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A Physical Model of Deadmans Run

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A PHYSICAL MODEL OF DEADMANS RUN

by

Quinn H. Brandt

A THESIS

Presented to the Faculty of

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A PHYSICAL MODEL OF DEADMANS RUN

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University of Nebraska, 2022

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A physical model of Deadmans Run and a pair of railroad bridges was constructed to assess the impacts of the bridges on flood flows. Lower Platte South Natural Resources District is planning a series of improvements to Deadmans Run to improve flood conveyance capacity and remove approximately 500 homes and businesses from the floodplain. The rail bridges are located less than a mile from the confluence of Deadmans Run and Salt Creek, meaning the bridges present a significant bottleneck to the planned improvements.

The physical model was used to characterize the drag effects caused by the bridges, which was used to improve computer models. Drag coefficients were determined from tests with individual bridges, then combined to predict losses for both bridges. These predictions aligned well with results from tests with both bridges.

The model was modified with a flume to assess alternative designs to improve conveyance under the bridges. The addition of the flume caused a hydraulic jump to form at low tailwater depths, but the jump was drowned out for higher tailwaters. The addition of pier extensions and elliptical entrances to the spur bridge and flume, respectively, had similar effects: small benefits at high tailwaters and small detriments at low tailwaters. However, observed changes were only on the order of about 0.1 feet at prototype scale.

On the other hand, removing the spur bridge completely provided substantial benefits to flume performance, with head reductions approaching nearly 1.0 ft upstream of the bridge.

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Chapter 1. Introduction

1.1. Objectives

Salt Creek is the outlet for runoff from the City of Lincoln. Deadmans Run is a tributary to Salt Creek, running from Wedgewood Lake near 70th Street and O Street to the confluence north of Cornhusker Highway (Nebraska Highway 6), near 27th Street. Less than a mile upstream of the confluence, near 33rd and Baldwin Avenue, are two rail bridges: a steel spur line bridge operated by Omaha, Lincoln & Beatrice Railway (OLB) and a concrete main line bridge operated by the BNSF Railway. The bridges are shown in Figure 1.1 and an aerial map is shown in Figure 1.2.

Figure 1.1 Deadmans Run rail bridges, looking downstream.

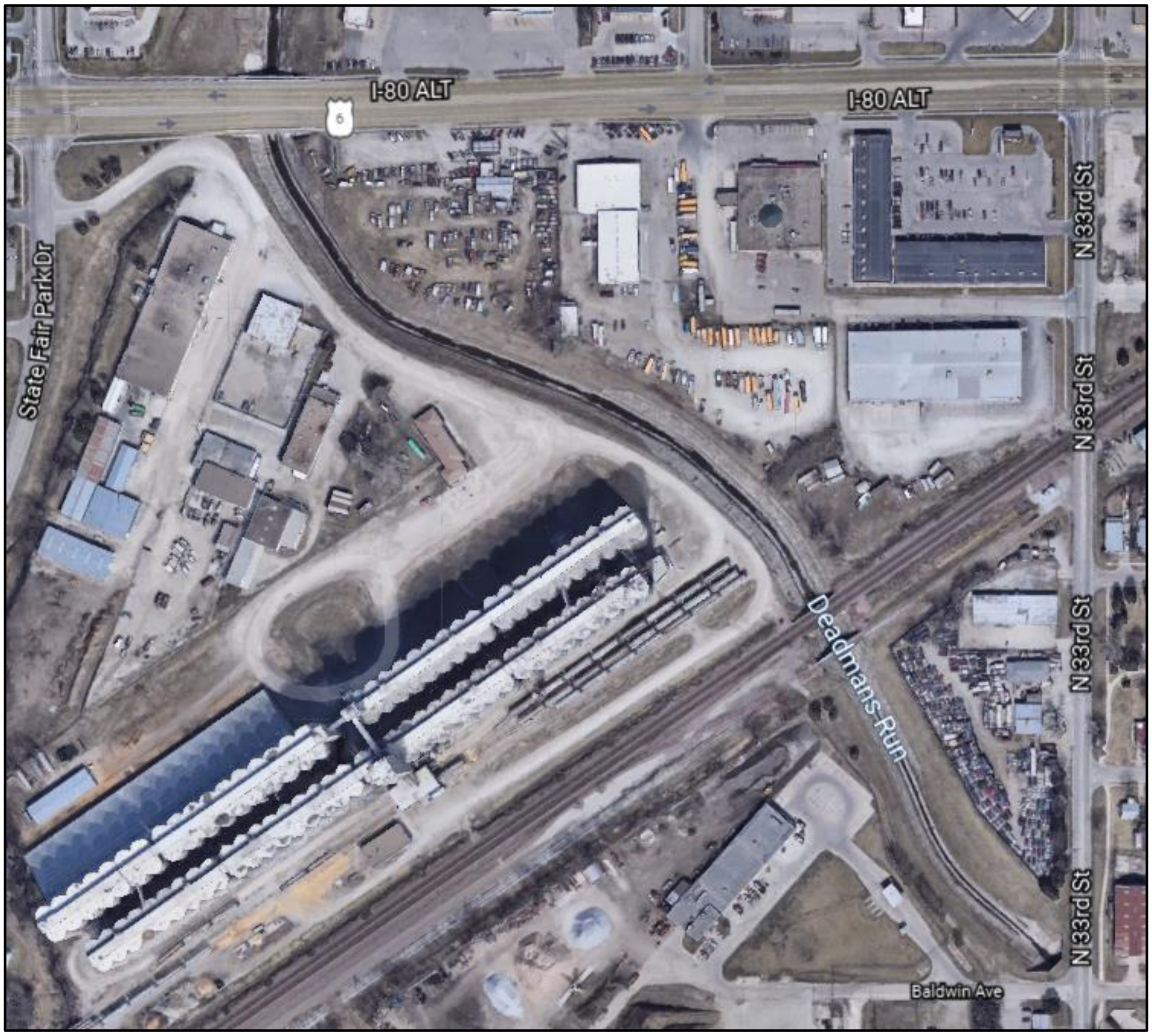


Figure 1.2 Aerial view of Deadmans Run from 33rd Street to Highway 6, from City of Lincoln/Lancaster County, NE GIS.

The Lower Platte South Natural Resources District (LPSNRD), the United States Army Corps of Engineers (USACE) - Omaha District, and the City of Lincoln have plans to improve the conveyance of Deadmans Run in the event of intense rain events, with the intention of removing approximately 500 homes and businesses from the 100-yr floodplain. Improving conveyance will require modification of the current bridge

structures and/or the channel below the bridges. Otherwise, the conveyance improvements will be limited by the bottleneck imposed by the bridges.

The goals of this project were to develop a physical model of the proposed Deadmans Run upstream and downstream of the rail bridges and test flume designs to determine their suitability for full-scale construction. An additional objective was to collect data about the flow energy losses due to the bridges to better inform loss coefficient estimates for computer models.

The sponsors for the construction of the Deadmans Run model were: LPSNRD, USACE Omaha District, and the City of Lincoln. The work was carried out at the University of Nebraska – Lincoln.

1.2. Organization of Report

The second chapter of this thesis provides a primer on models, including similitude, scaling and some important assumptions and limitations of physical modeling. The third chapter details the design and construction of the physical model, including simplifications and modifications made to accommodate the model in the lab space and the instrumentation and controls used to run tests. This chapter also describes construction associated with the addition of roughness elements and the flume. Testing methodology, the various conditions tested, and the test results are included in the fourth chapter. The fifth and final chapter contains general observations and potential modifications to the model for future tests.

Chapter 2. Background

2.1. Similitude

Physical modeling works because of a principle called similitude. If a model is carefully designed, it will behave similarly to the prototype, or full-scale version. The model must have geometric, kinematic, and dynamic similitude to achieve this. Geometric similitude is simply scaling all lengths by a length ratio L_r, which is the ratio of any length measurement in the model and the corresponding length measurement in the prototype. In most models (including the present model), all geometric measurements are scaled using the same ratio. As a consequence, all areas scale by $L_r{}^2$ and all volumes by $L_r{}^3$. Kinematic similitude is the scaling of all velocity vectors by the same velocity ratio V_r. Dynamic similitude is the scaling of all significant forces by the same ratio (relevant forces may include inertial, pressure, viscous, gravitational, compressibility, surface tension, and other forces). If geometric and dynamic similarity are achieved, kinematic similarity is automatically satisfied because of Newton's Second Law.

