The Use of Physical Modeling to Enhance Nut Island Headworks Design

A program of physical modeling, after using mathematical modeling on the initial design, can be an indispensable tool in eliminating functional flaws and operational problems.

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Construction of 360-mgd (15,700 l/s) headworks has been recently completed at the existing Nut Island primary treatment facility to provide screening and grit removal prior to discharge to the new Deer Island treatment facility. Flow enters in a 90-degree turn and then is distributed into six screening channels followed by degritting. The 90-degree turn created a large stable vortex and secondary eddies that resulted in an unacceptable distribution of flow between screening channels, with heavy deposition under all design conditions. A curved entrance deflector wall and other hydraulic enhancements satisfying functional design criteria were recommended from the model experiments and were incorporated into the design package. All enhancements have been constructed.

Introduction

As part of the $4 billion Massachusetts Water Resources Authority's (MWRA) Boston Harbor cleanup program, the new Nut Island Headworks has recently been constructed at the site of the existing Nut Island primary treatment plant, which was demolished. The headworks provides screening and grit removal prior to discharge into the new Inter-Island Tunnel for final treatment at the new Deer Island 1,200 mgd (52,500 l/s) facility (see Figure 1).

An existing 12-foot (3.7-meter) high level sewer (HLS) drains the southerly portion of the greater metropolitan Boston area. Its flow enters a junction chamber constructed around the HLS and turns at a right angle into the new headwork's transition section. This new transition conduit distributes the flow into six sepa-

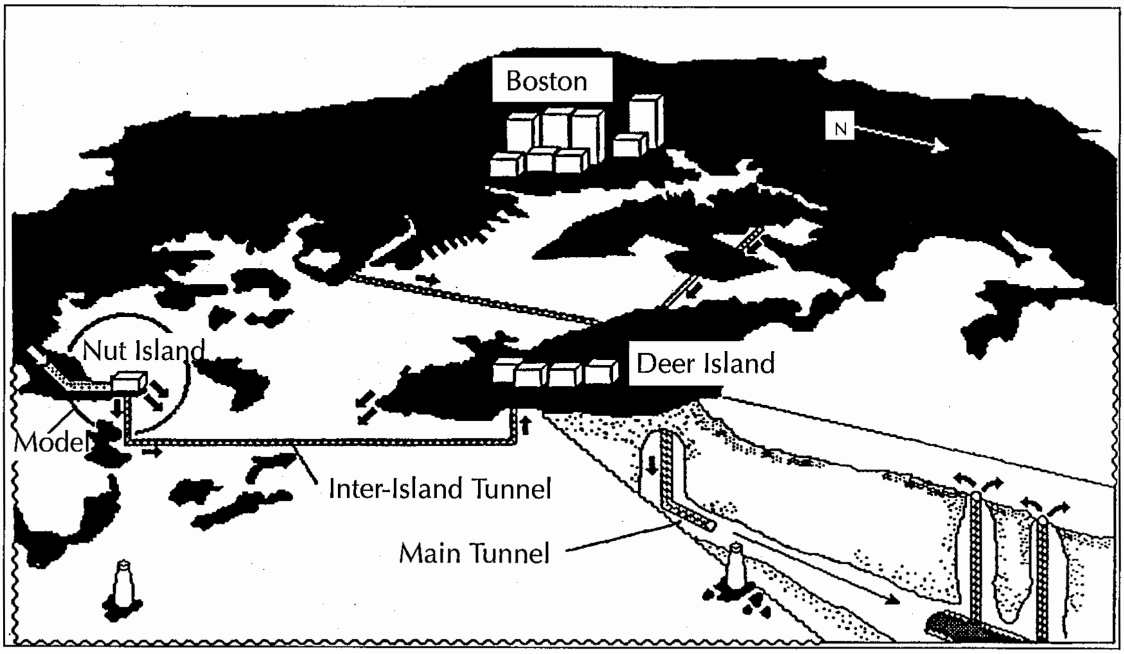


FIGURE 1. General layout of the MWRA Boston Harbor cleanup program.

rate channels for velocity reduction and flow straightening prior to entering the new headworks facility.

