-down from maximum reservoir elevation to reservoir elevation 1061 m (3480 ft). It is important to note that air-entraining vortex action was not observed in the model at submergences of 6.1 m (20 ft) and greater for any of the operating conditions given in table 1.

Table 1. - Operating configurations tested in the model.

| Water Surface Elevation | Discharge |
|---|---|
| 1085 m (3560 ft) | 65.1 $m^3/s$ (2300 $ft^3/s$) |
| 1079 m (3540 ft) | 62.3 $m^3/s$ (2200 $ft^3/s$) |
| 1073 m (3520 ft) | 60.8 $m^3/s$ (2150 $ft^3/s$) |
| 1067 m (3500 ft) | 59.5 $m^3/s$ (2100 $ft^3/s$) |
| 1061 m (3480 ft) | 58.1 $m^3/s$ (2050 $ft^3/s$) |

Figures 11 and 12 represent the head loss versus submergence relationships for the above operating conditions. Head loss data were measured for submergences of 6.1 m (20 ft) and 12.2 m (40 ft) for each flow. Curves given linking the measured points were estimated based on the functional relationship:

$$\text{Head loss} \propto 1/(\text{submergence})^2$$

The thick solid curves above and below the curves based on the model data show the upper and lower limits of expected performance. The upper limit shows the results obtained for the highest discharge tested at the maximum reservoir elevation plus the uncertainty associated with these results. The lower limit indicates the results of the lowest discharge tested at the minimum reservoir elevation minus the uncertainty associated with these results. Recall that the fractional uncertainty for head loss versus discharge results was reported as ±0.4.

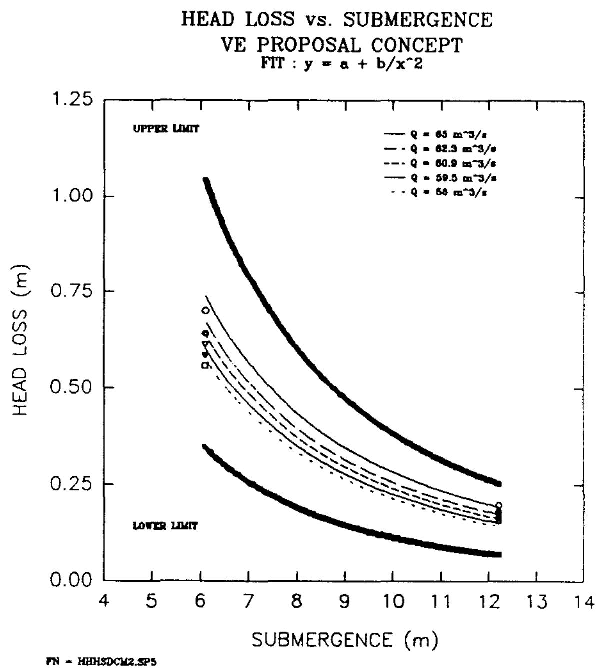



Figure 11. - Head loss verses submergence results (SI/metric).

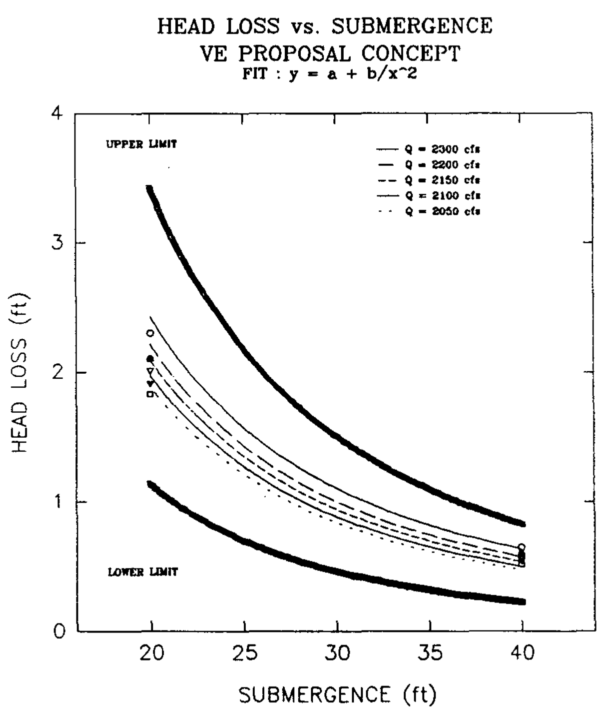



Figure 12. - Head loss verses submergence results (in-lb).