Comparing lengths for geometric similarity is trivial. Comparing forces is significantly more involved, requiring the equivalence of a set of dimensionless numbers, one for each force ratio. For the equivalence of inertial, pressure, viscous, gravitational, compressibility, and surface tension force ratios in the model and the prototype, the coefficient of pressure, Reynolds number, Froude number, Mach number, and Weber number must be the same in the model and prototype. These ratios are shown in Table 2.1 Dimensionless parameters used for determining similitude.

Table 2.1 Dimensionless parameters used for determining similitude.

Force	Dimensionless Number	Definition
Pressure	C_p - Coefficient of pressure	$\frac{\Delta p}{\rho \frac{V^2}{2}}$
Viscous	Re - Reynolds Number	$\frac{VL}{\nu}$
Gravitational	Fr - Froude Number	$\frac{V}{\sqrt{gL}}$
Compressibility	Ma - Mach Number	$\frac{V}{c}$
Surface Tension	We - Weber Number	$\frac{\rho V^2 L}{\sigma}$

Note: p is pressure, ρ is density, ν is kinematic viscosity, g is gravitational acceleration, c is the speed of a pressure wave in the fluid, and σ is the surface tension of the fluid.

For complete dynamic similitude, each of these dimensionless parameters must be the same in the prototype and model. However, not all forces are significant for all types of flows. For a stream flow like that of Deadmans Run, length scales are large enough that surface tension forces have negligible influence on the flow. The velocities in streams, even flooded, are quite small in comparison to the speed of sound in water, meaning compressibility forces are also negligible. Of the remaining force ratios, one can be treated as a dependent variable and automatically scales if all others are scaled. In the present case, pressure forces automatically scale. This leaves gravitational and viscous forces as the primary forces for consideration.

Stream flows are driven by gravity, meaning that if viscous forces are negligible, Froude scaling is required. By setting the Froude number of the model equal to that of the

prototype, the velocity ratio can be obtained:

$$Fr_m = Fr_p \tag{2.1}$$

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}} \tag{2.2}$$

Where Fr is Froude number, V is velocity, g is gravitational acceleration, and L is length. The subscripts *m* and *p* refer to model and prototype variables. Since the gravitational acceleration is the same for the model and the prototype:

$$V_r = \frac{V_m}{V_p} = \sqrt{\frac{L_m}{L_p}} = \sqrt{L_r} \tag{2.3}$$

For complete similitude, the Reynolds number of the model must also be set equal to that of the prototype:

$$Re_m = Re_p \tag{2.4}$$

Or:

$$\frac{V_m L_m}{\nu_m} = \frac{V_p L_p}{\nu_p} \tag{2.5}$$

Where Re is Reynolds number and ν is kinematic viscosity. To satisfy both 2.1 and 2.4, 2.3 is substituted into 2.5 to show that:

$$\nu_r = \frac{\nu_m}{\nu_p} = \frac{V_m L_m}{V_p L_p} = L_r\sqrt{L_r} = (L_r)^{\frac{3}{2}} \tag{2.6}$$

Thus, to simultaneously achieve Froude and Reynolds number similitude, a fluid with a different viscosity must be used in the model. This type of modeling is rarely practical. Fortunately, at high Reynolds numbers, in wholly turbulent regimes, viscous forces are nearly independent of Reynolds number. In other words, if model flows have a sufficiently high Reynolds number, the viscous forces will be representative of prototype values even if the viscosity is not scaled. This is a requirement that should be checked during the scaling process for all Froude-based physical models.

2.2. Scaling

While an initial scale of 1:23 was selected, there were concerns about lab space and the capability of the pump to meet flow requirements. For this reason, scaling calculations were also done at 1:25 and 1:27.

Discharge (Q) can be calculated using the continuity equation:

$$Q = VA \tag{2.7}$$

Where A is flow area. Calculating the discharge ratio, using the velocity ratio from Froude similarity:

$$Q_r = \frac{Q_m}{Q_p} = \frac{V_m A_m}{V_p A_p} \tag{2.8}$$

In which:

$$A_r = \frac{A_m}{A_p} = \frac{L_m L_m}{L_p L_p} = \left(\frac{L_m}{L_p}\right)^2 = L_r^2 \tag{2.9}$$

Substituting 2.3 and 2.9 into 2.8 yields:

$$Q_r = \frac{Q_m}{Q_p} = \sqrt{L_r}(L_r^2) = (L_r)^{\frac{5}{2}} \tag{2.10}$$

Using Manning's Equation, the reach roughness (n) can also be scaled:

$$n = \frac{K_n}{Q} A(R_h)^{\frac{2}{3}}(S_0)^{\frac{1}{2}} \tag{2.11}$$

In which K_n is a unit conversion coefficient (1.0 for metric units and 1.486 for English units), R_h is the hydraulic radius of the channel, S_0 is the channel bed slope (or the slope of the energy grade line for nonuniform flow), and n is the resulting Manning roughness. Thus, the ratio of roughness in the model and the prototype is:

$$n_r = \frac{n_m}{n_p} = \frac{\left(\frac{K_n}{Q} A(R_h)^{\frac{2}{3}}(S_0)^{\frac{1}{2}}\right)_m}{\left(\frac{K_n}{Q} A(R_h)^{\frac{2}{3}}(S_0)^{\frac{1}{2}}\right)_p} \tag{2.12}$$

The bed slope (S_0) and the unit conversion term (K_n) are identical in the model and prototype. Area, hydraulic radius (which is a length scale), and discharge ratios shown in the equations above can be substituted into 2.12 to get:

$$n_r = \frac{n_m}{n_p} = (L_r)^{-\frac{5}{2}}(L_r)^2(L_r)^{\frac{2}{3}} = (L_r)^{\frac{1}{6}} \tag{2.13}$$

While 2.13 can be used to determine the equivalent Manning roughness (n) of the model, the Manning roughness is not immediately useful for modeling since it is a reach roughness and not a physical measurement. It needs to be converted to a local roughness length scale so that the model roughness can be appropriately selected. Strickler (1923) suggests that the reach roughness length scale can be replaced by the product of the sand

grain roughness (k) to the 1/6th power and a function (ϕ) of the ratio of the hydraulic radius and sand grain roughness. Chow (1959) states that as ϕ is only a weak function of R_h/k, it can be replaced with a constant of 0.034 if k has units of feet.

$$n = \phi\left(\frac{R_h}{k}\right)k^{\frac{1}{6}} \sim 0.034k^{\frac{1}{6}} \tag{2.14}$$

In which k is the equivalent sand grain roughness of the channel walls. Equation (2.14) allows the determination of a roughness length scale based on a known Manning roughness. This is useful because channel design is usually done with Manning roughness in mind, but when a model is selected, the sizes of roughness elements must be assessed for installation in the model.

2.3. Flow Regime

As previously suggested, the Reynolds number of any Froude based physical model should be checked to make sure it is sufficiently high so that viscous forces may be neglected. For a typical model, the Reynolds number is calculated using VL/ν with an estimated kinematic viscosity. Then, it must be checked to make sure that the flow is in the “wholly rough” regime – the condition for which energy losses become independent of Reynolds number. This requirement is enumerated by Ettema et al. (2000) as:

$$Re\frac{k}{D}\sqrt{f} > 200 \tag{2.15}$$

Where f is the friction factor, D is the equivalent pipe diameter of the channel cross-section or $4R_h$, and Re is the Reynolds number using $4R_h$ as the length scale. The

friction factor can be determined by equating energy slope from Manning's Equation to head loss (h_l) per length from the Darcy-Weisbach Equation:

$$S_0 = \frac{V^2 n^2}{(R_h)^{\frac{4}{3}}(K_n)^2} = \frac{f}{4R_h}\frac{V^2}{2g} = \frac{h_l}{L} \tag{2.16}$$

Solving for friction factor yields:

$$f = \frac{8gn^2}{(R_h)^{\frac{1}{3}}(K_n)^2} \tag{2.17}$$

Which can be introduced into Equation (2.15) (along with the equivalent diameter) to form the model requirement:

$$\frac{V(4R_h)}{\nu}\frac{k}{4R_h}\frac{n\sqrt{8g}}{(R_h)^{\frac{1}{6}}K_n} > 200 \tag{2.18}$$

After selecting a preliminary model scale, the bulk average velocity (V), hydraulic radius (R_h), and Manning roughness (n) are determined from the design discharge, geometry, and Manning roughness of the prototype and are scaled to model quantities. Sand grain roughness is determined from the scaled Manning roughness. A standard kinematic viscosity of water (ν) is chosen, and the gravitational acceleration (g) and unit conversion coefficient (K_n) are constants. All these model-scale variables are then inserted into Equation (2.18) to determine if the model scale will satisfy Reynolds number requirements. If the model scale does not satisfy requirements, the model scale must be adjusted accordingly.

