FINAL PROJECT REPORT
HYDRAULIC MODEL STUDY
NEORSD MILL CREEK TUNNEL

Report UMCEE 96-28

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December, 1996

For

Applied Science, Inc.
Detroit, Michigan

and

Montgomery Watson
Cleveland Ohio

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INTRODUCTION

The Northeast Ohio Regional Sewer District (NEORSD) Mill Creek Tunnel is to be constructed for the purpose of providing relief for the existing Mill Creek Interceptor. A control structure is proposed to store flow in the upstream tunnel during peak wet weather flows and to restrict downstream flows to the capacity of the Southerly waste water treatment facility. The control structure is to be located at Shaft No. 2, on the west side of Mill Creek. The proposed design utilizes two 4 feet wide by 8 feet high sluice gates to control the flow. Only one of the gates will be in operation at times when upstream storage is required. Under certain flow conditions, the discharge downstream of these gates may reach the maximum allowable capacity of 464 cfs (300 mgd). Whenever the flow is throttled by the gate, a hydraulic jump will occur in order to reduce the velocity to what is required in the downstream Mill Creek interceptor. A stilling basin is included in the control structure design for the purposes of containing the hydraulic jump within the structure and alleviating potential problems with air entrainment in the jump. A physical model study was performed, which examined the flow conditions within the control structure downstream of the sluice gate. The physical model reproduced the control structure including short lengths of the upstream Mill Creek tunnel and the downstream Mill Creek interceptor.

The purpose of the model was to study the ability of the proposed stilling basin to confine the hydraulic jump within the control structure under a range of flow rates up to a maximum of 464 cfs, as well as the ability of the stilling basin to remove the air entrained in the hydraulic jump prior to entering the Mill Creek interceptor. Testing of the proposed design was necessary due to the fact that design calculations were based on the assumption of two-dimensional flow. Since only one of the two sluice gates will be in operation at a time, the flow in the stilling basin may not be horizontally uniform and therefore may not behave in the expected fashion due to variations in the flow across the width. Additional aspects of the model testing included examination of the prospects for cavitation on structural elements downstream of the gate and those regions where sedimentation would be likely to occur within the stilling basin. The physical model was used to examine and test modifications to the original design. This report documents the testing procedures and modifications to the proposed design that were implemented in the physical model study.

GENERAL SYSTEM DETAIL

The control structure is located in a 20 ft diameter construction shaft with a center dividing wall in which the sluice gates for controlling the flow into the downstream interceptor are located. The top of the divider wall is at an elevation of 658 feet, which is intended to be the maximum hydraulic grade line (HGL) under any given flow condition. Flow enters into the control structure from a 9 foot diameter tunnel with a slope of 0.20% and the floor elevation at the upstream end of the control structure was set at an elevation of 608.0 ft. At 608.0 feet, the elevation of the control structure matches the upstream invert of the incoming tunnel. A slope of 0.20% through the stilling basin allows it to meet the downstream interceptor.

A SWMM model of the Mill Creek Tunnel, prepared by Montgomery Watson, determined that for the 25 year, 1 hour storm, the maximum HGL reached at the downstream end of the Mill Creek Tunnel at the control structure would be 658 feet with the flow restricted to 170 cfs (110 mgd).

Two 4 feet wide by 8 feet high sluice gates were selected for use in controlling wet weather flows to the downstream Mill Creek interceptor. It is envisioned that only one of the gates is to be throttled while the other gate remains closed for this purpose. With the maximum upstream head, the velocity on the immediate downstream side of the gate will be approximately 56 ft/s, resulting in a supercritical flow. The control structure was designed to include a stilling basin to control the formation of the hydraulic jump on the downstream side of the gate. A memo by Applied Science Inc. (ASI) dated September 27, 1996 outlines the details of and basis for the preliminary design. Figure 1 presents the preliminary design proposed for the control structure. The stilling basin serves both sluice gates and is located in a 15 foot wide channel. Two rows of baffle blocks were proposed to be located 10 ft downstream of the gates to control the hydraulic jump. A baffle wall is also included within the stilling basin to provide the tailwater required for the hydraulic jump to occur within the stilling basin. The proposed 10 foot high baffle wall has a 2 ft high by 7 ft wide opening at the bottom to allow the passage of solids and dry weather flows under the baffle wall. The flow across the baffle wall is intended as a combined orifice flow through the opening and as a weir flow with the top of the baffle wall as a weir crest.

MODEL DESCRIPTION
Modeling Criteria
The physical hydraulic model was constructed according to Froude scaling principles for dynamic similarity, which fixes the relation between model and

prototype conditions for a selected model scale. Dynamic similarity requires that the Froude number, defined by $F_r = V/\sqrt{gL}$, remain equal in both the model and prototype. Here V refers to any characteristic fluid velocity, g refers to the gravitational acceleration, and L refers to any characteristic system length. The relationships between the prototype and model parameters are directly related to the scale ratio L_r, which is defined as the geometric ratio between any length in the prototype and the corresponding one in the model,

$L_r = L_{prototype}/L_{model}$. For a Froude scaled model, assuming the same fluid in model and prototype, the following ratios must hold true with the numerical values appropriate to the selected scale ratio of 7.71:

PARAMETER	RATIO
Length (L_r)	$L_r = 7.71$
Velocity (V_r)	$L_r^{1/2} = 2.78$
Discharge (Q_r)	$L_r^{5/2} = 165$
Time (T_r)	$L_r^{1/2} = 2.78$
Pressure Difference (ΔP_r)	$L_r = 7.71$

Both the model size and discharge are critical factors with respect to model facilities. The scale ratio can be determined by either the space available in the laboratory facility or the installed pumping capacity. An effort is made to make the model as large as feasible to avoid scale effects associated with the fact that viscous effects are over represented in a reduced scale Froude model. This consideration indicates a minimum model size required to avoid distortion of the model flow due to the effects of viscosity. As long as the characteristic model Reynolds number (based on flow depth and average velocity) remains greater than about 10^5 viscous effects are considered negligible and the lack of complete dynamic similarity is unimportant. For this specific model a length scale ratio of 7.71 was selected to match the nine foot diameter tunnel with commercially available PVC pipe and to utilize the capacity of the recirculating water supply in the hydraulics laboratory. With this scale ratio, the Reynolds number at the lowest discharge (110 mgd) on the immediate downstream side of the model gate is about 2×10^5 satisfying the above criterion for minimum Reynolds number.

Additional issues related to incomplete dynamic similarity include sedimentation, air entrainment, and cavitation. Sedimentation can be properly

scaled to a close approximation by ensuring that the settling velocity for model sediments follows the velocity scaling criterion listed in the above table, i.e. that the model settling velocity should be a factor of the square root of the length scale ratio less than the prototype settling velocity. The major limitation is that information regarding potential prototype solids is not available and no basis for selecting model sediment is available. In a previous model study, (Wright, et al, 1988), dynamically similar sediment was developed from the characteristics of a sediment sample obtained from the primary sedimentation tank at the Columbus, Ohio WWTP. Since the length scale ratio of 7.5 in that study is close to that of the present model, this may be representative of sediments moving through the NEORSD system as well. In a previous physical hydraulic model study for NEORSD (Wright and Metriyakool, 1996), this sediment size was not retained in the stilling basin and much coarser sediment was introduced into the model for purposes of defining sedimentation patterns. The latter approach was utilized in this study and the same source of sediment discussed in that study was used in the current testing.

The processes of air entrainment are incompletely understood and only general principles for modeling the process are available. According to Kobus (1991), air bubble size, which is controlled in large part by surface tension effects, is largely independent of model size. This would imply that air bubbles in a reduced scale model are larger than required for purposes of geometric similarity and therefore would rise more rapidly in a scale model compared to the corresponding prototype. This consideration indicates that the reduced scale model would be de-aerated more rapidly than the prototype.

Finally, in order for cavitation to be properly reproduced in a reduced scale model, the absolute magnitude of pressures would have to remain the same in the model as in the prototype. However, pressure differences in the model are reduced relative to the prototype as outlined in the above table and therefore the lack of cavitation in the model does not ensure the same outcome in the prototype. However, this limitation is easily overcome by measuring pressures at critical locations in the model and using the scaling relation to project to corresponding prototype pressures and deducing the likelihood of cavitation. This approach was followed in the analysis of the model test results.

Model Construction

As discussed above, the physical hydraulic model was constructed at a scale ratio of 1:7.71. The model included approximately 50 feet (prototype) of the inflow tunnel, the tunnel construction shaft, the divider wall with one sluice gate

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(due to symmetry of the system), the stilling basin, and another 50 ft section of the downstream tunnel.

Drawings provided by ASI gave the detailed dimensions to which the model was originally constructed. These dimensions were in accordance with the preliminary design specified in the ASI memorandum dated September 27, 1996 to Montgomery Watson and are detailed in Figure 1. The stilling basin and construction shaft were constructed primarily of plywood, which was painted to provide a smooth finish. One side of the model stilling basin was constructed of Plexiglas for visualization purposes. The upstream and downstream tunnels were modeled with 14-in diameter PVC pipes, each approximately 6.5 ft in length. All essential system detail was modeled at the correct scale ratio and was constructed of Plexiglas and plywood as required. The top of the basin was not included in the model since the basin is not intended to flow in a surcharged condition. The absence of the top of the structure allowed for better inspection of the flow conditions within the stilling basin.

The required discharges were provided through the use of a constant head supply reservoir. Water was pumped from a sump into a 12-in supply line. Flow from the 12 inch line was reduced through an 8 inch valve, which regulated the flow to the model and entered the model through an expansion to the 6.5 ft length of 14 inch pipe.