The upper limit shows that the maximum head loss which can be expected for a submergence of 6.1 m (20 ft) and a discharge of 65 $m^3/s$ will not be more than about 1.08 m (3.5 ft). On the other hand, the minimum head loss that can be achieved for the lowest discharge tested and a submergence of 12.2 m (40 ft) will not be better than about 0.1 m (0.3 ft).

Entrance loss coefficients were also estimated for operating conditions given in table 1 from the results presented on figures 11 and 12. These results are given in table 2.

Table 2. - Entrance loss coefficients.

| Submergence m (ft) | Entrance Loss Coefficient $K$ |
|---|---|
| 12.2 (40.0) | 1.2 |
| 11.1 (36.4) | 1.4 |
| 10.0 (32.8) | 1.7 |
| 8.9 (29.2) | 2.1 |
| 7.8 (25.6) | 2.7 |
| 6.7 (22.0) | 3.7 |
| 6.1 (20.0) | 4.4 |

Entrance loss coefficients varied with submergence as expected and were determined as the measured head loss divided by the calculated velocity head at a point within the bulkhead structure along a streamline. Since entrance loss measurements were not made directly, the head loss versus submergence results were used to calculate entrance loss coefficients. The relationship between head loss and velocity head is given as:

$$h_L = K(v^2/2g)$$

where:

$h_L$ = measured entrance loss, m
$K$ = entrance loss coefficient
$v^2/2g$ = velocity head, m

It is important to note that the Reynolds number will influence the entrance loss coefficient slightly over the range of discharges tested. Thus, the reported entrance loss coefficients, $K$, for the above submergences will not remain constant over the range of discharges likely to be encountered in the prototype.

## Near Field Velocity Profiles

Velocity profiles in the near field of the trashrack structure were investigated. Velocities were measured at the discharge, $Q$ = 65 $m^3/s$ (2300 $ft^3/s$), for maximum reservoir EL 1085 m (3560 ft). The control gate submergence was set at 6.1 m (20 ft). Figures 13 through 17 represent the velocity profiles measured along the structure centerline at distances of 1.4 m (4.5 ft), 2.7 m (9 ft), and 5.5 m (18 ft) from the trashrack structure, respectively.

Velocities are expected to vary slightly for each of the five bays of the trashrack structure because of variations in geometry. However, the flow field is expected to be symmetrical with

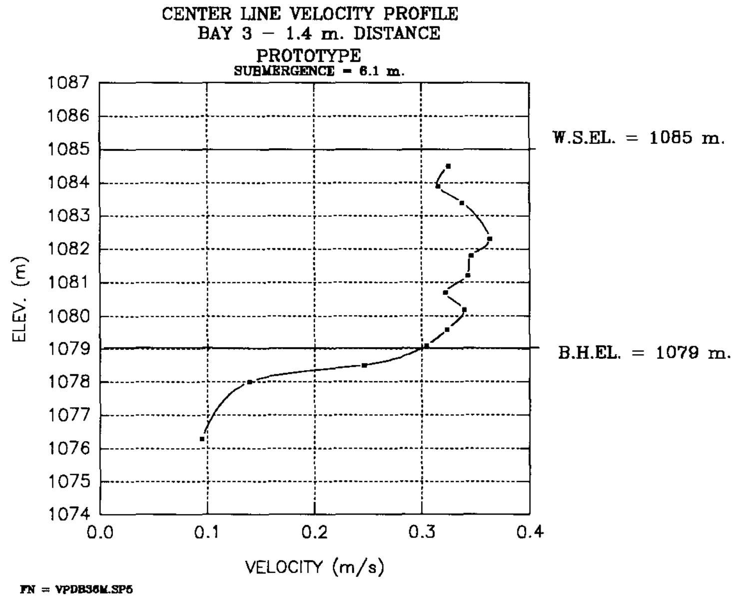



Figure 13. - Near field velocity profile for discharge $Q = 65\ m^3/s$ and reservoir EL = 1085 m at a distance of 1.4 m from trashrack structure (SI/metric).