Chapter 3. Model Design and Construction

3.1. Overview

This section contains an operational overview of the major components of the model. Details on scale selection, construction and instrumentation are included in subsequent sections.

A GE oil-bearing impeller pump is available to supply flow to the model. It has a variable frequency drive (VFD), meaning the impeller speed can be adjusted, allowing different flow rates. The supply line also has a valve that can be adjusted to limit flow, if necessary. The maximum available flow rate from the pump for the current sump configuration is approximately 4 ft^3/s, though the flow can be augmented by increasing the amount of water in the sump or adding a second pump in parallel. Available discharge has some impact on model scale selection.

3.2. Scale Selection

An initial scale of 1:23 was proposed, as it was estimated to be the largest that would fit in the lab space. Scaling calculations were also done at 1:25 and 1:27, in case 1:23 would prove to be impractical. At each of the selected model scales, discharge, Manning's roughness, sand grain roughness, bulk average velocity, hydraulic radius, and Reynolds number were determined.

Based on prototype design information provided by the U.S. Army Corps of Engineers (USACE), a spreadsheet was constructed to determine model Reynolds number based on the model scale and discharge. Using roughness and geometry

information, normal depths were determined for a wide range of discharges. Then, flow information provided by the spreadsheet was used to calculate Reynolds numbers for each discharge. These Reynolds numbers were then used to establish the range of discharges for which Equation (2.18) was satisfied. If the design discharge fell within the range of acceptable discharges, the model scale was considered to be adequate. For a design discharge of 12,000 ft^3/s (prototype), model scales of 1:23, 1:25, and 1:27 were all found to perform adequately. In fact, all model scales were observed to satisfy Equation (2.18) even for flow rates that were several orders of magnitude less than the design discharge.

Ultimately, a model scale of 1:25 was selected because the 1:23 scale model was deemed to be too large and required more flow than could be reliably supplied by the model pump. There was sufficient space to fit the 1:25 scale model within the existing floor plan. The results provided by a physical model are generally more accurate if the model is closer in size to the prototype scale. Since building a 1:25 scale model was practical, the 1:27 scale model was ruled out.

3.3. Model Plan

3.3.1. Laboratory Model Layout

This section provides a basic overview of the final model, with a plan view shown in Figure 3.1. Details of individual parts and construction are provided in the following sections.

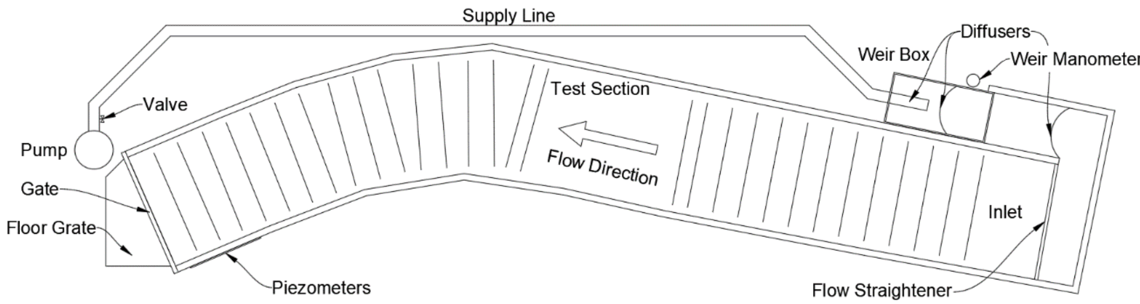


Figure 3.1 Plan overview of model, not to scale.

The pump draws water from the storage sump below the floor of the laboratory and transfers it to the weir box through a 10-inch PVC pipe along the side of the model.

Water flows into the weir box and through a perforated pipe diffuser, then through another perforated sheet diffuser, and out the V-notch weir into the inlet. The diffusers reduce turbulence, causing a more stable water surface. There is a piezometer in the bottom of the weir box that connects the box to a manometer with a point gauge. The point gauge indicates the depth in the weir box during operation, enabling measurement of the flow rate into the model through the V-notch weir.

Another sheet diffuser is located downstream of the v-notch weir, followed by a steel grate supporting a mat of “rubberized hair,” a mesh of long rubber strands resembling hair. The grate is followed by a rounded transition into the upstream end of the model. All of this is intended to break up the flow, remove turbulence and provide smooth entry of the flow into the physical model.

At the outlet of the model is a three-section gate that directly controls the tailwater depth in the model. Downstream of the gate, a walled chamber directs water down through a grate, back into the laboratory sump.

3.3.2. Template Layout

Before beginning construction, several preparatory tasks needed to be completed. Detailed stream cross-sections were provided to us by the USACE, describing the positions and elevations of the proposed prototype stream modifications. These plans are shown in Figure 3.2.

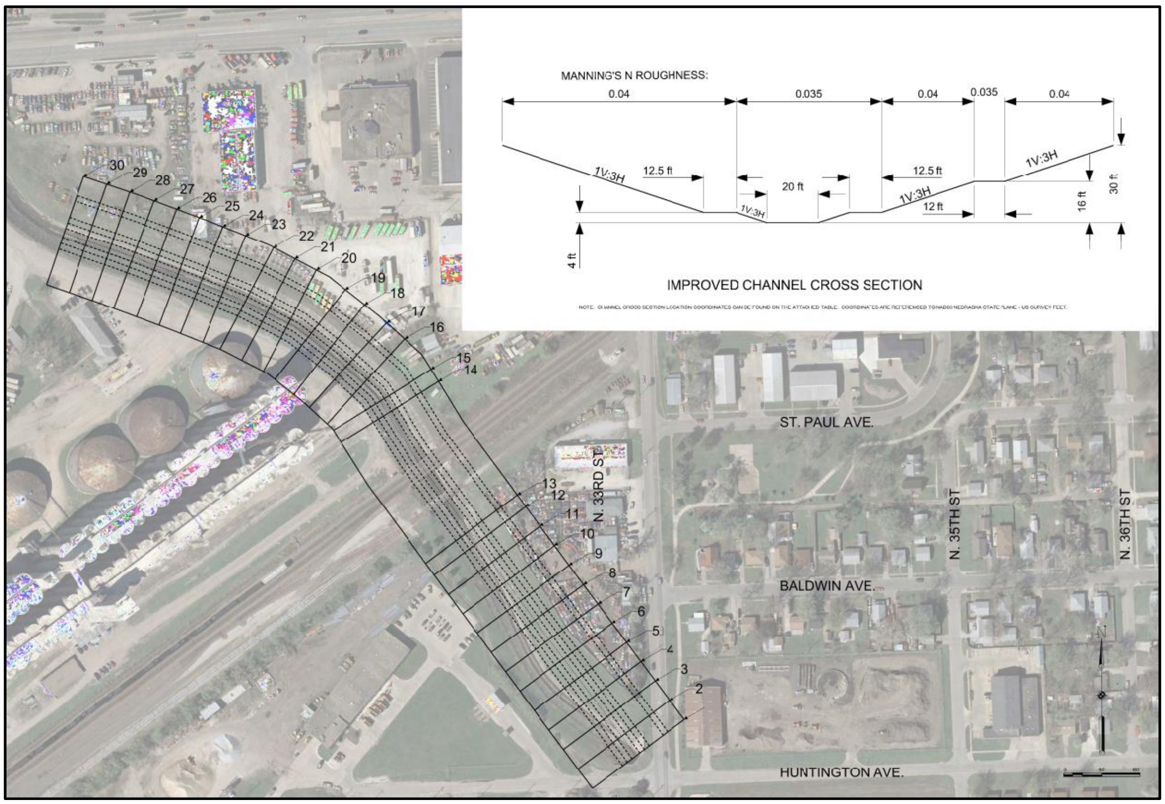


Figure 3.2 Proposed Channel Geometry provided by the USACE.