INSTRUMENTATION

The flow supplied to the model was metered through the use of a venturi meter located in the 12 inch supply line. A differential mercury manometer was utilized to measure the head difference across the venturi meter. The relationship between the head difference and the discharge through the meter has been previously calibrated and was used for determining flows in the model study.

Measurements of pressure differences were made by installing pressure taps on the face of one of the model baffle blocks which could be installed in different positions as required. The pressure tap locations were chosen based on a consideration of the flow past the block and the most likely locations where low pressures would be achieved. These locations are indicated in Figure 2 and it was felt that the most likely location for low pressures was the location near the bottom of the block; this was subsequently born out be the testing. The pressure tap was connected to one side of a differential pressure transducer with the second side simply exposed to atmospheric pressure. In this fashion, pressures relative to atmospheric were measured. The outputs from the pressure

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transducer were routed to a data acquisition system from which average pressure differences over a thirty second interval were obtained. Measurements at any location were repeated several times to verify that consistent results were obtained.

The examination of flow conditions in the control structure and stilling basin was primarily done visually and has been recorded with videotape and still photographs. A videotape recording of the nature of the flow under the various testing conditions was created and an edited version has been provided. Still photographs are discussed and presented in this report.

TEST CONDITIONS

Two different flow cases were examined in the testing procedure. These cases included:

- Restricting the flow into the Mill Creek Tunnel to 170 cfs (110 mgd) with the upstream HGL at the control structure at its maximum of 658 feet.
- Restricting the flow into the Mill Creek Tunnel to 464 cfs (300 mgd), with the upstream HGL at the control structure at its maximum of 658 feet.

The 25 year, 1 hour flow of 170 cfs tested at an HGL of 658 ft for the purpose of represents a particular design target while the maximum discharge of 464 cfs reprsents the downstream capacity in the sewer system. These flow conditions were established in the model by adjusting the gate opening at a given flow rate until the water level on the upstream side matched the desired upstream hydraulic grade line elevation. In this testing, the discharge and hydraulic grade line elevations were set while the gate opening was varied and therefore depended on the degree of submergence on the downstream side of the gate. In the prototype, the actual procedure would be to monitor the upstream water level and adjust the gate position regardless of the flow rate so that the HGL does not exceed 658 ft; the only practical difference between this situations is due to submergence on the downstream side of the gate which would alter the gate position required to pass a given flow at the maximum HGL.

During the course of the model testing, it became clear that certain changes in the still basin configuration would be desirable. Once the testing had proceeded to a point where the configuration in the final recommendation was developed, testing was performed at a variety of flow rates between the two limiting cases discussed above to verify that no unexpected flow behavior would occur at intermediate flow rates. In addition, independent testing was performed

at the two limiting flow rates to measure the pressure differences on the baffle blocks and to introduce sediment into the upstream side of the construction shaft to observe any sedimentation.

TEST RESULTS
Initial Design

The model was initially constructed in accordance with the proposed design and was tested under the two flow cases mentioned previously. In this configuration, with the 464 cfs flow, the design was functional in that a hydraulic jump formed, however the hydraulic jump was submerged against the gate to a depth greater than 12 feet. The occurrence of submergence on the downstream side of the gate will result in a lower discharge for a given upstream elevation and the need to measure both the upstream and downstream depths in order to regulate the flow accurately. In addition to the submerged jump condition, a strong upflow, localized to the side of the channel with the open gate, occurred at the baffle blocks. This upflow reached to at least twenty feet above the stilling basin floor or to the crown of the basin. In addition, the submergence of the hydraulic jump would result in less air entrainment immediately downstream of the gate. Air entrainment in this region would serve to prevent cavitation damage on the baffle blocks although it was not established that cavitation was indeed a problem in this flow configuration. With further investigation, it was discovered that at both flow rates, the formation of the hydraulic jump could be controlled without the baffle wall although the flow was very rough in the stilling basin at the higher flow rate. In the same manner, the second row of baffle blocks was found to be unnecessary and only a minor difference in flow conditions was observed if this second row was removed. In comparison to the final recommended design for the Contract 7A control structure (Wright and Metriyakool, 1996), the flow area between baffle blocks is substantially less, apparently leading to the greater control on the hydraulic jump. For example, the fifteen inch spacing with fifteen inch wide baffle blocks in the Contract 7A design restricts about half of the channel width while the 12 inch spacing with 20 inch baffle block width constricts closer to two-thirds of the flow width. These flow conditions for the two discharges can also be seen on the videotape which has been provided.

Modifications

As a result of the flow conditions that were observed in the testing of the initial design, a decision was made to remove the downstream row of baffle blocks

and to reduce the number of baffle blocks in the upstream row from six to either five or four, thereby increasing the spacing between blocks.

Testing of the Revision 1 model design was performed under the two flow cases. At the higher flow rate of 464 cfs, the flow at the gate was still submerged with the five block configuration, but the submergence was reduced to about eight feet. With the four block configuration, the submergence was substantially removed but the flow was much rougher in the stilling basin downstream of the blocks. The five block configuration still had some upflow at the baffle blocks but less than the original design while it more or less disappeared with the four block arrangement. Observations indicated that the jet of water downstream of the gate had only expanded to slightly over half the stilling basin width at the baffle blocks.

Modifications were subsequently made to the downstream baffle wall due to observations of fairly large quantities of air carried into the downstream interceptor. The source of this air appeared to be the plunging flow over the top of the baffle wall. In order to reduce this effect, the height of the opening in the baffle wall was increased to four feet and the overall wall height was reduced to seven feet. There was some improvement in air entrainment with less air observed downstream from the baffle wall and entering the downstream interceptor.

The results of the modifications to the Revision 1 design suggested that moving the row of baffle blocks further downstream would most likely be beneficial in that the flow issuing from the gate would be more uniformly distributed over the width of the stilling basin. This would result in a number of positive influences; less submergence of the gate, lower velocities impinging on the baffle blocks and a reduced likelihood of cavitation damage. Therefore, the baffle blocks were moved further downstream to a location eighteen feet downstream of the gate. Observations with this configuration indicated that the high velocity flow extended over to the next to last block on the opposite side of the channel. The number of baffle blocks was maintained at five but the width of the blocks was subsequently reduced from 20 inches to 18 inches. This would result in a spacing between blocks of 18 inches with a nine inch spacing at the side walls. Additionally, the dimensions of the opening in the baffle wall were adjusted along with the wall height to allow more flow to pass through the opening and less to pass over the crest for purposes of reducing the air entrainment in the plunging flow over the baffle wall. After a number of modifications in the test, a wall opening with four ft height and nine ft of width was selected along with a wall height of 7.5 ft. Final testing was performed with

the upstream edge of the baffle wall crest rounded off to better guide the flow over the baffle wall and the wall height had to be increased to 8.0 ft in order to achieve the same general flow conditions. These modifications to the model are hereafter referred to as Revision 2. Figure 3 presents the modifications which comprise the Revision 2 design.

With the Revision 2 design, the nature of the flow was more uniform. The upflow in front of the baffle walls was greatly reduced compared to the original or the Revision 1 design with five baffle blocks, and at a flow of 110 mgd, there was no submergence of the hydraulic jump. Additionally, all of this flow was able to pass under the opening in the baffle wall reducing the air entrainment downstream of the baffle wall. At the higher flow rate, the submergence is minimal, only about a foot, and a large fraction of the entire flow is still able to pass through the opening in the baffle wall. In order to achieve this minimal submergence, the baffle wall serves to provide some control on the hydraulic jump. The flow at the baffle wall is clearly concentrated on the side of the channel with the open gate. Lateral variations in water surface elevation across the channel at the baffle wall were only on the order of a few inches and only somewhat greater further upstream. It was apparent that with the larger opening in the baffle wall, flow passed through this opening with a tendency to cross over from the gate side of the channel to the opposite side. An attempt was made to straighten the flow by moving the baffle wall further downstream, but this resulted in substantially more air moving into the downstream interceptor due to moving the plunging flow over the baffle wall closer to the stilling basin exit. In order to avoid the necessity of increasing the overall length of the stilling basin, it is recommended to maintain the location of the baffle wall at its position recommended in the original design, accepting the local nonuniformities in flow at the baffle wall. Even though this configuration still permits some air to remain in the flow entering the downstream interceptor, the fact that the maximum flow of 464 cfs does not result in full conduit flow allows for a path for this air to escape at the top of the interceptor. The air remaining as the flow passes into the interceptor is distributed only in the upper two feet of the flow and would escape over relatively short distances downstream in the interceptor. At the design flow of 170 cfs, only a minor amount of air passes into the interceptor and the less than full conduit flow allows a pathway for air release.

Sedimentation

A coarse sediment was then introduced in order to develop a condition with solids coarser than would be generally expected in the prototype. A graded coarse sand

was introduced into the construction shaft upstream of the control gate and allowed to move downstream into the stilling basin. The sand was gradually poured in at the water surface and the flow was allowed to continue for another minute to allow it time to settle and to be flushed into the stilling basin. The flow was then shut down and the distribution of sand within the channel was observed. This procedure was repeated at both flow rates for both the original proposed design and for the Revision 2 design. The only deposition upstream from the baffle walls was observed upstream of the control gate at the lower discharge rate. Rotating operation of the two control gates should avoid this sort of deposition. With the original design, a small amount of sand was deposited in the upstream corner of the baffle wall on the same side of the stilling basin as the gate, however, there was no deposition in this location with the larger wall opening of the Revision 2 design. Otherwise there was some sand deposition downstream of the baffle wall. This appeared to be generally more significant in the Revision 2 configuration and was on the same side of the basin as the gate was located. This occurrence was associated with the concentration of the flow from the gate on that side of the channel and the interaction with the baffle blocks and wall forcing the flow to the opposite side of the channel downstream from the baffle wall. This sediment appeared to be fairly persistent and running the model for a longer period of time did not result in its removal. Again, however, switching use of the two control gates from one high discharge event to another should prevent long term buildup of solids in the stilling basin.