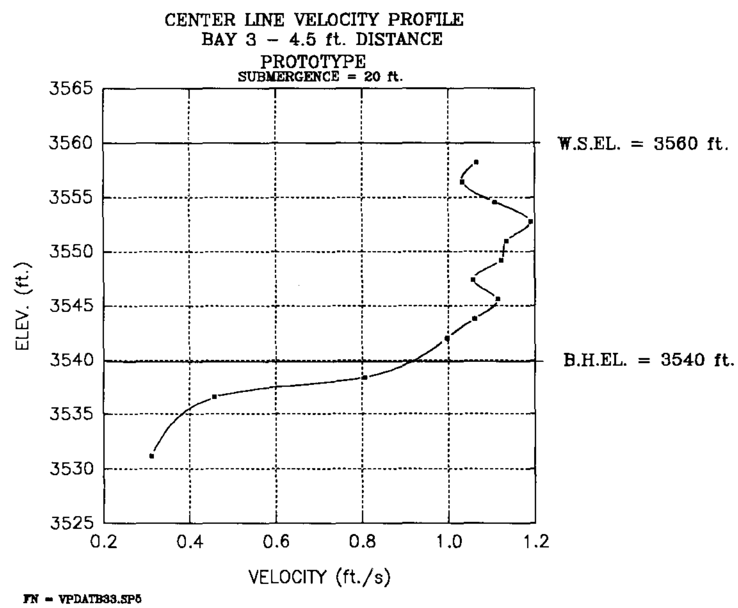



Figure 14. - Near field velocity profile for discharge $Q = 2300\ ft^3/s$ and reservoir El. = 3560 ft at a distance of 4.5 ft from trashrack structure (in-lb).

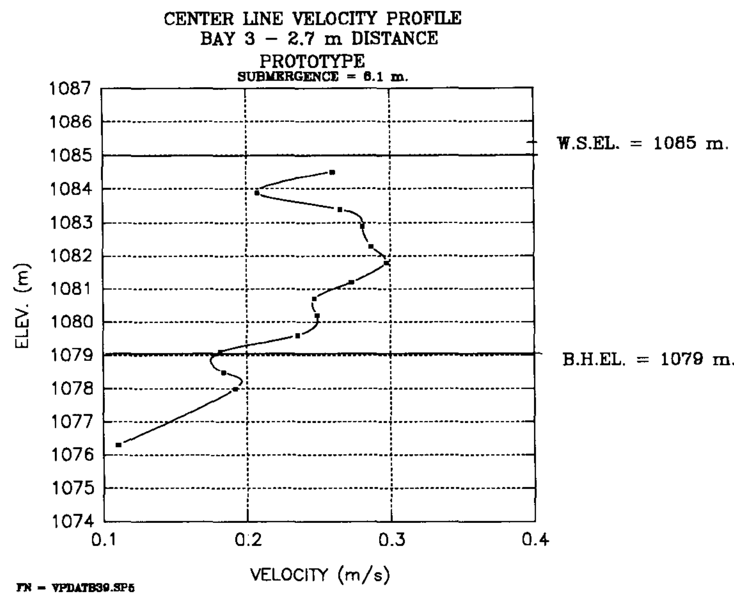



Figure 15. - Near field velocity profile for discharge $Q$ = 65 m$^3$/s and reservoir EL = 1085 m at a distance of 2.7 m from trashrack structure (SI/metric).