Although the provided cross sections extend 30 feet vertically above the centerline, Lancaster County LiDAR of the area indicated the banks were a maximum height of about 25 feet above the centerline. Additionally, the spreadsheet discussed in Section 3.2 showed that the normal depth at the target discharge would be well below the 25-foot-high banks. For these reasons, the cross-section was modified, as shown in

Figure 3.3, reducing the prototype width by 30 feet, 15 feet on each bank. At scale, this reduced the needed model width by over a foot.

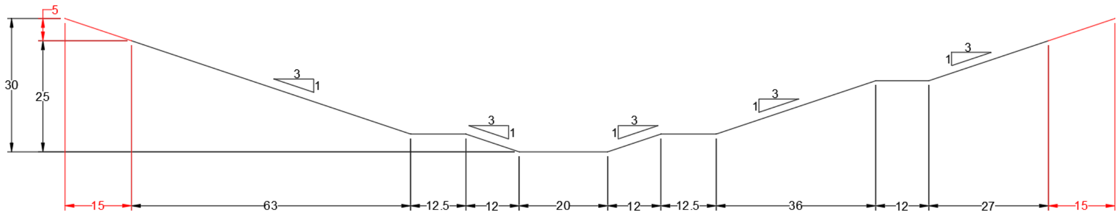


Figure 3.3 Modified cross-section used to generate templates. Red lines indicate edges trimmed from provided cross sections. Prototype scale, dimensions in feet.

The cross-section geometry was entered into CAD software, scaled down by a factor of 25, and adjusted to use the shortened cross-section. The basin walls were drawn around this. Coordinates for both the basin walls and cross-sections were determined so that they could be surveyed in during construction.

3.4. Basin Model Construction

Based on the model cross-section layout, basin wall positions were surveyed in, forms were built for the walls, and the concrete walls were installed, as shown in Figure 3.4. The walls were then covered in an asphalt sealant.

Figure 3.4 Freshly poured basin walls.

The scaled channel cross-sections were plotted on paper which was glued to 16-gauge steel sheets, as shown in Figure 3.5. The steel templates were cut out with an electric shear, as shown in Figure 3.6.

Figure 3.5 Paper template adhered to 16-gauge sheet steel.

Figure 3.6 Steel template cut with electric shear.

Additional steel sheet was used to make sets of brackets to mount the templates to the floor and side walls of the basin. Once the asphalt sealant cured, template positions were surveyed in based on the model layout. Three brackets were placed on the floor for each section at the points previously surveyed, then secured with concrete screws. Each steel section was then surveyed to the correct elevation and welded in place as shown in Figure 3.7.

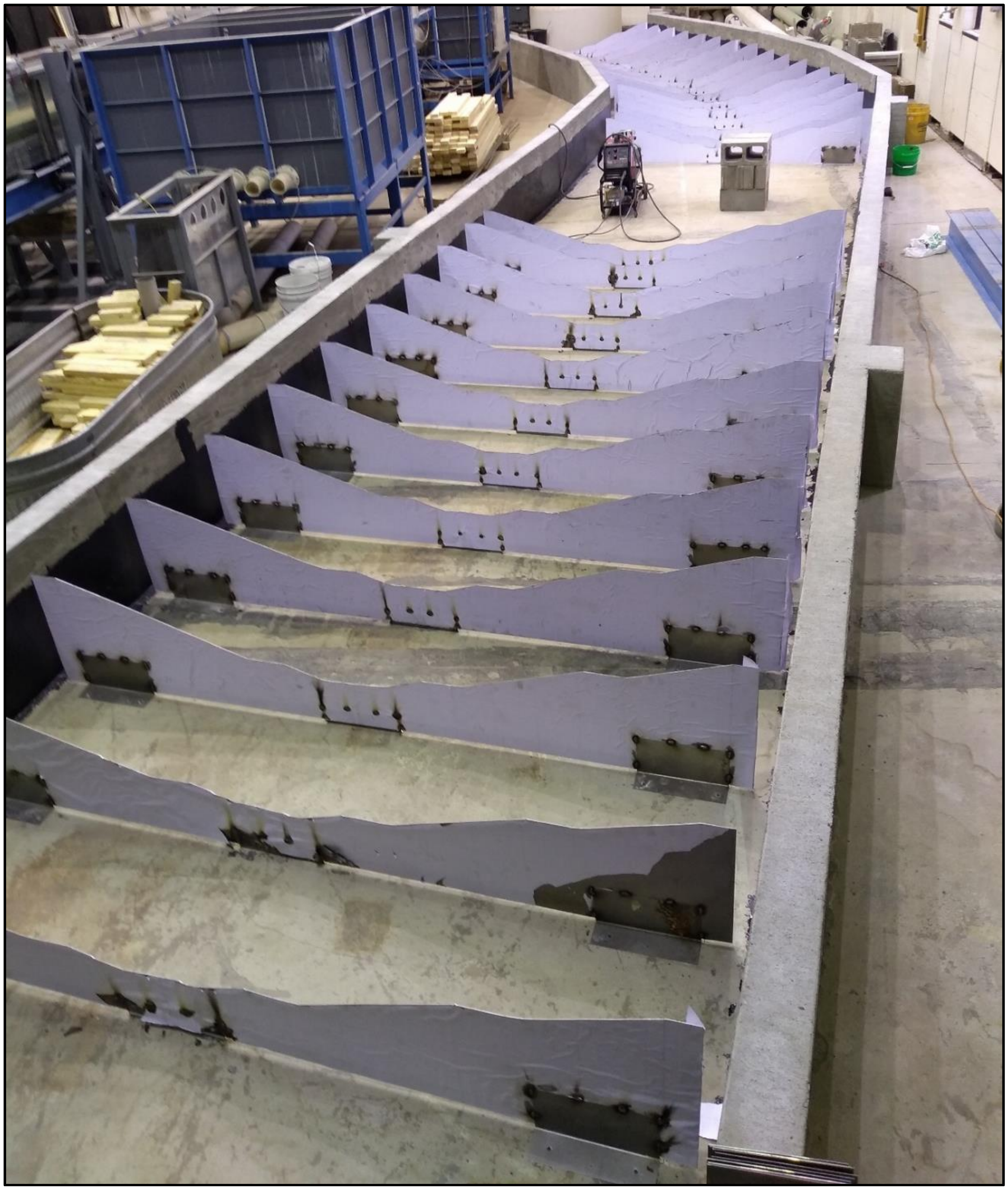


Figure 3.7 Basin walls sealed with asphaltic sealant, steel brackets surveyed in and steel templates welded at surveyed heights.

Additional brackets were added to the walls. A small bracket was mounted to the center of each section to hold piezometer tubes, which were fastened to the templates and then routed along the basin wall to the downstream end of the model. The space between sections was mostly filled with cinderblocks and covered with leftover sheathing from the

concrete forms as shown in Figure 3.8. Plastic sheets were run wall to wall in each section and duct taped to the section plates to seal the sheathing.

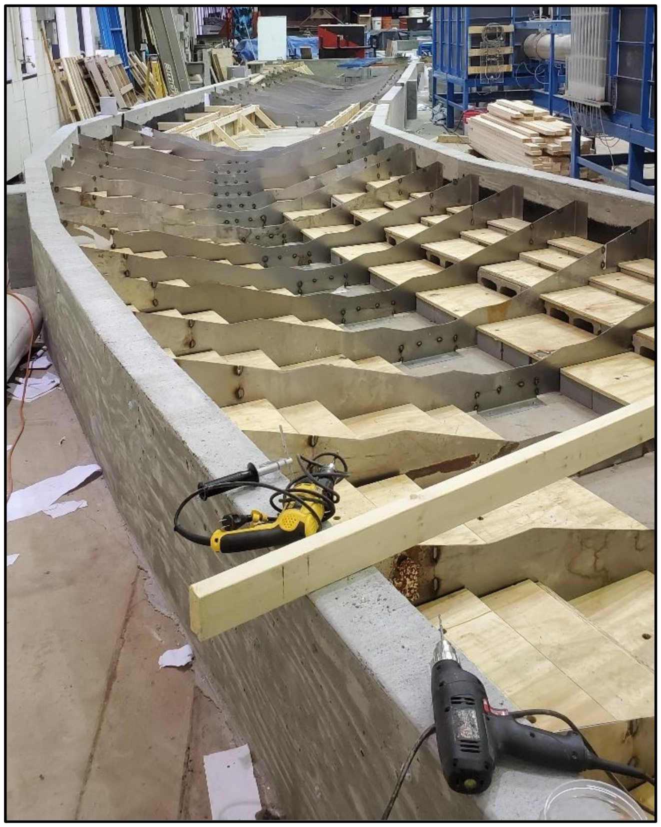


Figure 3.8 Sections filled with cinderblocks and sheathing covers.