Cavitation considerations

As mentioned previously in the discussion of the modeling criteria, cavitation phenomena are not correctly reproduced in a Froude scaled model. However, the effect can be assessed by measuring pressure differences at critical locations and scaling those pressure differences to prototype conditions. In general the prototype pressure differences would have to be less than about 14.5 psi below atmospheric in order to produce cavitation conditions. Within the highly turbulent flow of a hydraulic jump, there are certain to be considerable fluctuations in the pressure and intermittent cavitation could be possible even if the time-averaged pressure difference is closer to atmospheric. Considering the model scale ratio, cavitation could be expected if the pressure differences are in excess of about 14.5/7.71 or about 2 psi below atmospheric. The most likely location for cavitation will be on the baffle blocks since they are exposed to the highest flow velocities. In particular the lowest pressures would be expected in regions of flow separation or on the sides and top of the baffle blocks. Cavitation

on propellers, etc. generally is found near the attachment point of vanes to the hub or in the context of the baffle blocks, near the attachment of the baffle blocks to the basin floor. Consequently, pressures were measured near the front edge and bottom of the baffle blocks as indicated in Figure 2. This location was indeed found to have substantially lower pressures than the pressure tap located near the top of the baffle block.

The baffle block with the pressure taps was initially installed so that it was directly downstream of the control gate, i.e. the second baffle block from the wall with the pressure taps located close to the lateral position of the gate centerline. Additional measurements were made with the tapped baffle block in the adjacent block positions and these pressures were found to be higher, indicating that the baffle block immediately downstream of the gate centerline would be the most susceptible to cavitation. Pressures on the side near the bottom of the baffle block were measured to range from 0.38 to 0.44 psi below atmospheric for repetitive measurements in the same location for the flow of 464 cfs. At the lower flow rate of 170 cfs, the pressure deficits were smaller and ranged from 0.21 to 0.25 psi. In contrast, pressure difference along the top of the baffle block ranged from 0.10 to 0.12 psi. The pressures in the lower pressure tap ranged from 0.26 to 0.31 psi in the baffle block closest to the side wall while the pressure on the top of the baffle block were scarcely below atmospheric. Even the largest pressure deficits would correspond only to 3.9 psi below atmospheric in the prototype. The presence of large quantities of air entrained into the flow and visible in the model testing would also tend to provide a cushion against cavitation. Even with allowances for turbulent fluctuations and the possibility that the location with the lowest overall pressures was not located, this result indicates pressures that are sufficiently far away from cavitation conditions that it is concluded that cavitation will not be a problem during the operation of the stilling basin at the highest flow rates intended or at any lower flow rates.

CONCLUSIONS AND RECOMMENDATIONS

The test results indicated that the flow downstream of the sluice gate would never be laterally uniform unless the length of the stilling basin is substantially increased. This does not appear warranted on the basis of economic considerations and the stilling basin can be made to perform acceptably even with the lateral variations in the flow. However, due to the variation in flow across the width of the channel, it is difficult to estimate the correct amount of initial energy dissipation using conventional design procedures, therefore several modifications were made to the preliminary design in order to achieve desirable

flow conditions. The test results determined that a downstream baffle wall provided sufficient tailwater to control the jump within the stilling basin and that a single row of five baffle blocks provided necessary energy dissipation downstream of the sluice gate. The flow tended to be higher and more turbulent on the side of the channel where the flow issued from the sluice; however, because of the energy dissipation that occurs as the flow impacts on the baffle blocks and undergoes the jump, the flow became more uniform on the downstream side. Tests indicated that there would be no concern about cavitation in the system.

The objective is to distribute flow more uniformly across the channel and avoid the submergence of the hydraulic jump against the downstream side of the control gate. Under the range of flow rates under consideration (170 to 464 cfs), the final modified Revision 2 design was successful in both controlling the location of the jump and removing most of the air in the flow at the downstream tunnel. Testing of potential problems with sedimentation indicated that no sediment deposition would be expected within the stilling basin upstream of the baffle walls. Sediment deposition downstream of the baffle walls is related to the concentration of flow along the wall on the opposite side of the basin from the operable control gate and can be minimized by alternating use of the two control gates from one storm event to the next. It is therefore recommended that the final modifications discussed will be able to serve the NEORSD Heights Mill Creek Tunnel control structure. Figure 3, which represents the Revision 2 design, shows the dimensions of this recommended final design. Five baffle blocks 18 inches wide by 26 inches high are located 18 feet downstream of the sluice gate. A baffle wall located about 31 feet downstream of the sluice gate with a crest height of 8.0 feet and a bottom opening 4 feet high by 9 feet wide would also be required.

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Hydraulic Model Study, NEORSD Heights Interceptor Contract 7A Control Structure, (S.J. Wright and S. Metriyakool) Report No. UMCEE 96-08, The University of Michigan, Department of Civil and Environmental Engineering, 1996.

Sedimentation Engineering, ASCE Manual 54, V.A. Vanoni, ed., 1977

SECTION A-A

SECTION B-B

BASIN FLOOR

BAFFLE WALL

BAFFLE WALL

BOTTOM PLAN VIEW

SHAFT No. 2
20' I.D.

MILL CREEK
TUNNEL
9' DIA

BAFFLE BLOCK
(SEE DETAIL)

9' DIA

TYPICAL BAFFLE BLOCK DETAIL

BASIN FLOOR
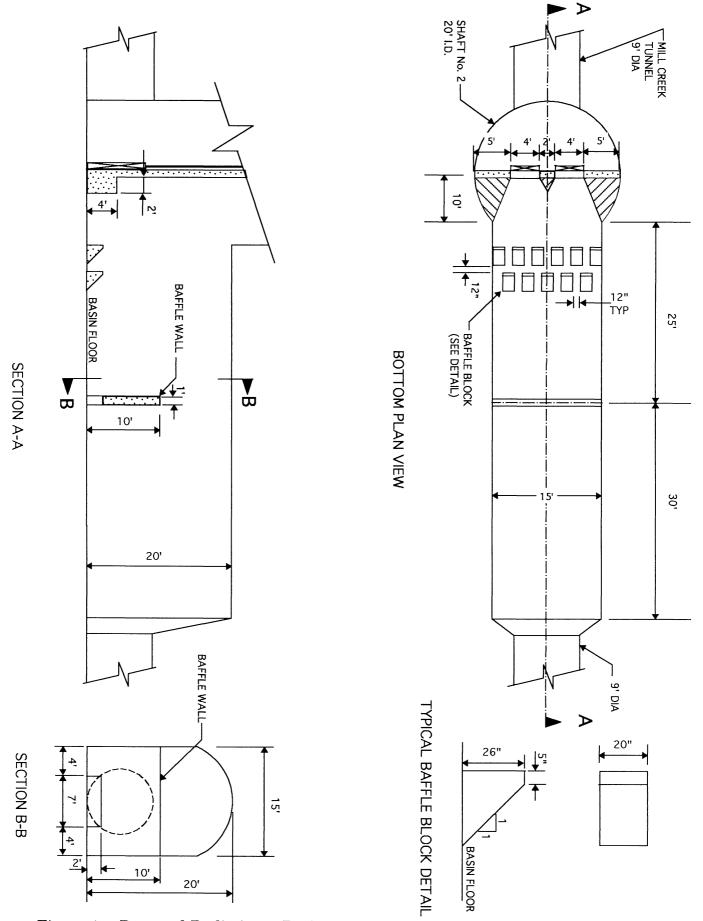
Figure 1.   Proposed Preliminary Design.

14
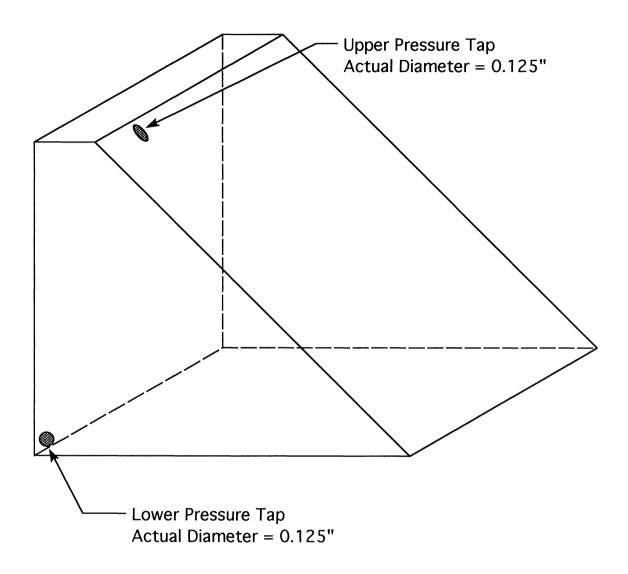
Figure 2. Location of Pressure Taps on Baffle Block.