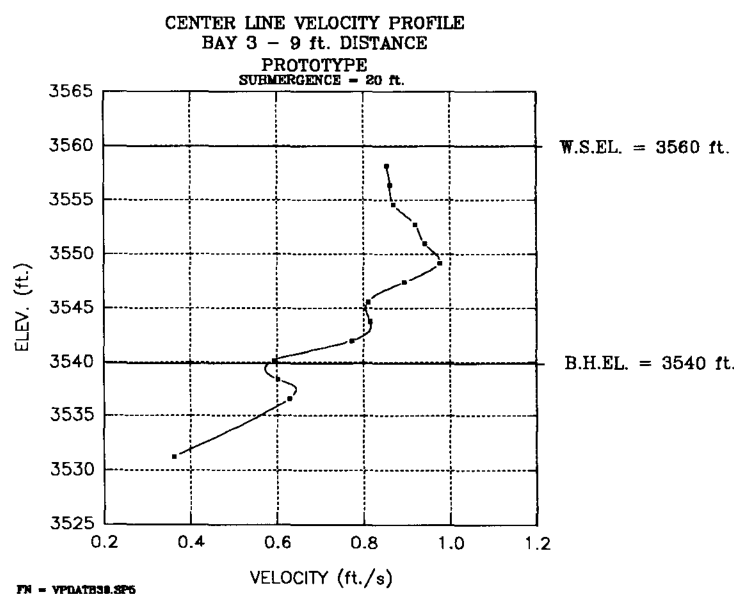



Figure 16. - Near field velocity profile for discharge $Q$ = 2300 ft$^3$/s and reservoir El. = 3560 ft at a distance of 9 ft from trashrack structure (in-lb).

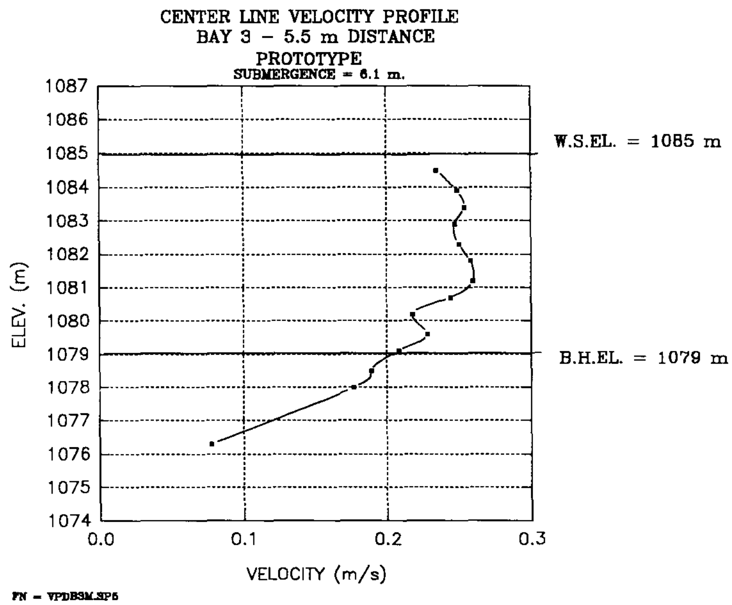



Figure 17. - Near field velocity profile for discharge $Q = 65$ m$^3$/s and reservoir EL = 1085 m at a distance of 5.5 m from trashrack structure (SI/metric).

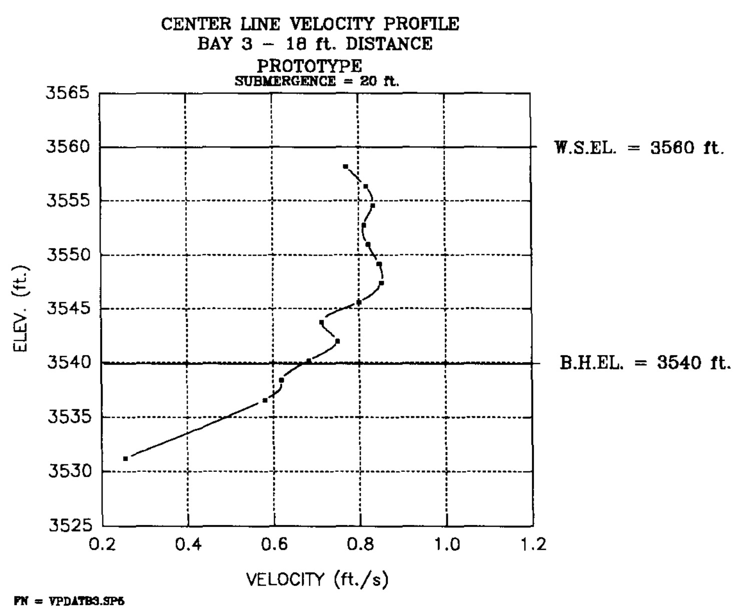



Figure 18. - Near field velocity profile for discharge $Q = 2300$ ft$^3$/s and reservoir El. = 3560 ft at a distance of 18 ft from trashrack structure (in-lb).

respect to the centerline of the trashrack structure. It is important to note that multiple unit operation will affect the flow field near the trashrack structure. Based on the results given for a single unit, potential flow theory could be used to develop a flow net estimate of the near field for multiple unit operation. This estimate was beyond the scope of this study.