Crushed concrete was piled and compacted to approximately 4 inches below the tops of the steel templates. The remainder was filled with a lightweight concrete of 45 pounds Portland cement, 15 gallons of vermiculite, and 7.5 gallons of water. (This mix ratio was based on the one presented in Haberman (2004), with a slightly higher water content for more workability.) This vermiculite concrete is workable on slopes, and once set, can be modified with normal woodworking tools. Prior to installation of the concrete, wire mesh reinforcement (poultry wire) was placed between the templates. During concrete installation, the wire mesh was pulled up to about half the depth of the concrete.

The concrete was poured in alternating sections, as shown in Figure 3.9, to allow working space on each side. After screeding to the steel templates, the concrete was covered and allowed to cure.

During installation, the vermiculite concrete tended to bulge when it was poured between the sloping sides of the templates. This was partially remedied by pouring the concrete in batches. However, many of the sections were later planed with an electric planer to flatten the flow cross-sections so that they better matched adjacent templates.

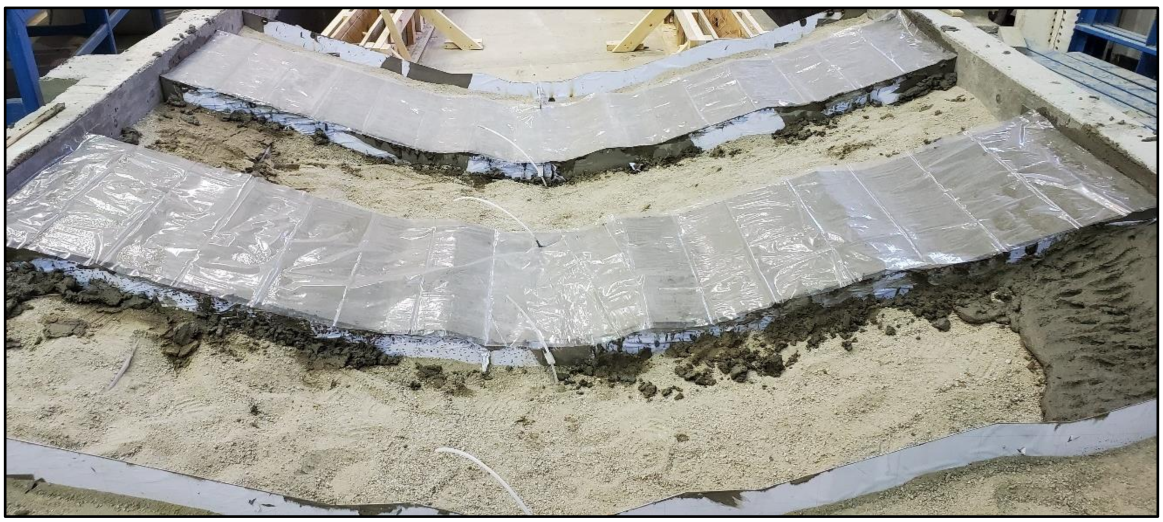


Figure 3.9 Sections filled with crushed concrete and Vermiculite concrete.

The test section, where model bridges needed to be installed, was made similarly, but with aluminum templates instead of steel to allow for easier modification. This is shown in Figure 3.10.

Figure 3.10 Test Section with aluminum templates and plastic piezometer tubing.

The inlet section transitions from a rectangular cross-section to the channel cross section, as shown in Figure 3.11. The inlet base was made using normal weight concrete and flexible forms. Curved sections were formed on top of the base using the same steel-template and vermiculite concrete methods as the main sections of the model. The curved sections have a 2:1 elliptical shape that transitions to match the upstream-most template. The grate with rubberized hair and the upstream diffuser were added after initial tests to reduce entrance effects, causing a more uniform flow into the model.

After construction, the model was painted with blue pool paint, and the piezometer tubes were trimmed to be level with the bed.

Figure 3.11 Inlet section with diffuser and grate with rubberized hair.

3.5. Instrumentation and Controls

3.5.1. Weir Box

The weir box is a 4-foot wide by 8-foot long by 4-foot deep open-top tank that provides a method of measuring flow into the model and is shown in Figure 3.12. The supply line from the pump connects to the back of the weir box. Water flows into the tank, through the diffusers shown in Figure 3.13, and out of the V-notch into the model.

Attached to the side of the weir box is an acrylic manometer connected to the bottom of the weir box. A point gauge is used to read the water elevation in the manometer, which is the same as the water elevation in the tank. Based on the manometer

reading, the head above the V-notch crest and thus the flow rate through the V-notch, and thereby the model, can be determined.

Figure 3.12 Weir box with manometer and point gauge for measurement at right.

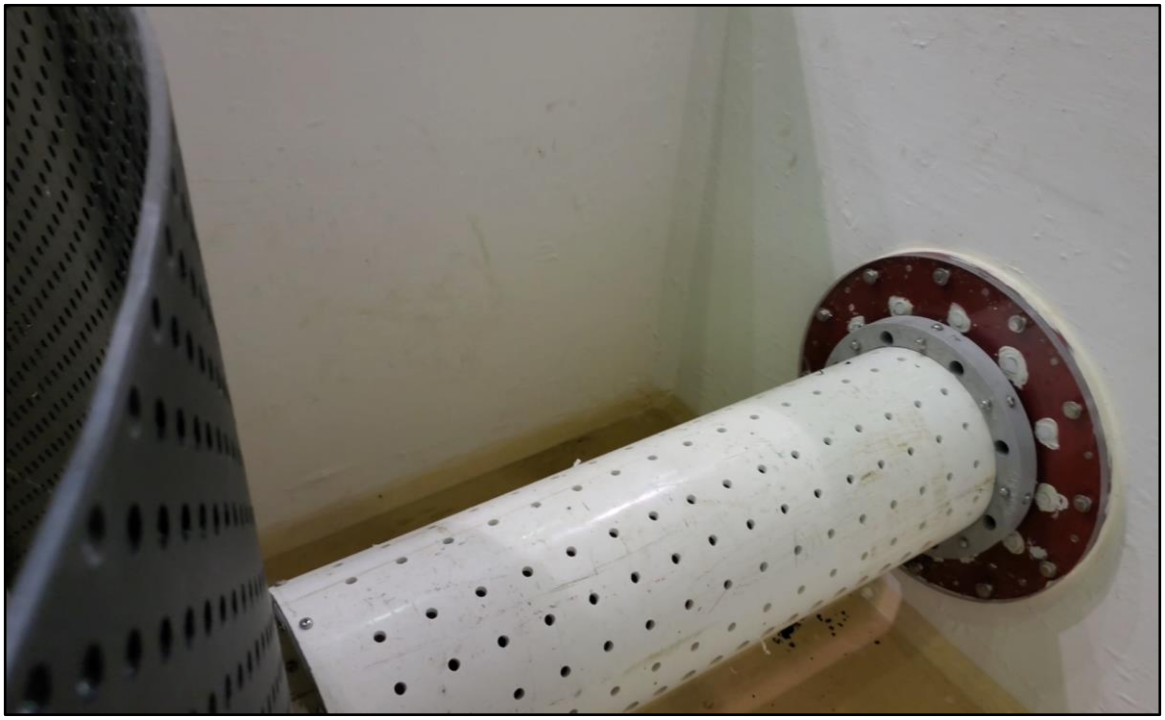


Figure 3.13 Pipe diffuser and sheet diffuser inside weir box.

3.5.2. Control Gate

At the outlet of the model is a 3-section gate, shown in Figure 3.14. This is the primary control for the downstream tailwater elevation in the model and is used to set the tailwater to match desired piezometer readings at the downstream end of the model. Each section is independently adjustable, though height measurements were only taken from the center gate, with the side gates adjusted to match.