SECTION A-A

SECTION B-B

BOTTOM PLAN VIEW

TYPICAL BAFFLE BLOCK DETAIL
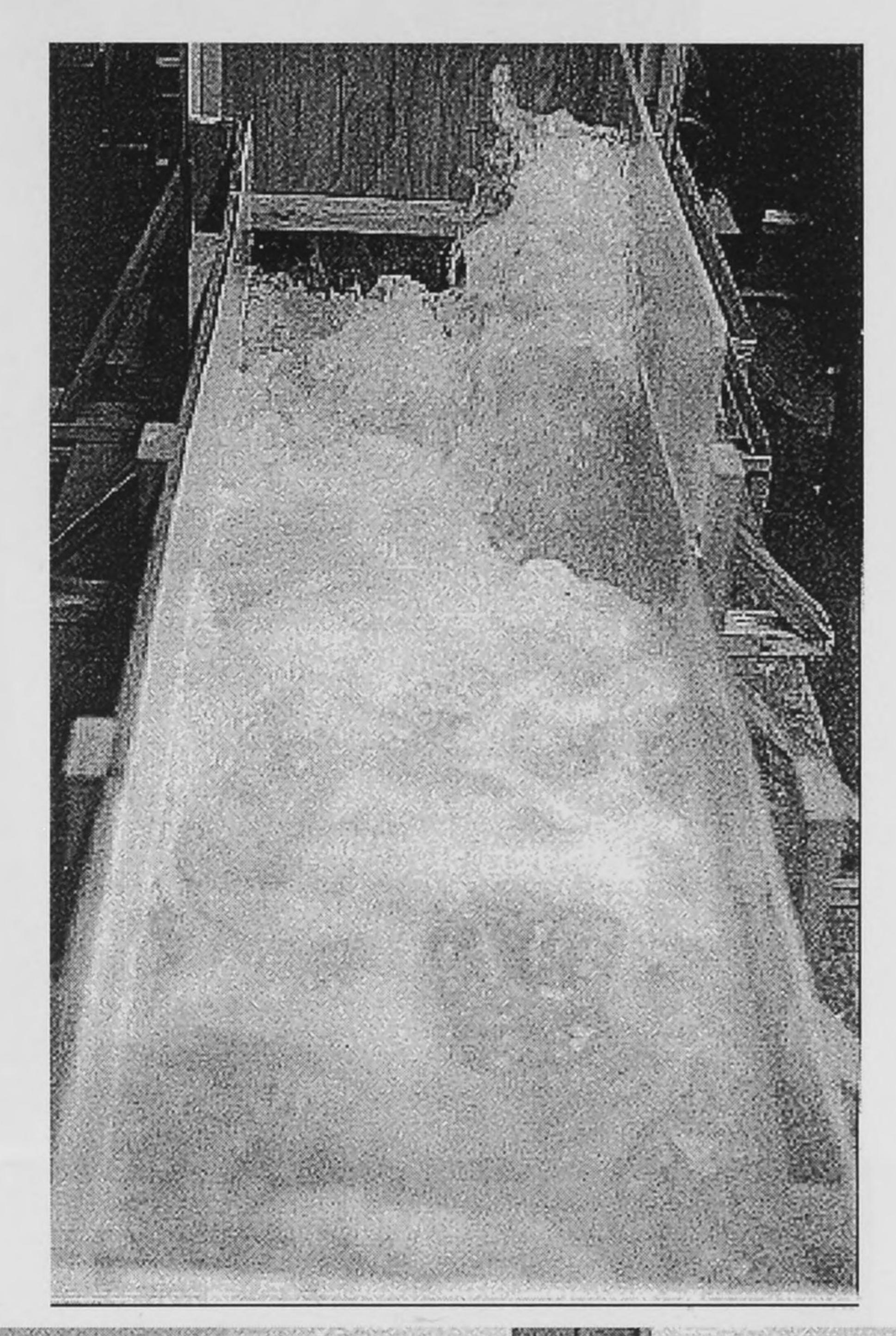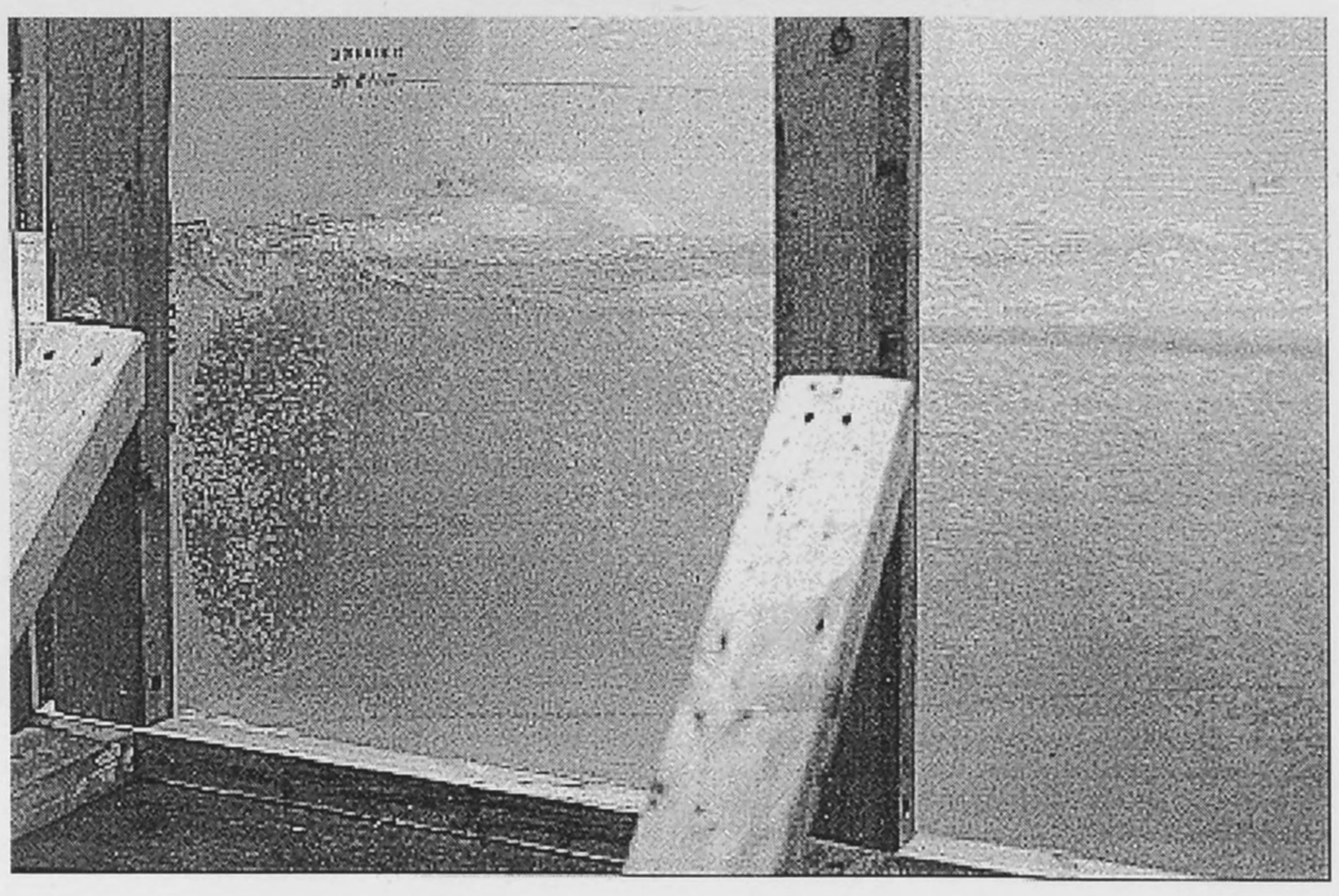
Figure 3.   Revision 2 and Recommended Design.

16
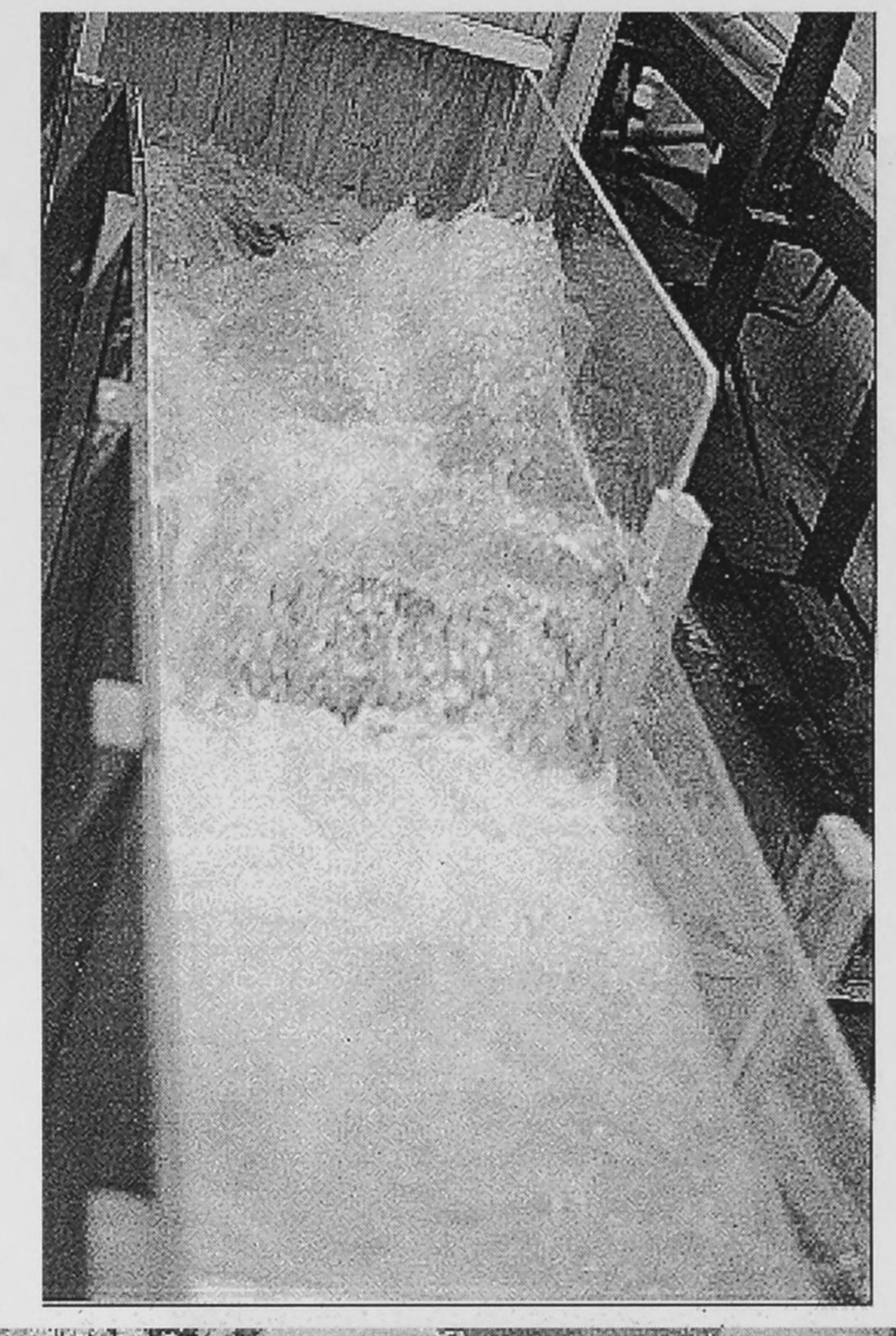
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a.)