Velocities greater than zero existing below the elevation of the top of the control gate (as illustrated by each of the measured profiles) indicate a vertical or up-welling component in the reservoir. This component was expected because under non-stratified conditions, the withdrawal zone will extend deep into the reservoir in the far field (Bohan and Grace, 1973). Although the physical model was not a stratified model, previous research results may be applied to estimate the extent of the withdrawal zone. This estimate can be done to determine the depth to which the withdrawal zone is expected to extend under specific stratification conditions and operating configurations. Previous work suggests that the withdrawal zone will extend to the free surface (Bohan and Grace, 1973). The following relationship was developed by Bohan and Grace:

$$V_w = 0.32[(Z_o + H_w)/H_w][(\Delta\rho_w/\rho_w)gZ_o]^{1/2}$$

where:

$V_w$ = average velocity over weir, (ft/s)
$Z_o$ = vertical distance from elevation of weir crest to the lower limit of the zone of withdrawal, (ft)
$H_w$ = depth of flow over weir, (ft)
$\Delta\rho_w$ = density difference of the fluid between the elevation of the weir crest and the lower limit of the withdrawal zone, g/cm$^3$
$\rho_w$ = density of fluid at elevation of weir crest, g/cm$^3$
$g$ = gravitational acceleration, m/s$^2$

By applying reservoir density profile information, the lower limit of withdrawal may be predicted for various stratification and operating conditions using the above equation.

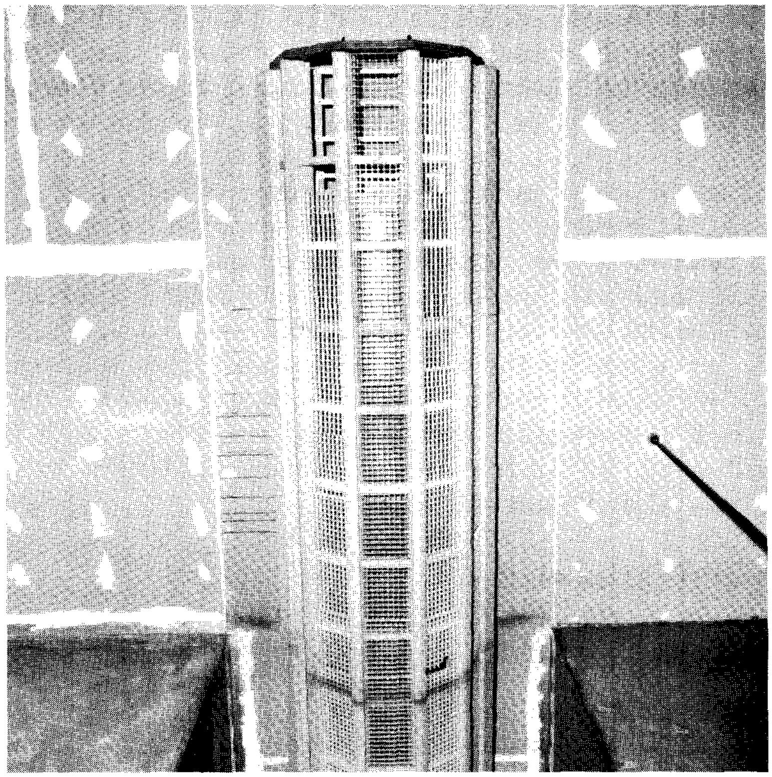


Figure 19. - Power penstock intake trashrack structure (hydraulic model). Note: elevation of internal bulkhead structure crest.