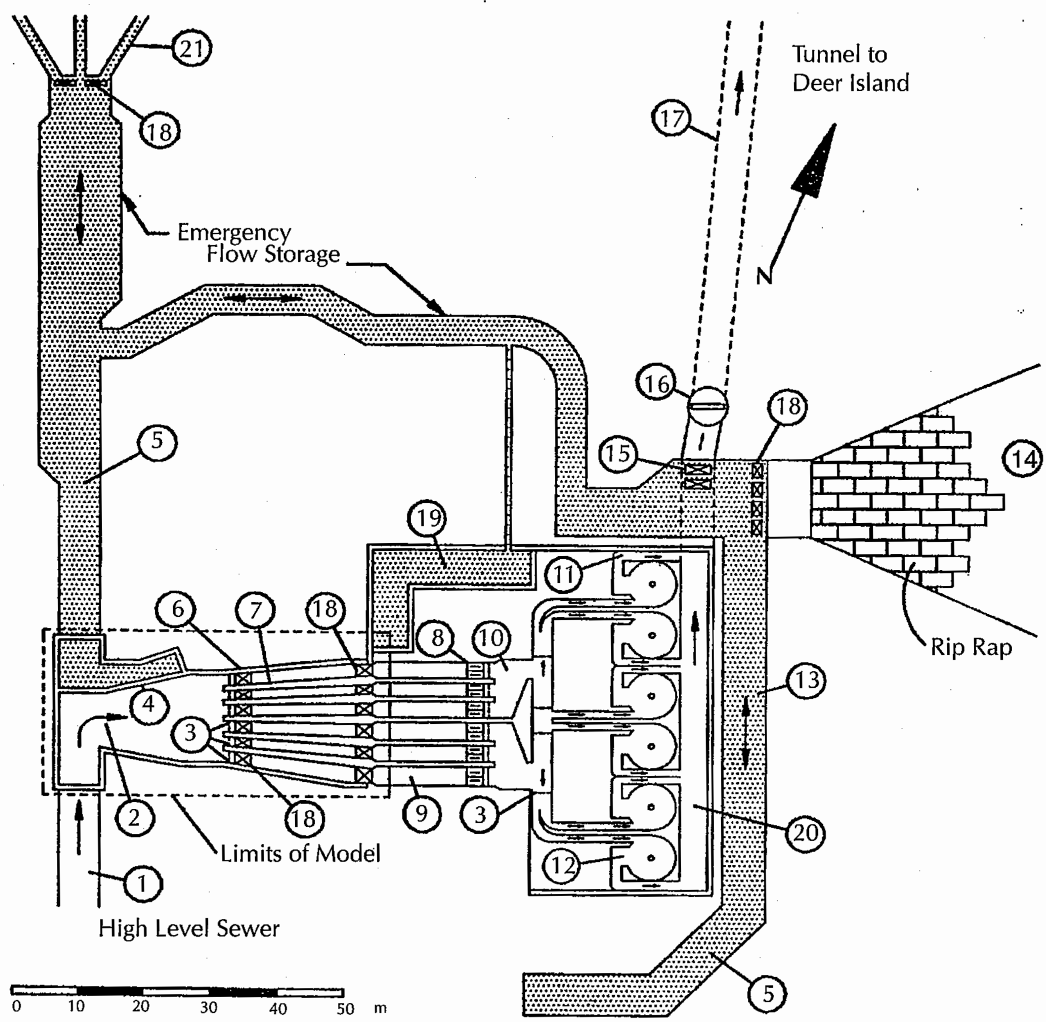
Inside the new headworks facility the six separate channels expand to six screening channels. Six catenary type mechanical screens have been installed, with four units on line at maximum flow and two units as standby. The number of screens in service will vary with discharge (dry weather flow of 80 mgd [3,500 l/s], maximum design flow of 360 mgd [15,700 l/s] and maximum hydraulic capacity of 400 mgd [17,500 l/s] — see Figure 2).

Flow exiting the screen channels enters a common grit chamber influent channel for redistribution to six grit influent channels and six vortex grit removal chambers. Five grit units are online at maximum design flow (72 mgd [3,150 l/s] each), with one standby unit. Grit removed (airlifted) from the vortex units is classified and washed. Both the removed grit and screenings are mechanically conveyed to container storage for off-site disposal.

Flow exiting the grit chambers enters a common effluent channel that conveys the flow to the Inter-Island Tunnel shaft. The new facility is equipped with an emergency bleedback storage system for capturing any spills over an emergency weir located within the junction chamber. Such flows are directed into storage created using existing influent/effluent conduits.