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a.)

b.)
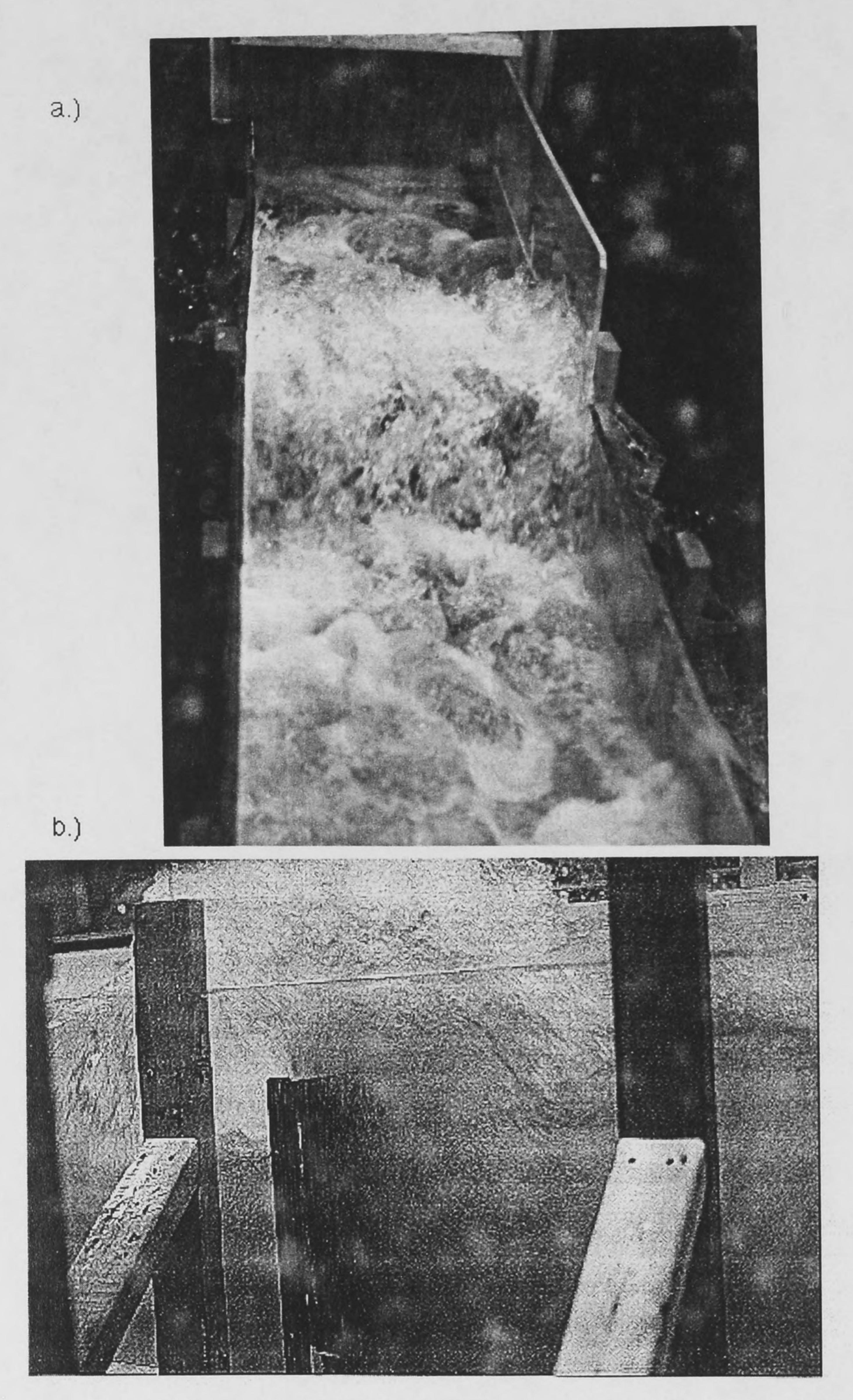
Figure 6. 300 mgd flow with initial design with second row of baffle blocks
removed and four baffle blocks in first row, viewed from a.) downstream; b.) side.
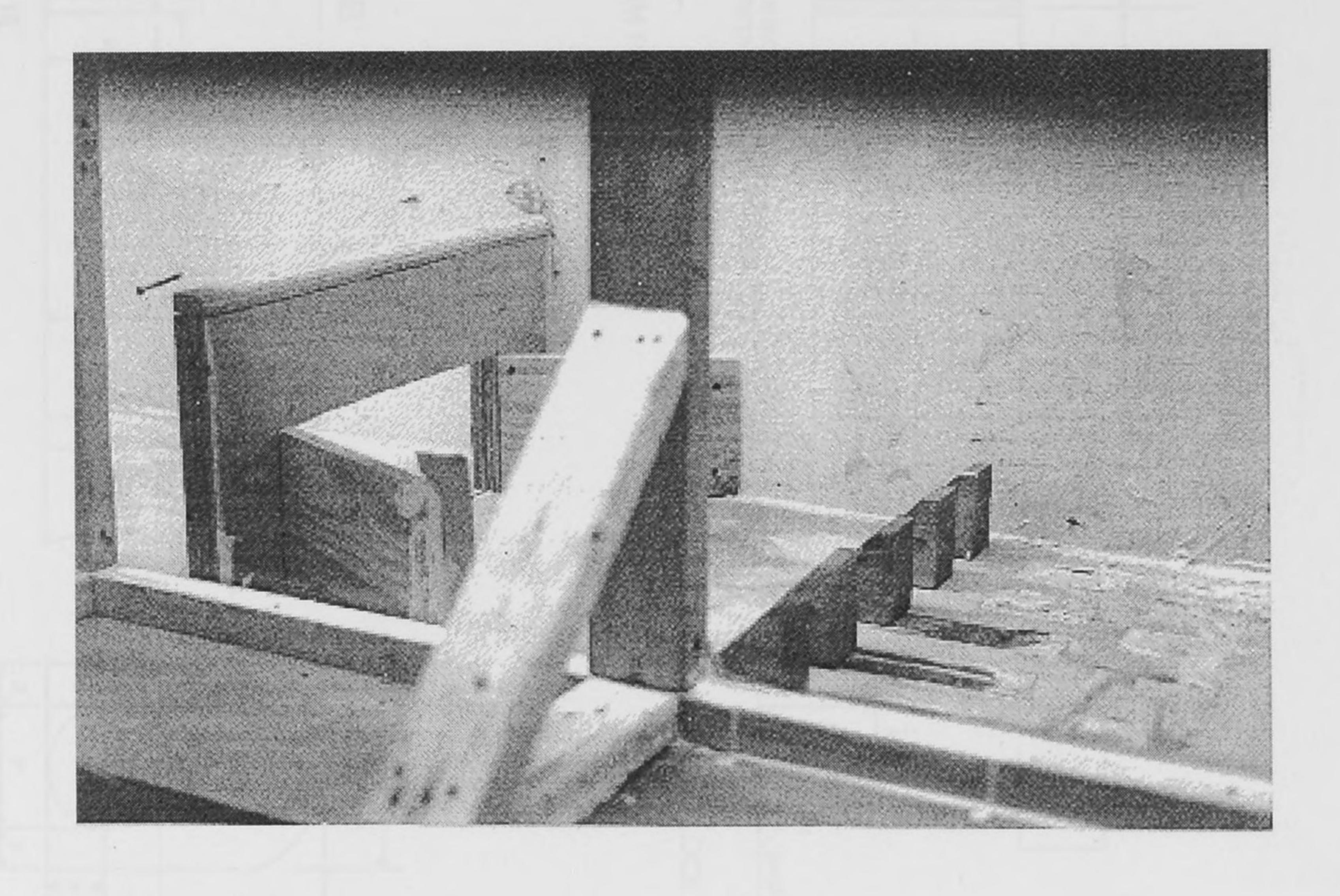
Figure 7. Revision 2 stilling basin. The wing wall upstream of the baffle wall are not included in final recommended design.