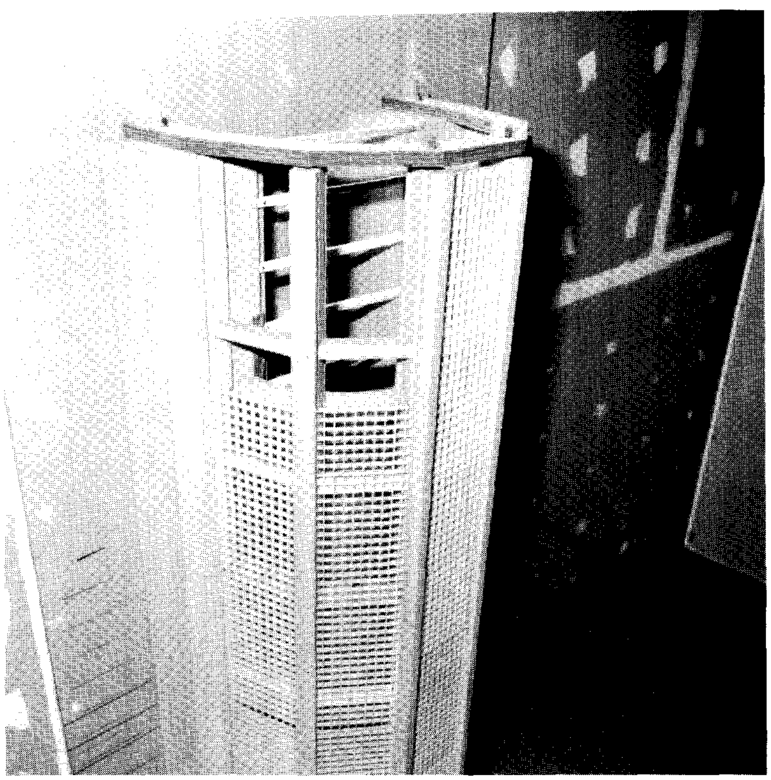


Figure 20. - Power penstock intake trashrack structure (hydraulic model). Note: internal support structure cross members.

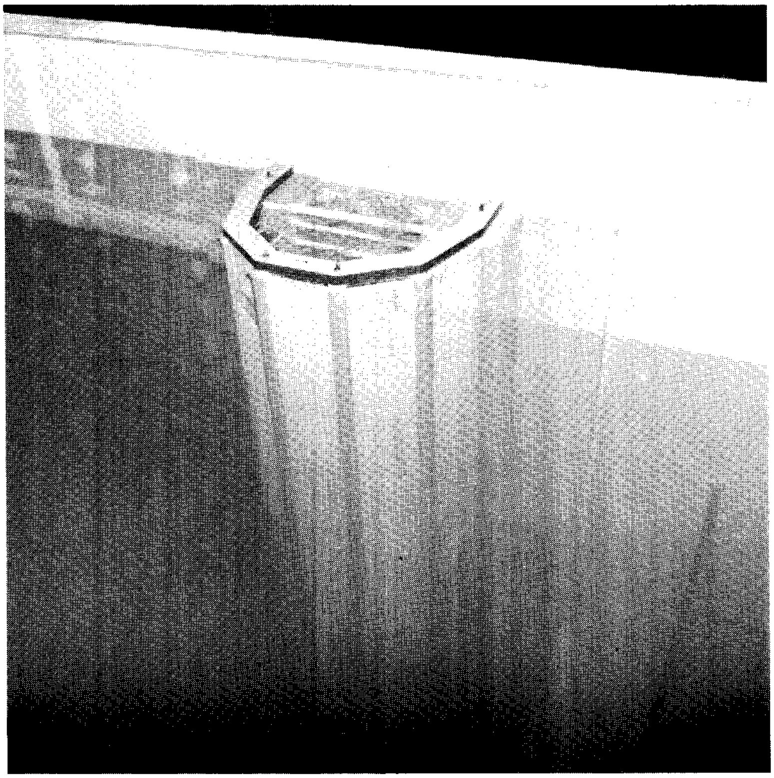


Figure 21. - Hydraulic model operated at maximum reservoir elevation at the maximum passable discharge of 87 $m^3/s$ (3070 $ft^3/s$). Note: surface action inside trashrack structure.

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## Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.