The preliminary concept design of the headworks (see Figure 3 on page 66) was optimized during the final construction design phase.[1,2] The project was constructed for $70 million and was put into service in October 1998. Hydraulic physical modeling was performed on the design.[3-5]

A concurrent mathematical hydraulic modeling effort was conducted to note hydraulic gradients of the upstream HLS (the immediate 12,000-foot [3,660-meter] section) and through each element of the headworks facility with linkage to a hydraulic surge model of the Inter-Island Tunnel.[2] However, the mathematical model could not describe the complications of vorticity caused by the 90-degree turn in the junction chamber. Therefore, the physical model was used to overcome this deficiency, but it was limited to the inner portions of the headworks. The physical model included the HLS entrance, the junction chamber (and emergency overflow), influent channels to the screens and the channels through the screens. The downstream vortex degritters were not ex-



1. Influent
2. Junction Chamber
3. Distribution Channel
4. Overflow Weir
5. Emergency Flow Storage
6. Transition Section
7. Channel Divider Wall
8. Screens
9. Screening Channel
10. Collection Section
11. Degritter Effluent
12. Vortex Degritter
13. Interim Conduits Converted to Emergency Flow Storage
14. Emergency Spillway
15. Surge Relief Orifices
16. Inter-Island Tunnel Shaft
17. Inter-Island Tunnel
18. Sluice Gates
19. Emergency Flow Storage Wet Well
20. Headworks Effluent Channel to Tunnel Shaft
21 Emergency Outfall

Note: Screen Effluent & Degritter Isolation Gates Not Shown.

FIGURE 2. An overview of the Nut Island Headworks.

plicitly modeled, but the degritter effluent tailwater conditions estimated by the mathematical model were simulated by adjustable weirs. The vortex degritter tailwater conditions became the terminal boundary conditions for the physical model investigations.

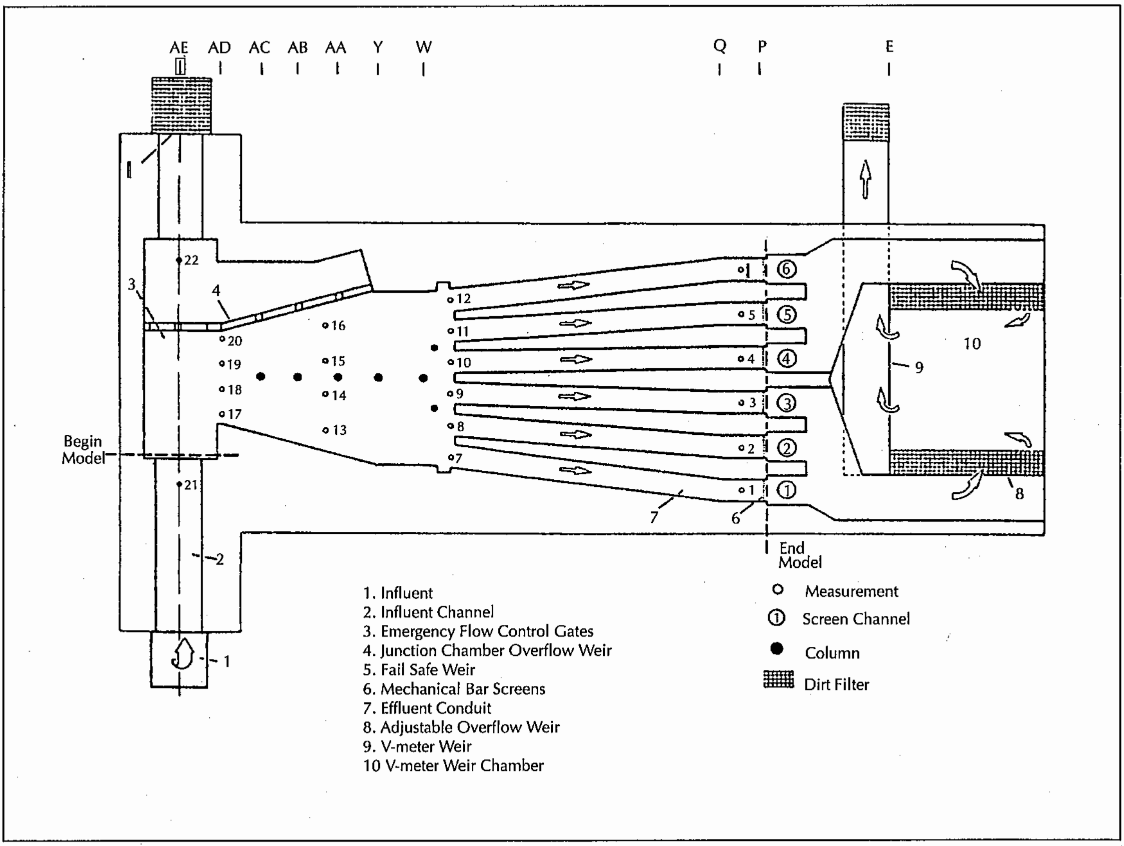


FIGURE 3. A model of the original design concept.

Objectives of Physical Modeling

This task included the construction, operation and optimization of a physical model of the headworks inlet area from immediately upstream of the connection with the HLS to immediately downstream of the six new mechanical screens.