SECTION A-A

BASIN FLOOR

4'

2'

BAFFLE WALL

1'

8'

20'

B

B

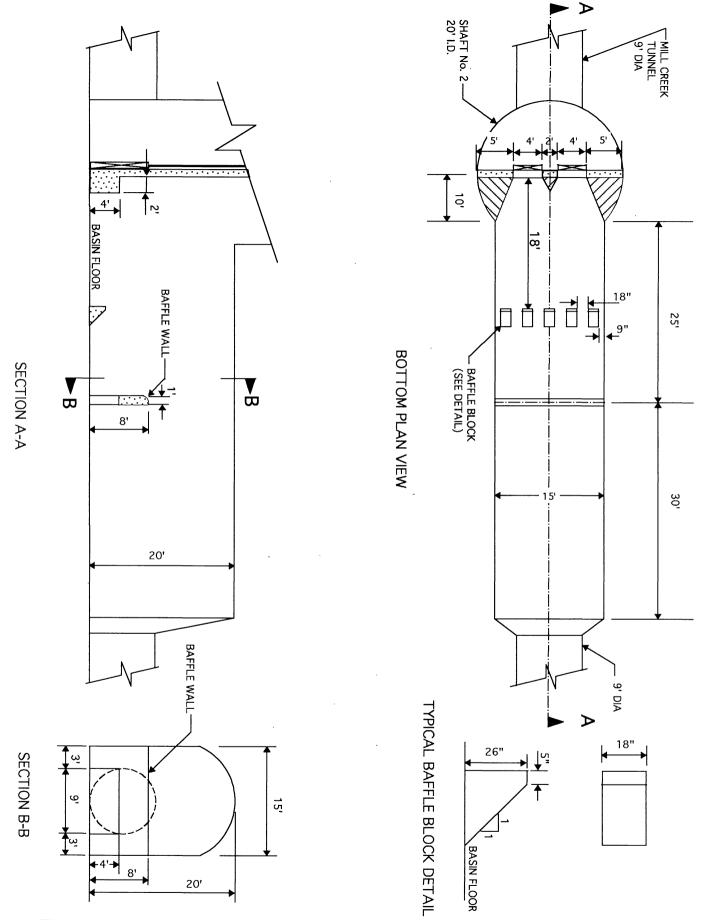## SECTION B-B

BAFFLE WALL

3'

9'

3'

4'

8'

20'

15'

BOTTOM PLAN VIEW

MILL CREEK TUNNEL
9' DIA

SHAFT No. 2
20' I.D.

A

5'   4' 2' 4'   5'

10'

18'

18"

9"

25'

15'

30'

BAFFLE BLOCK
(SEE DETAIL)

9' DIA

A

TYPICAL BAFFLE BLOCK DETAIL

26"

5"

1
1

18"

BASIN FLOOR

Figure 8.   Revision 2 and Recommended Design.

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Figure 9.   a.) 110 mgd flow with Revision 2 design, viewed from downstream; b.) side view at entrance to downstream tunnel.
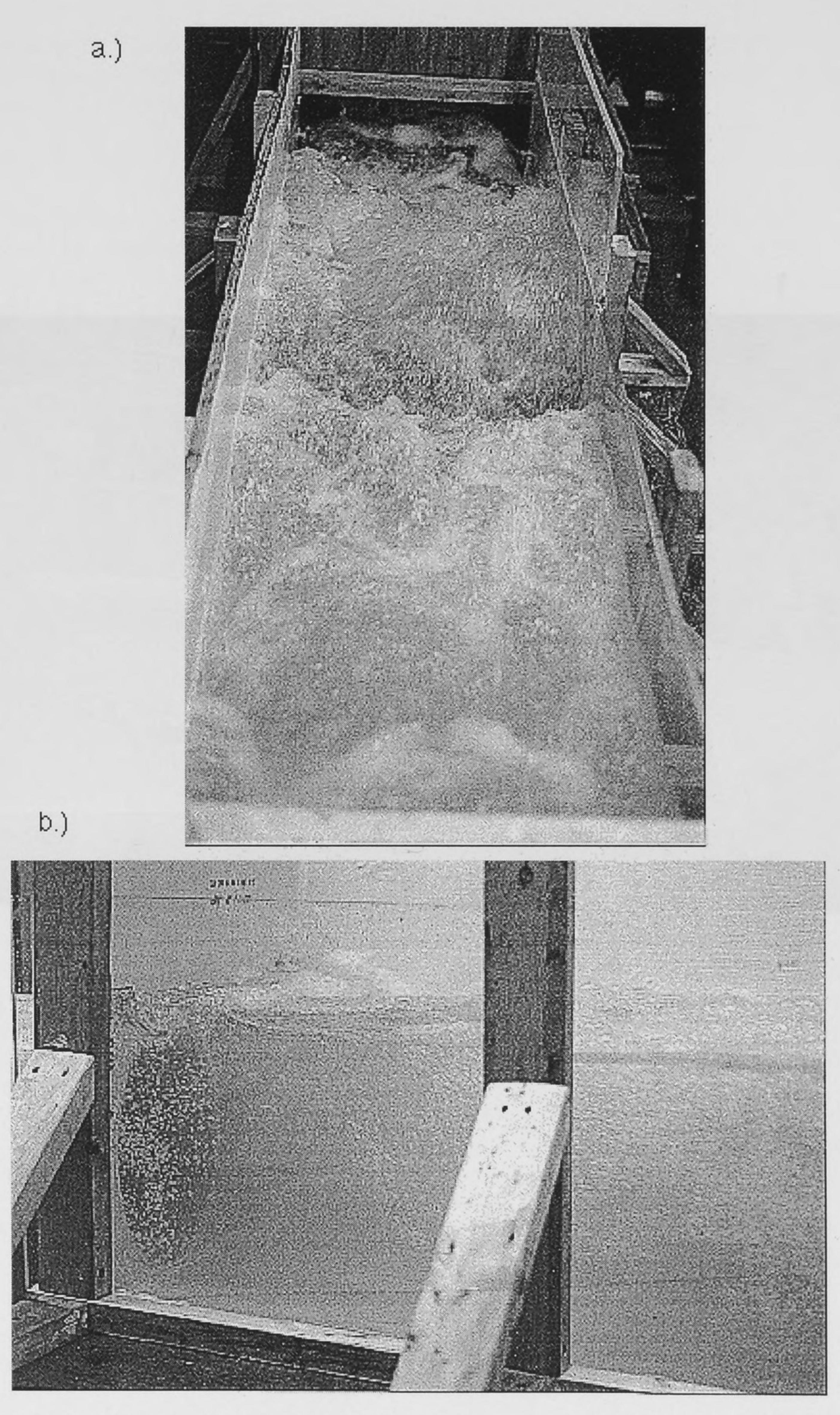
Figure 10. a.) 300 mgd flow with Revision 2 design, viewed from downstream; b.) side view at entrance to downstream tunnel.
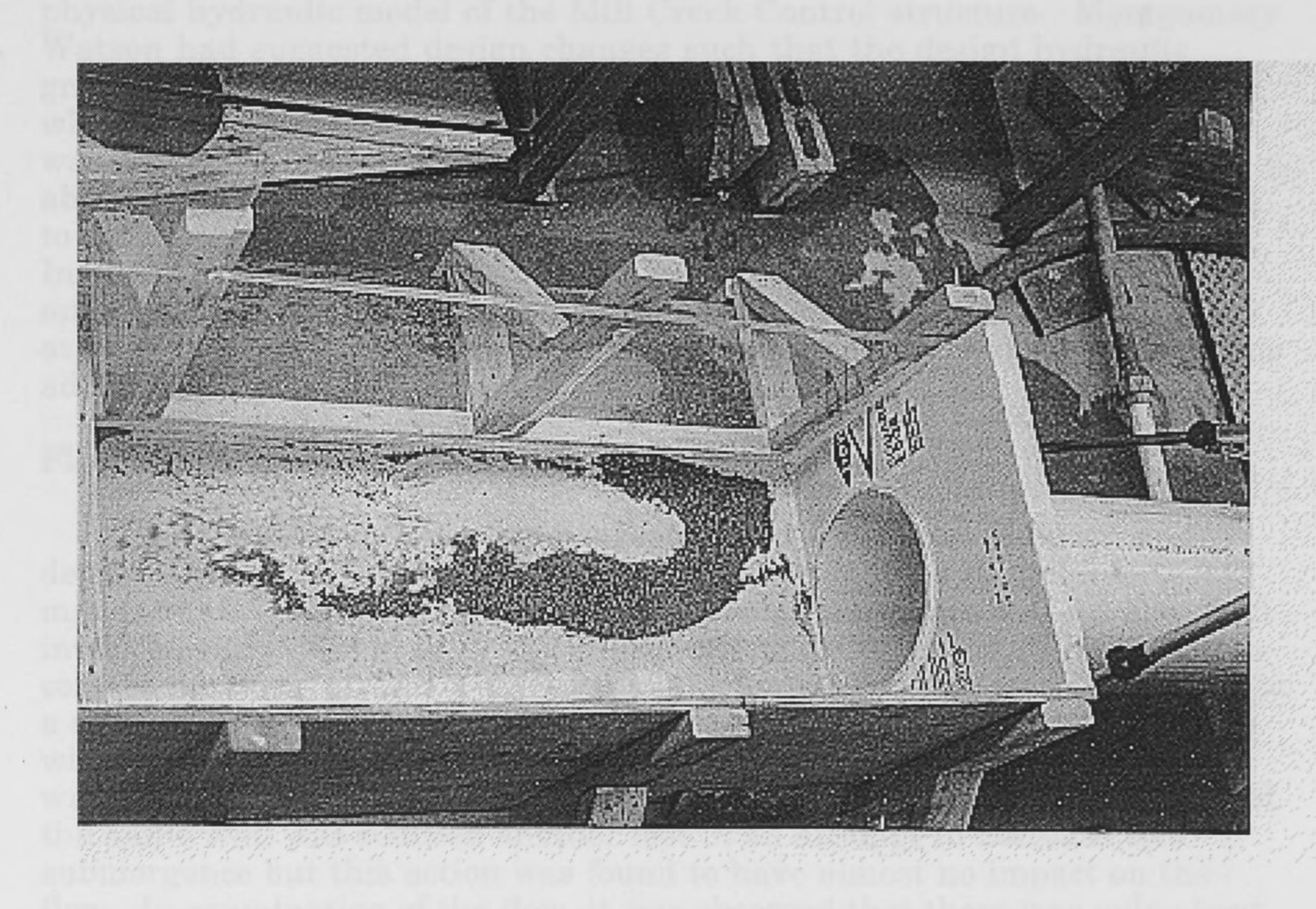
Figure 11. Sedimentation downstream of baffle wall following a discharge of 110 mgd.