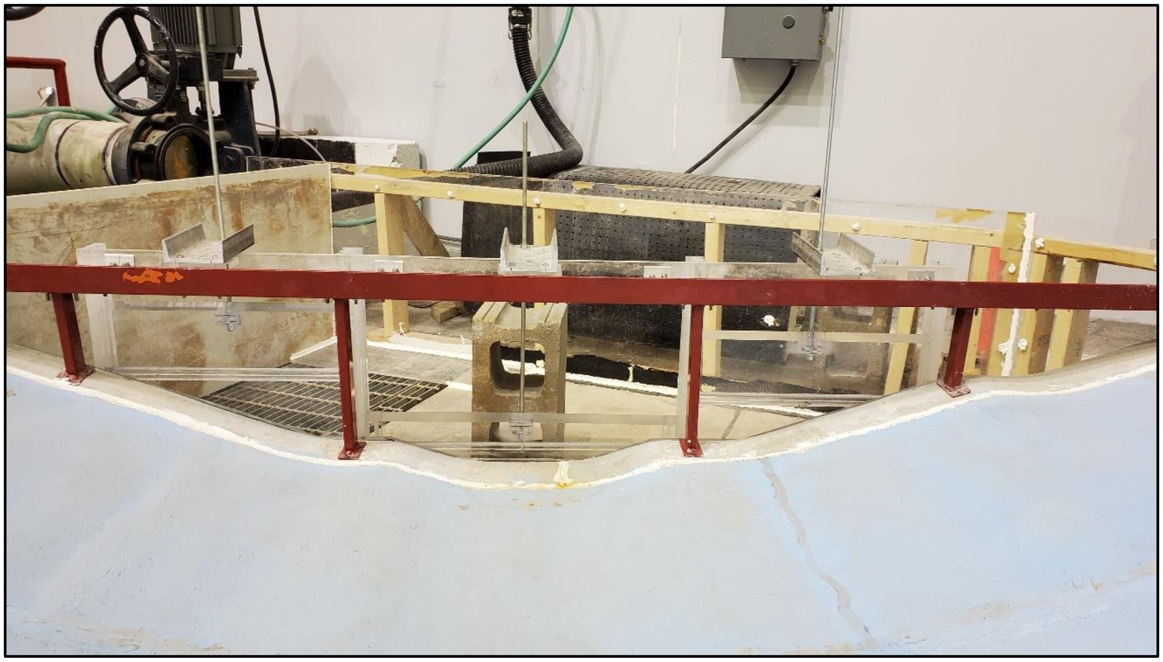


Figure 3.14 Gate control structure at model outlet.

3.5.3. Piezometers

The 39 manometers, shown in Figure 3.15, are the primary data source for all tests. The manometers are glass tubes set in front of a scale graduated in 0.1 cm increments. The top of each manometer is open to the atmosphere. The bottom of each manometer leads to a quick-connect fitting. Each piezometric tube from the model terminates in the matching fitting, with each one numbered.

When the model is used, water fills each manometer to match the water surface elevation of the piezometer to which the manometer is connected. From these readings, water surface profiles are measured. As piezometer readings are measured from an arbitrary datum, some correlation to the model depth at each cross-section is required. This is discussed in Section 4.4, along with piezometer corrections and the aluminum plates that were added over piezometric tubes in the model.

Figure 3.15 Piezometers. Right is upstream, left is downstream.

3.5.4. Point Gauges

After initial tests, four point gauges were added to the model, as shown in Figure 3.16. Aluminum beams were anchored so that the point gauges were over piezometers 5, 13, 23, and 36. Piezometers 13 and 23 are at the beginning and end of the test section, respectively. Piezometer 5 is well upstream of the test section, but far enough downstream of the inlet to minimize the influence of the entrance on depth readings. Piezometer 36 is well downstream of the test section, but far enough upstream of the gate to minimize the influence of the outlet on depth readings. These locations were chosen for verifying the piezometer readings throughout the model. The point gauges were used to correlate piezometer data with flow depth, as discussed in Section 4.4.

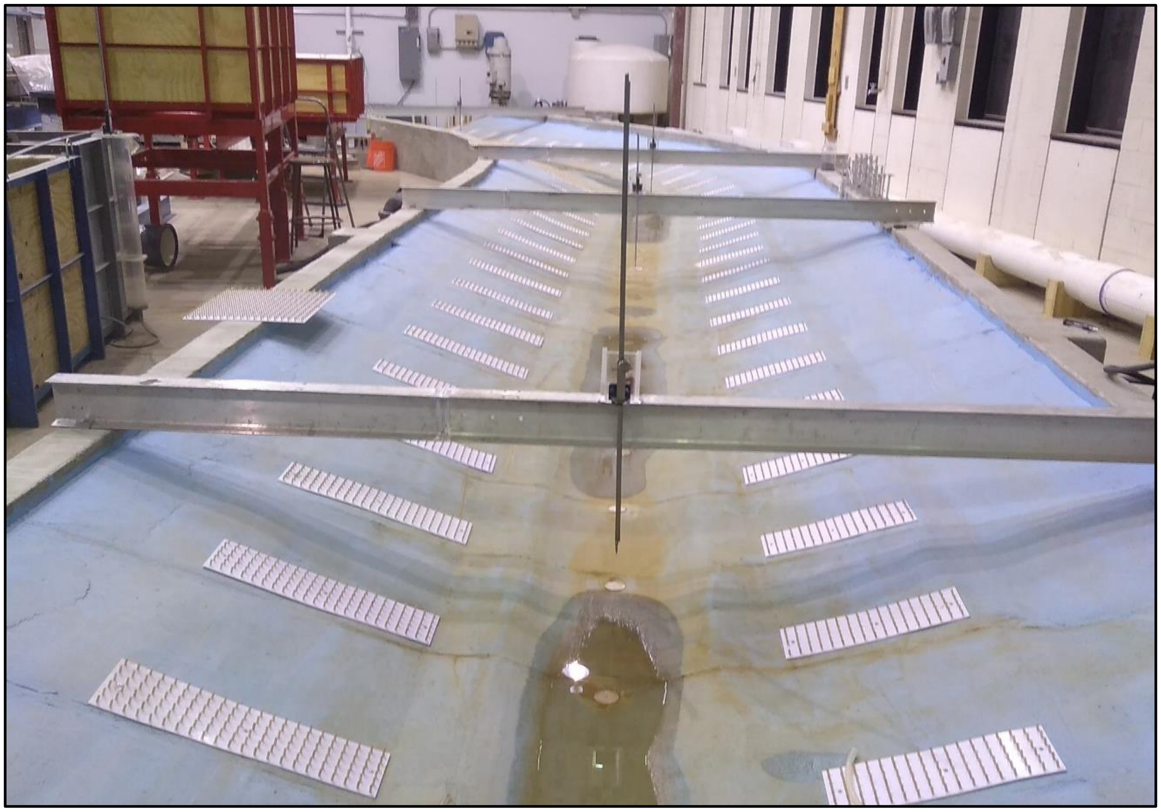


Figure 3.16 Aluminum beams with mounted point gauges.

3.6. Roughness Element Construction

According to Equation (2.14), the lengths of roughness elements were determined to be approximately 0.4 inches. However, this is a rough estimate for the sand grain roughness, initially presented for its simplicity. Three other (similar) methods were also used to determine relations between Manning roughness and sand grain roughness: the Colebrook White equation, the Log Law for an open channel, and Keulegan’s equation for the Log Law. These methods gave results that averaged 0.5625 inches. This larger roughness length was used for creating the roughness elements since roughness elements are continually added to the model until calibration requirements are met. If the roughness elements are too short, it may be impossible to meet calibration requirements,

but if they are too long, the problem can be remedied by adding fewer of them. It would have been a significant amount of work to remake roughness elements.

Wooden dowels 36 inches long and 0.1875-inch diameter were cut to 0.6875 inch in length using a jig and a bandsaw, as shown in Figure 3.17. After approximately 45,000 were cut, see Figure 3.18, they were individually inserted to fill 18-inch x 22-inch polyethylene pegboard sheets, leaving 0.5625 inches exposed. One hundred sheets were made, see Figure 3.19, and it was as arduous and mind-numbing as it sounds. They were then sealed front and back with polyurethane to both secure the dowels and reduce swelling of the wood dowels.

The installation of roughness elements for calibration is discussed in Section 4.5.

Figure 3.17 The jig and bandsaw used to cut roughness elements.

Figure 3.18 Approximately one cubic foot of roughness elements or 45,000 dowels.

Figure 3.19 Completed roughness element boards.

3.7. Bridge Model Construction

Detailed measurements of the existing rail bridges were taken. This entailed multiple site visits with a total station and tape measures. The main line bridge has a benchmark on it, which simplified determining elevations from the survey. Each bridge member had its size, length and location detailed so that it could be recreated. These

measurements also included the lengths of piers above ground, allowing a rough re-creation of the existing channel section for comparison.