The principal objectives of the modeling effort included confirmation and/or implementation of simple modifications (enhancements) to:

- Ensure the adequacy of flow distribution through the junction chamber to the six new screens;
- Ensure the adequacy of grit distribution through the junction chamber to the two halves of the system — left hand side (LHS) and right hand side (RHS) looking at the headworks from the LHS;
- Ensure that undue grit deposition does not occur for the range of design flows;
- Identify unforeseen hydraulic conditions and develop corrective changes; and,
- Determine capacity of the side-overflow weir under peak flow emergency conditions.

Functional Objectives

These physical modeling objectives were translated into functional objectives.

For dry weather flow conditions (80 mgd [3,500 l/s]), the functional objectives were:

- Two screens in service — one screen on each half of the system (LHS and RHS);
- Adequacy of flow and grit distribution as defined by achieving approximately equal distribution to each of the two channels in service; and,
- No undue grit deposition.

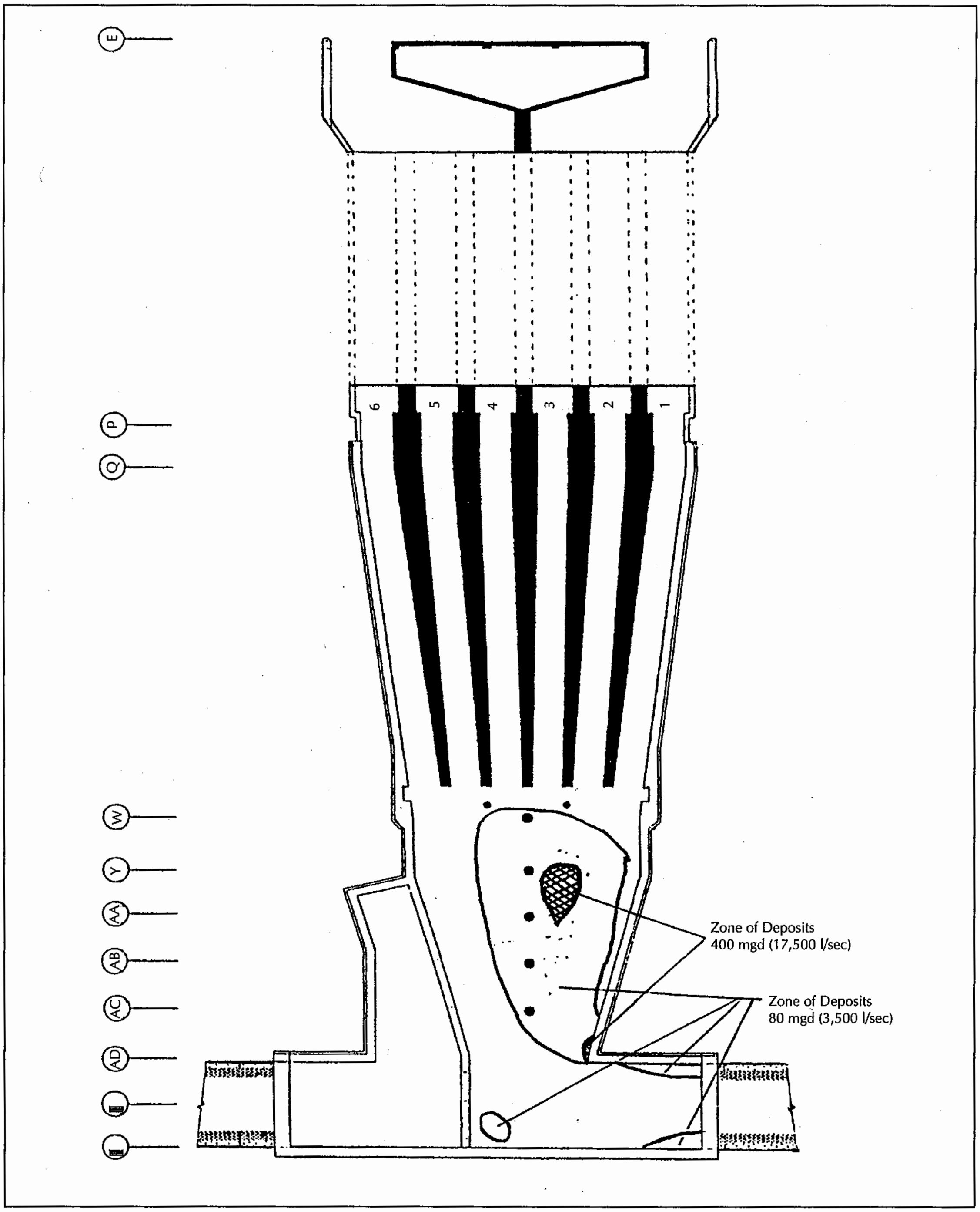


FIGURE 4. Zones of grit deposition (no control, preliminary design concept).