Addendum to **Final Project Report, Hydraulic Model Study NEORSD Mill Creek Tunnel Control Structure, Report UM CEE96-28 by Steven J. Wright, Danielle L. LeFevre, and Andrew D. Santini**

February 2, 1997

This Addendum is in response to a 17 January, 1997 memo from John Michalski of Applied Science, Inc. requesting additional testing of the physical hydraulic model of the Mill Creek Control structure. Montgomery Watson had suggested design changes such that the design hydraulic grade line in the control structure would be reduced from 658.0 to 647.0 ft, while the shaft inv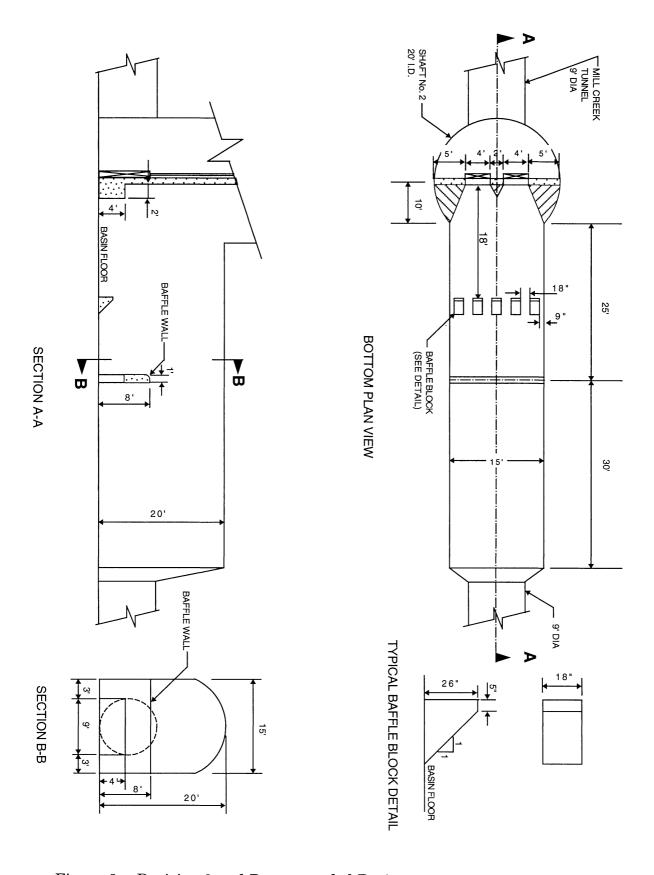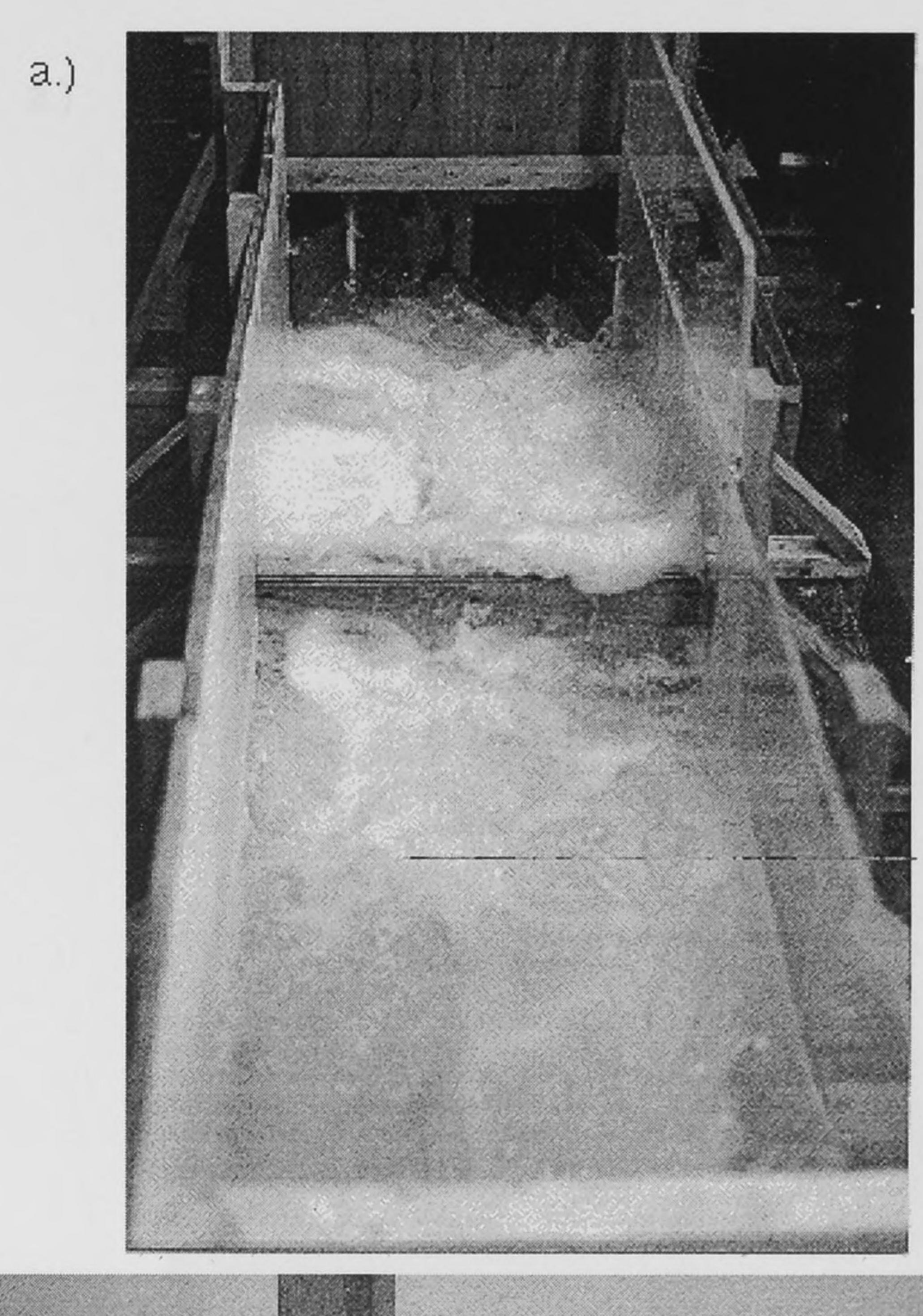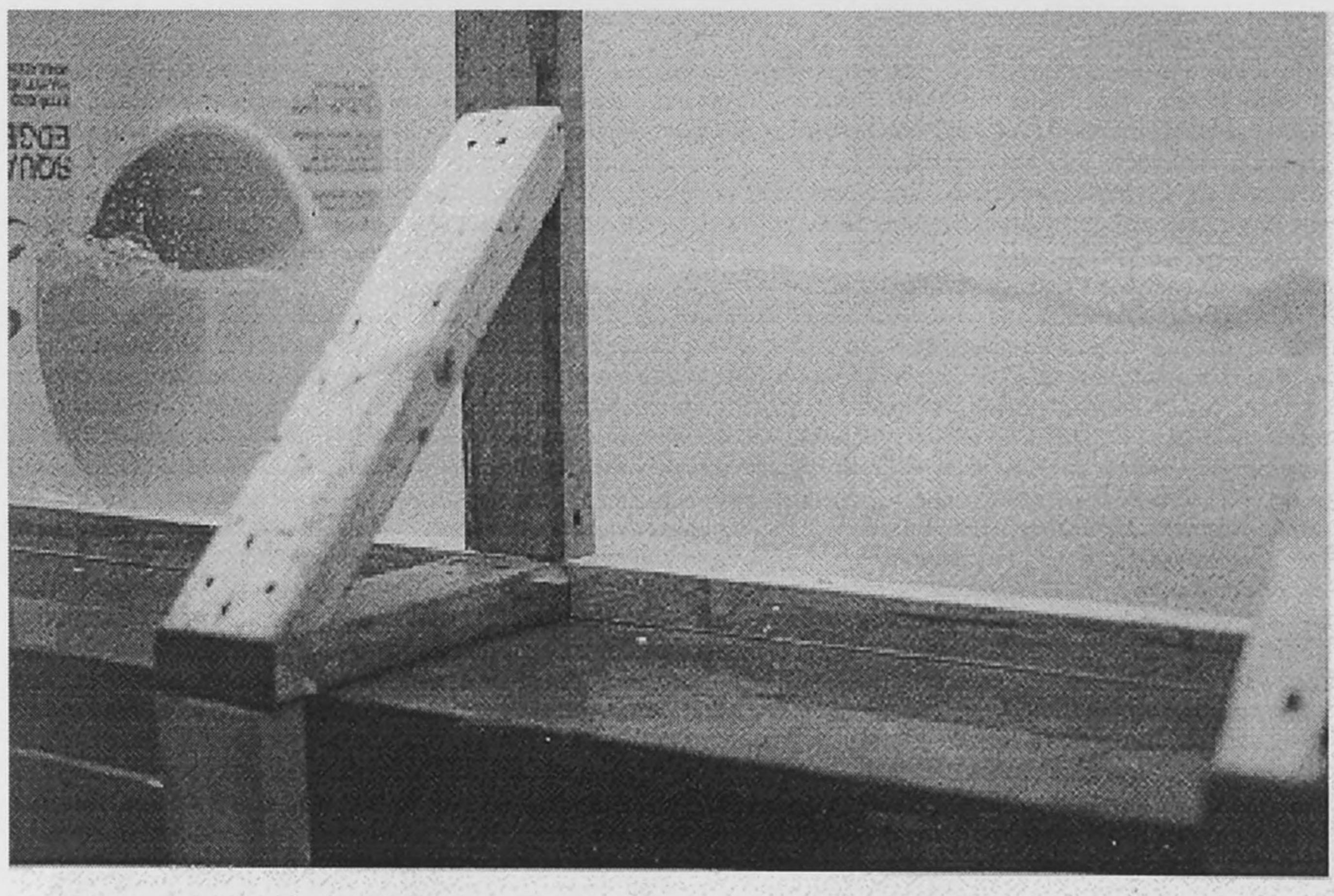ert elevation would be reduced from 608.0 to 606.5 ft. It was requested to test the model at these new elevations to determine the ability of the stilling basin to pass the maximum discharge of 300 mgd and to determine the gate openings at the design flow rates of 110 and 300 mgd. In addition, it was requested to test the model at a series of gate openings and upstream water depths to determine the discharge through the model at each of these conditions. This Addendum summarizes the results of this additional testing.