From these measurements, a set of drawings was produced, shown in Appendix A. These were scaled down and reproduced with longer columns to match the proposed cross-section.

The OLB steel bridge model piers were made from aluminum C-channel cut to size, with the I-beams modeled with back-to-back C-channel. The piers were attached to an acrylic bridge deck with epoxy, with spanwise members attached afterwards. Some of the pier sets are shown in Figure 3.20.

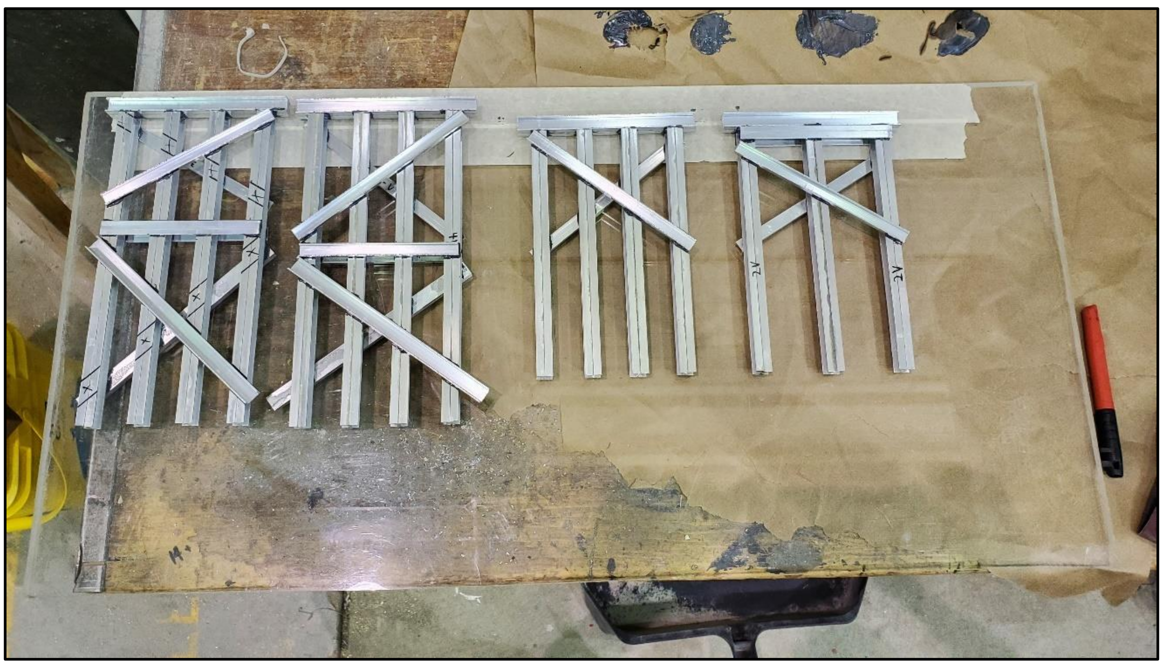


Figure 3.20 Spur bridge piers.

The BNSF concrete bridge was more complicated. The piers were replicated with six-sided acrylic boxes with 28 acrylic piles glued to the bottom of each, as shown in Figure 3.21. On top of each pier is a thin staggered spacer that supports the side and central decks of the bridge, simulating the trapezoidal block and rollers of the full-size

bridge. The decks are four-sided acrylic boxes, with the left and right sides left open for ease of construction. The piers were drilled and tapped so that the decks could be fastened to the piers. This also provided a repeatable method of aligning the various pieces when the bridge was uninstalled and reinstalled.

The finished, but unpainted, bridges were placed in the model, as shown in Figure 3.22, with their locations marked so they could be removed and replaced as needed.

Figure 3.21 Main line bridge pier with spacers used to align piles.

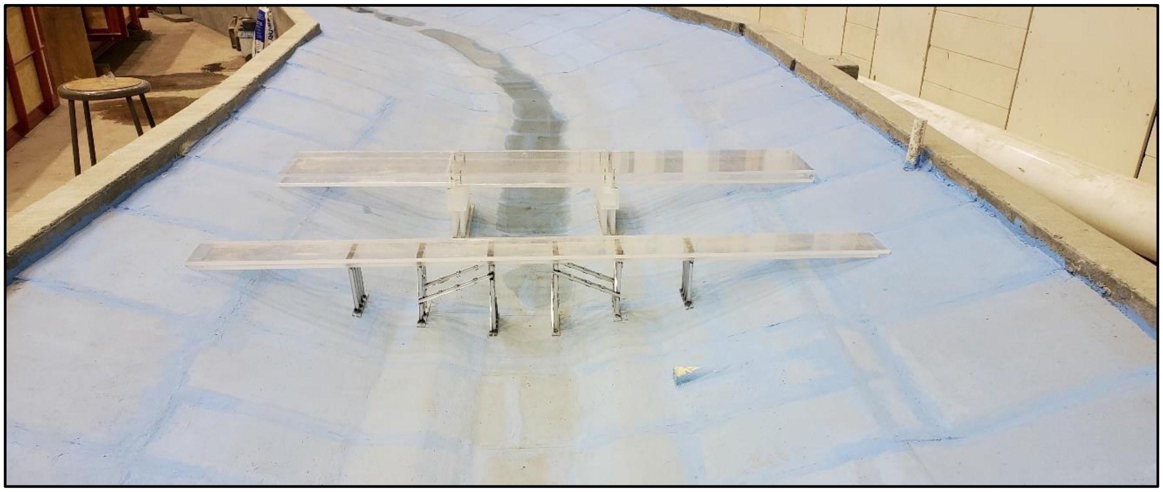


Figure 3.22 Finished Model bridges in position before being painted.

3.8. Flume Construction

After preliminary tests in the model, described in Chapter 4, the flume was built. Some roughness elements in the test section needed to be removed when the flume was installed. The locations of bridge piers were marked, and the bridges moved. Then the center section of the flume was marked, with 2:1 inlets and outlets for the inlet and outlet of the flume. Plan and section views of the flume are shown in Figure 3.23 and Figure 3.24.

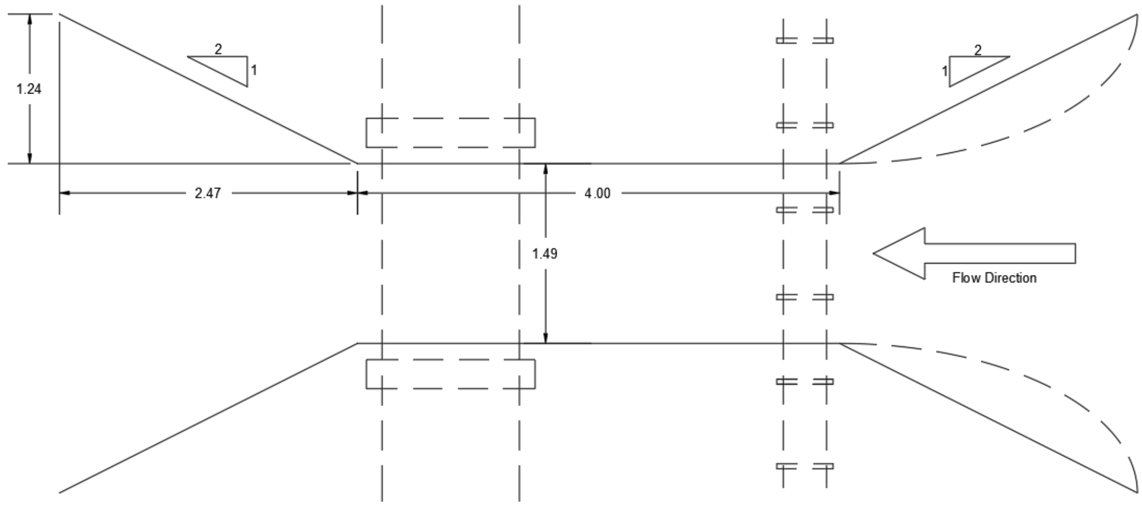


Figure 3.23 Plan view of flume at model scale, dimensions in feet.