For maximum treatment capacity (360 mgd [15,700 l/s]) and peak hydraulic capacity (400 mgd [17,500 l/s]), the functional objectives were:

- Four screens in service — two screens on each half of the system (LHS and RHS);
- Adequacy of flow distribution as defined by achieving maximum flow less than 110 mgd (4,800 l/s), the maximum preferable hydraulic capacity of screens under nor-

TABLE 1.
Peak Flow Simulations (No Control)

Flow (mgd)	Channels in Service	Dirty or Clean Screen	Min/Max Flow Range (mgd)	Min/Max Flow Range (ratio)
360	1,2,5,6	Clean	125/65	1.9:1
360	1,2,5,6	Dirty	105/75	1.4:1
360	1,3,4,6	Clean	130/75	1.7:1
360	1,3,4,6	Dirty	115/80	1.4:1
360	2,3,4,5	Clean	110/80	1.4:1
360	2,3,4,5	Dirty	105/85	1.2:1
400	1,2,5,6	Clean	135/75	1.6:1
400	1,2,5,6	Dirty	125/85	1.5:1
400	1,3,4,6	Clean	130/65	2.0:1
400	1,3,4,6	Dirty	135/90	1.4:1
400	2,3,4,5	Clean	125/85	1.5:1
400	2,3,4,5	Dirty	125/95	1.3:1

Note: 1 mgd = 43.9 l/s

mal conditions, to any of the four screens in service;

- Adequacy of grit distribution as defined by achieving approximately equal distribution of grit of the two halves of the system (LHS and RHS);
- No undue grit deposition;
- No spillage over the emergency overflow weir at maximum hydraulic capacity; and,
- The HLS does not surcharge.

Construction of the Physical Model

The physical model was constructed, using a combination of plexiglass and laminated plywood, to a geometric scale of 1:10 (Froude similitude scaling). The model simulated the influent junction chamber emergency side overflow weir, transition section to screen influent channels, the screen channels through the six screens and the section leading to the common grit influent channel. The inflow to the model was measured by an inductive flow meter with an accuracy of ±0.5 percent. The water depths were measured at 22 points using piezometer pick-ups. Velocity was measured using a propeller flow meter at the height of the chamber and along the screen influent channels. Simulated gritty material (polystyrene particles) was used for color tracing to visually (qualitatively) define the solids distribution between the LHS and RHS and to identify any particular deposition problems (enhancement to velocity profiles). The gritty material used in the experiments simulated a settling velocity of 1.08 ft/s (33 cm/s), corresponding to very fine gravel with grain diameters from 2 to 4 millimeters. Floating lights with an underwater depth of 4 inches (10 cm) were used to show the middle velocity streamlines for photographs and videos. Styrofoam pieces were used to simulate floatables.

Results From Phase I Modeling

The initial phase of the modeling activities was conducted at three flow regimes: design low flow, maximum treatment capacity and peak hydraulic capacity. Runs were performed at each of the flow regimes for the logical variety of screen combinations (to determine the worst case for each flow regime) and for clean and dirty screen conditions (all screens clean or all screens dirty).

Phase I Findings & Conclusions

The principal findings and conclusions derived from the results of the initial phase of physical modeling activities include:

- Flow patterns in the transition section are non-symmetric for all three flow conditions (80, 360 and 400 mgd). A pronounced main vortex is developed plus secondary eddies.
- Severe sedimentation is identified for all flow conditions in the transition section (see Figure 4 on page 67).
- The system exhibits unequal flow distribution through channels in service, which is more pronounced at maximum and peak design flows (see Table 1 and Figure 5). The difference is lessened as in-service channels change from outside to inside pairs, and as the condition of the screens changes from clean towards dirty. At most maximum and peak flow conditions, the distribution of flow exceeds the peak hydraulic capacity of the screens (110 mgd [4,800 l/s]) for at least one channel.
- Non-uniform flow distribution occurs through the influent channels to the bar screens at peak hydraulic design flow. Velocities through the screen influent channels are adequate at all flow regimes to prevent significant grit deposition.
- Unacceptable spillage occurs over the emergency overflow weir at peak hydraulic flow conditions.
- Enhancements will be required to achieve the stated functional objectives.