Flow at new HGL and shaft invert elevation

The model configuration suggested as the Revision 2 design and is detailed in Figure 8 of the original report was tested at a design flow of 300 mgd (464 cfs) to determine whether the change in upstream HGL and shaft invert elevation would have any impact on the ability of the stilling basin to control the flow. It was observed that the hydraulic jump was submerged to a somewhat greater depth on the downstream side of the control gate than with the original HGL/shaft invert elevations but that the differences in water depth were only on the order of 1-2 ft increase in depth. The height of the baffle wall was reduced another foot in an attempt to decrease this submergence but this action was found to have almost no impact on the flow. In examination of the flow, it was observed that there was only about 2 ft of head difference across the baffle wall at this design flow. It appeared that it may be feasible to remove the baffle wall completely and still control the flow, but when this was attempted, the location of the hydraulic jump moved substantially downstream towards the interceptor leaving the control structure. Accordingly, it is concluded that the changes in the flow conditions at the new HGL and shaft invert elevations are minimal at the design flow rate of 300 mgd and that a change in the recommended design is not necessary to provide adequate control on the flow. The testing described below tested the model at a variety of lower discharge conditions and no adverse flow conditions were observed under any of those discharges as well.

With this final configuration, the model was tested to determine the required gate openings to pass discharges of 110 and 300 mgd at the new HGL of 647 ft. As in the previous model study, these flow conditions were established by setting the discharge by adjusting a control valve to obtain the required discharge as determined by a venturi meter in the supply line.

The gate opening was then adjusted until the design HGL was achieved. The following results were obtained:

Q = 300 mgd − Gate opening = 3.79 ft

Q = 110 mgd − Gate opening = 1.38 ft

These gate openings are within a few percent to what would be calculated for an unsubmerged gate (Figure 13-22, Olson and Wright, Essentials of Engineering Fluid Mechanics, Harper Collins), indicating that the minor submergence on the downstream side of the gate has minimal impact on the ability of the gates to regulate the flow based on the upstream depth.
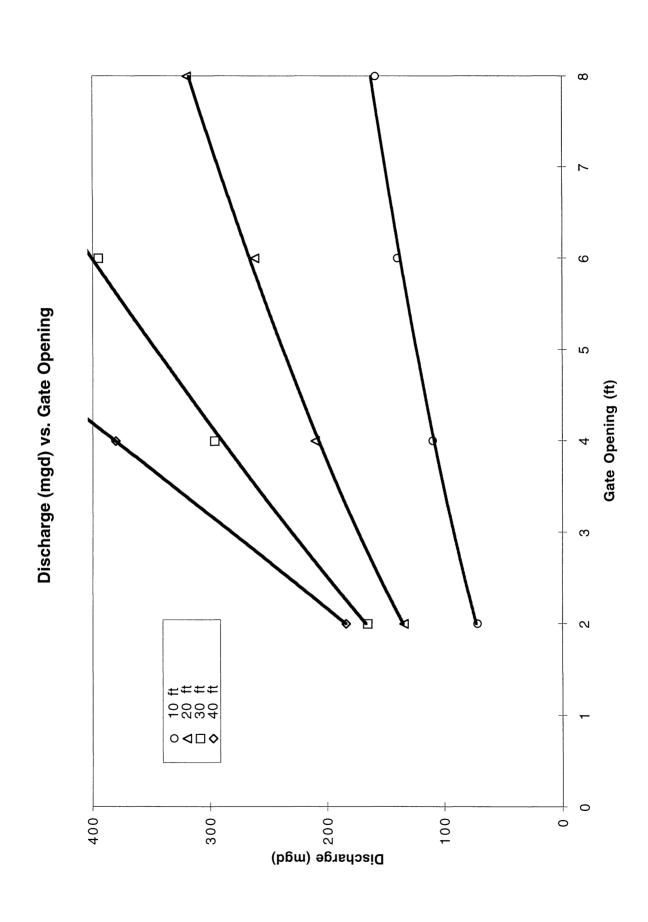
Flow rates for varying gate opening and upstream water depths
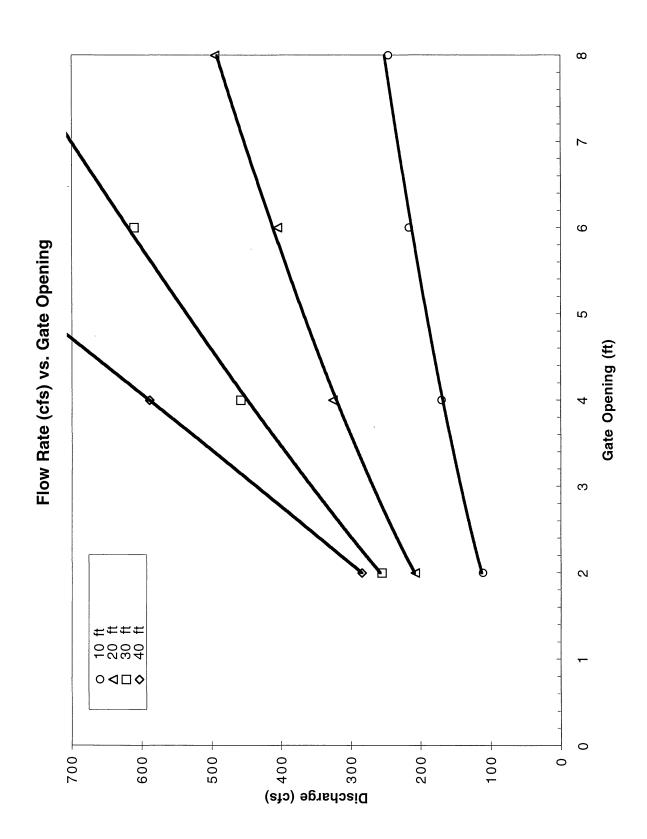
The model was tested at upstream water depths of 10, 20, 30 and 40 ft for gate openings that corresponded to 2, 4, 6, and 8 ft. In these tests, the gate opening was established and the flow rate was adjusted until the design HGL was achieved, at which time the flow rate through the venturi meter was recorded. At some of the lower flow rates, a lower capacity supply line with an independent venturi meter was used in order to more accurately meter the smaller discharges. For some of these flow conditions (the larger gate openings), the discharge was substantially in excess of 300 mgd and beyond the ability of the model to pass the flow. These conditions are reported in Table A-1 as > 300 mgd. Some of the flows that are reported are also in excess of 300 mgd, but were recorded for completeness. The results are also presented in Figs. A-1 and A-2. The table and figures includes the actual model flow rates recorded but scaled up to prototype discharges. It is felt that each one of these flow is probably accurate to within approximately 2-5 percent with the possible exception of the flows at a water depth of ten feet where the small head differences across the gate and the flow disturbances in the shaft upstream of the gate would make it impossible to establish a particular flow condition with that high of a precision.

Table 1. Control Structure Discharge versus Gate Opening and Upstream Water Depth.

Prototype discharges in cubic feet per second (mgd)

Gate Opening (ft)	2	4	6	8
Upstream Water Depth (ft)				
10	111 (72)	209 (134)	256 (165)	284 (184)
20	170 (110)	325 (210)	458 (296)	589 (380)
30	216 (140)	405 (262)	611 (395)	>300 mgd
40	245 (159)	494 (320)	>300 mgd	>300 mgd

Discharge (mgd) vs. Gate Opening

Flow Rate (cfs) vs. Gate Opening

Discharge (cfs)

Gate Opening (ft)

○ 10 ft
△ 20 ft
□ 30 ft
◇ 40 ft

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Greek and Math Symbols

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6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><>⟨⟩<≡

8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><>⟨⟩<≡

10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><>⟨⟩<≡

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MESH   HALFTONE WEDGES

65

85

100

110

133

150

RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71

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