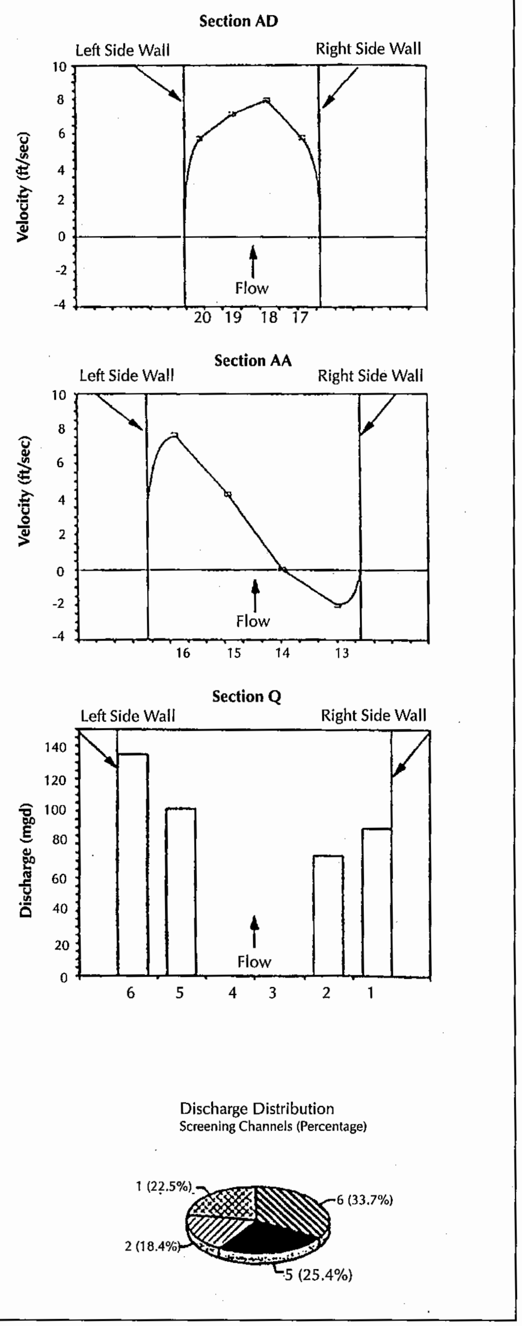


FIGURE 5. Model results for original design concept conditions (400 mgd flow, clean screens and open channels 1,2,5,6).

Recommended Enhancements for Optimization (Phase II)

Subsequent to the review of Phase I results, the following elements were recommended for in-

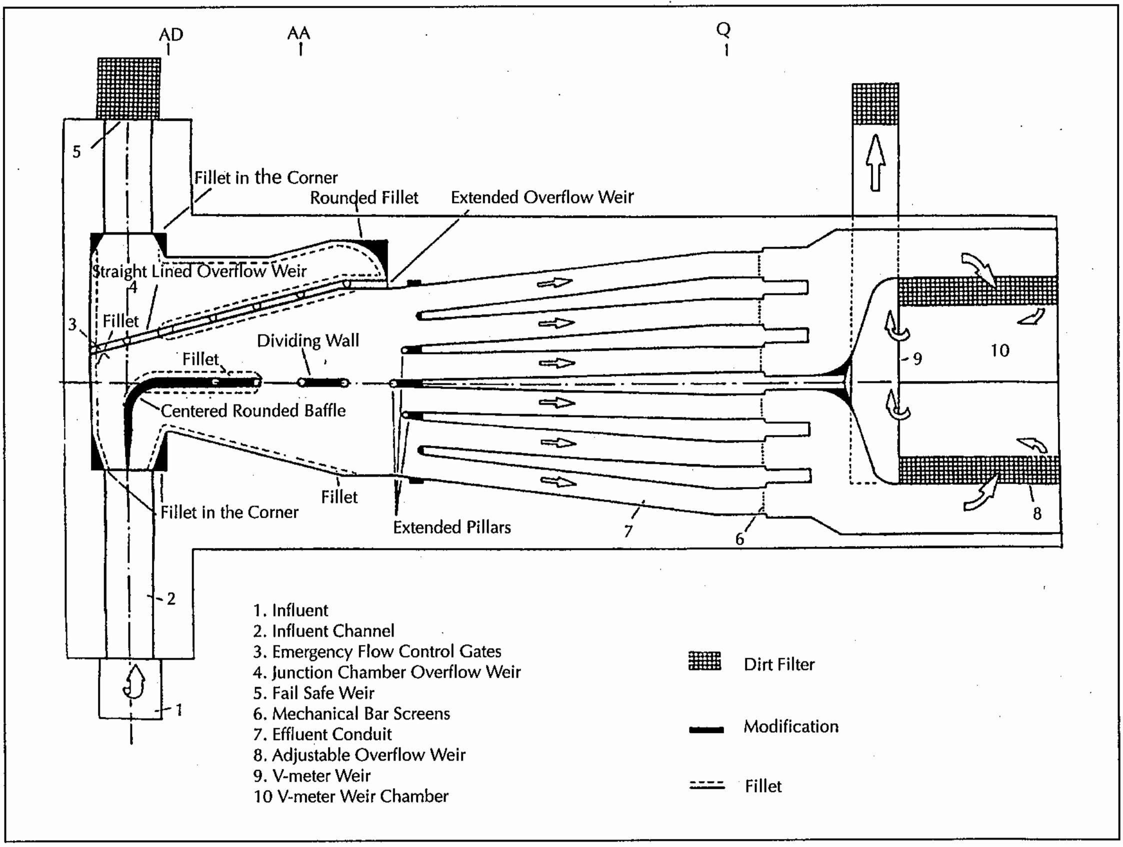


FIGURE 6. Model with optimized improvements.

vestigation in the optimization phase (see Figure 6):

- A single curved flow vane to improve distribution of flow to the transition section;
- A straight line junction to the chamber overflow offering the following advantages: no sedimentation corner under dry weather flow, and spillage over the weir reduced at peak flow;
- Two concrete fillets in the left and right corner at the HLS inlet to mitigate sedimentation;
- Concrete fillets in the corners of the overflow weir chamber to mitigate sedimentation;
- Rounded pillar profiles at the inlet to the influent channels;
- Rounded edges for the contraction section;
- Raise the emergency weir elevation and use rounded weirs and rounded columns between the weir windows to increase discharge capacity;
- Extend the wall dividing channels 3 and 4 to reduce length of stop log assemblies, thereby permitting easy isolation of each half of the system; and,
- Install an asymmetric flow vane near upstream end of eccentric flow vane to improve the distribution of grit between the two halves of the system (ultimately not recommended).

Phase II Optimization Results

The curved entrance deflector wall (see Figure 7) and the other hydraulic enhancements satisfied the functional criteria. Distribution of the original design concept flows and optimized design flows (after physical modeling) under maximum flow (400 mgd [17,500 l/s]) are presented in Figures 5 and 8, respectively, for the worst-case scenario of "open" outer and inner channels under clean screen con-

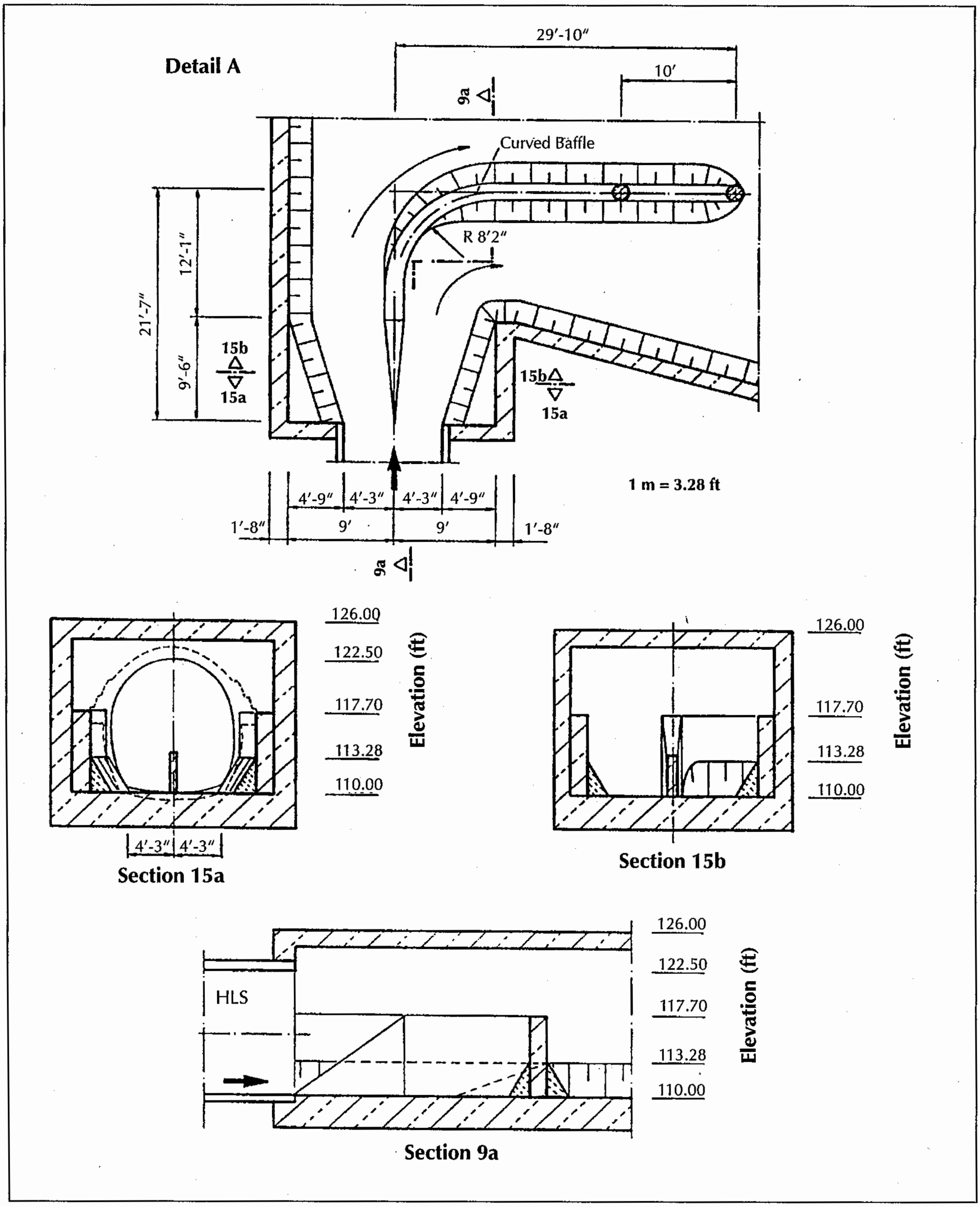


FIGURE 7. Detail of junction chamber (new curved baffle) for the Nut Island Headworks.

ditions. Spillage at the maximum hydraulic flow condition is eliminated. The distribution of floatables and "swimmers" showed acceptable uniformity and sedimentation was minimized for all flow conditions. These recommendations were included in the final design documents.

NOTES — *The preliminary design was optimized during final design by Montgomery Watson, Bos-*

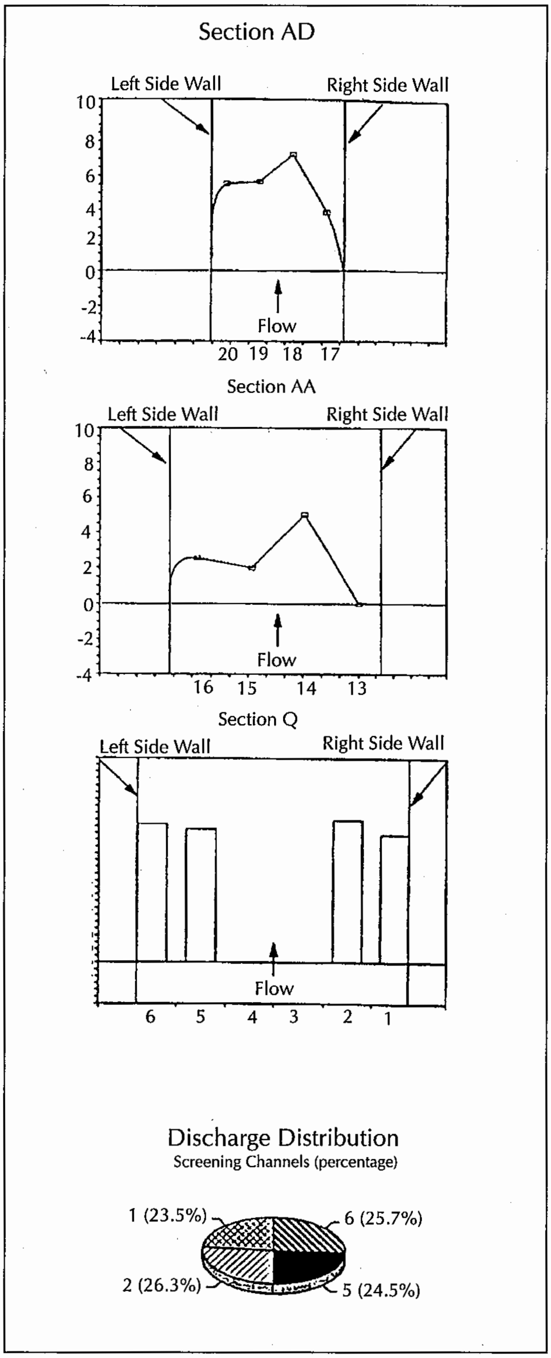


FIGURE 8. Model results for design-modified, optimized conditions (400 mgd flow, clean screens and open channels 1,2,5,6).

ton. Umwelt-und Fluid-Technik, Germany, under the direction of Dr. Hansjörg Brombach, used a hydraulic physical model to check and optimize the design concept. This article represents the opinions and conclusions of the authors and are not necessarily those of the MWRA.

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