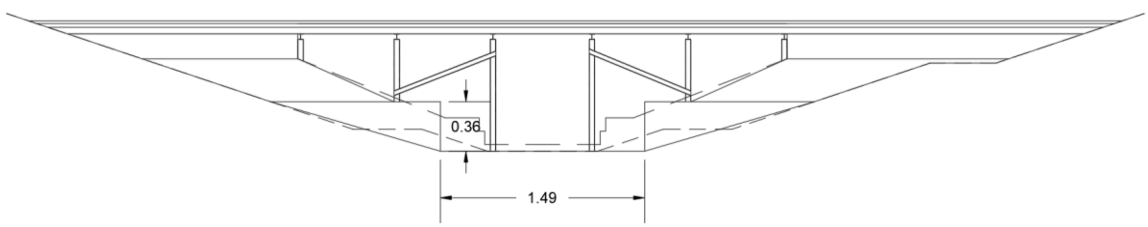


Figure 3.24 Section view of flume at model scale, dimensions in feet.

Unnecessary concrete and aluminum template was then removed using a circular saw, a reciprocating saw, and a planer. Flume walls and other forms were made from acrylic and secured to the model. A set of boxes was made to allow the spur line bridge to be removed. This was not done for the main line bridge, which was embedded into the new flume walls. Vermiculite concrete was again used, screeded to form the inlet, outlet, and profile of the flume. After it cured, roughness elements were replaced, and the flume was painted. The finished flume is show in Figure 3.25, with the bridges in place.

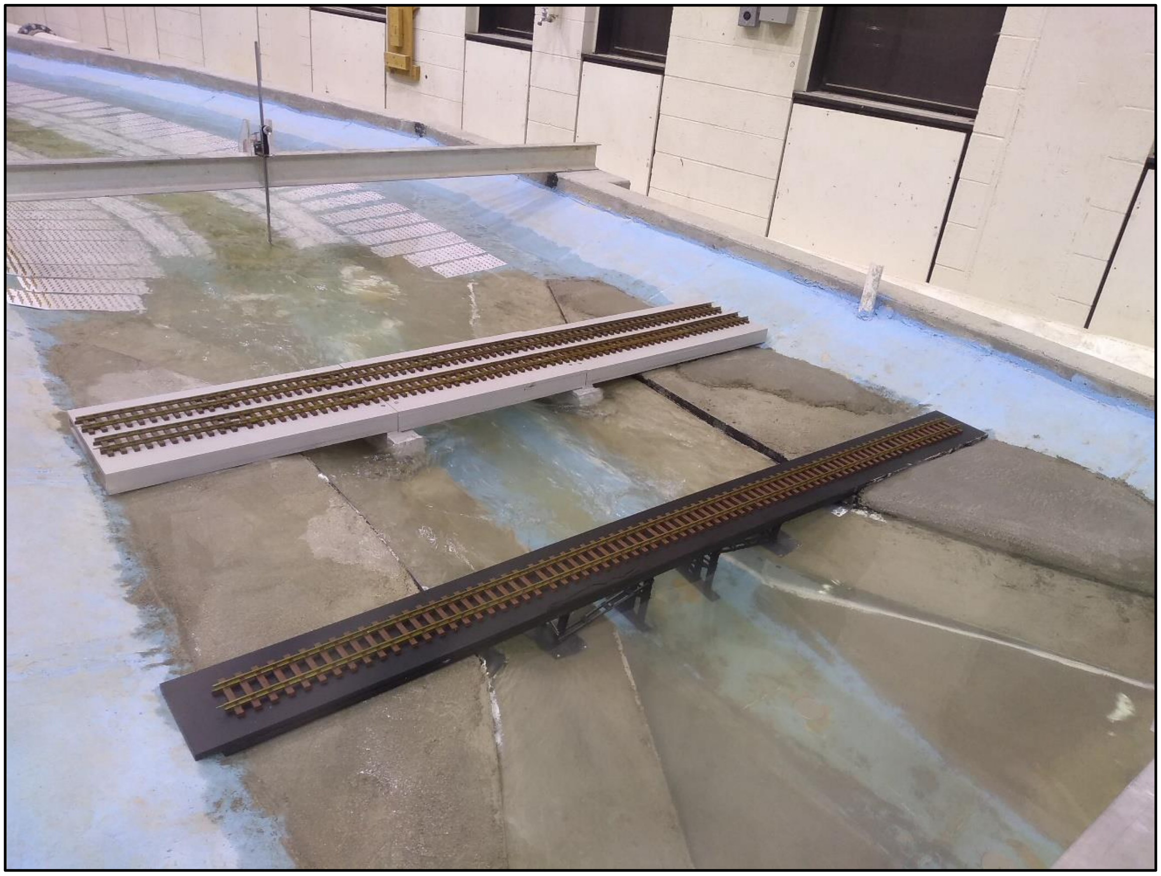


Figure 3.25 Finished flume with bridges.

An alternate, elliptical inlet for the flume was also constructed. As a smooth curve is difficult to create, both at model and prototype scales, the elliptical was approximated with 8-foot line segments, or 3.84 inches at model scale. Acrylic templates were created, and plates added to create the vertical walls of the inlet. They were cut to match the slope of the inlet. After tests with the initial flume were complete, the inlets were installed, pictured in Figure 4.11. Though both are pictured, the pier extensions and elliptical inlets were not tested together. The ellipticals were used for tests described in Section 4.10.

Chapter 4. Test Results

4.1. Methods

Before running any tests, it was necessary to remove air from the piezometer tubes. This was most simply accomplished by disconnecting the tubes from the manometers and letting them drain by running the model for approximately 45 minutes.

Each test begins with setting the pump frequency and tailwater gate height. The pump frequency controls the flow rate. The gate controls the water surface elevation at the downstream end, or the tailwater. Flow rate was calculated from a point gauge reading on the weir box and the weir equation; target point gauge readings were back calculated from target flow rates. In early tests, gate heights were arbitrarily chosen to span the range of possible model conditions. For later tests, gate heights replicated previous tailwater elevations for direct comparison between runs with differing geometries. Both pump frequency and gate height were adjusted as needed to match flow rate and tailwater elevation targets, respectively.

After waiting several minutes for steady state conditions, readings could be taken. These included temperatures, piezometer heights, water surface elevations using point gauges and the head in the weir box using a point gauge, as well as descriptive and organizational information.

4.2. Summary of Test Conditions

After preliminary model construction but before calibration with roughness elements, initial tests were run to assess problems with the model and make improvements.

Pre-calibration tests were run without and then with the bridges. While the model roughness was not properly represented and there were standing waves present for these tests, useful data were collected. The data collected were used to develop tools for data correction and analysis and to provide preliminary measurements of bridge loss coefficients. Bridge loss coefficients are mostly independent of channel roughness if modeled correctly.

Test data were collected throughout the calibration procedure, as it was an incremental process, detailed later in Section 4.5. The calibration was done without the bridges in place.

After calibration was complete, bridge energy loss tests were repeated to obtain better loss estimates. Additional tests with only the main line bridge and with only the spur line bridge were also performed to better understand the contribution of each bridge to the overall energy loss.

Constructing the flume involved significant modification to the model, as detailed previously. Once again, tests were replicated with the flume in place. Though the main line bridge is integral to the model flume as constructed and is not easily removable, the spur bridge was easily removed to allow the impact its removal on flume energy losses to

be studied. A set of pier extensions for the spur line bridge and a set of elliptical flume inlet structures were also tested to see if streamlining could help reduce energy losses.

For many of the tests, flow rates that were the equivalent of 12,000 cfs; 10,000 cfs; and 8,000 cfs at prototype scale were simulated. The highest flow rate (12,000 cfs) was used to calibrate the model, as it represents the initially estimated 100-year event. The other flow rates were selected to examine the performance of various model geometries for less demanding flow conditions.

4.3. Initial Tests

Tests with and without data collection were largely used to identify problems with model operation, develop data collection methods, and intuit model characteristics. The raw data, and the conversion to prototype water surface elevations, using the survey described below, are provided in Appendix C for the purpose of record only.

Some small leaks were found and sealed. Standing waves were present throughout the model. This was reduced by adding the diffuser and grate with rubberized hair in the model inlet. The water level in the piezometers also tended to oscillate by up to 4 mm. This was reduced to almost nothing by sanding the bed near the tubes and covering the exposed .17-inch inner diameter tubes with thin aluminum plates with 0.1-inch dimeter holes.

After the aluminum plates were installed, a survey was done at the locations of the piezometers, as they are approximately 3.25 inches upstream of their corresponding templates, or 6.77 feet at prototype scale. These were converted to prototype Northing

and Easting coordinates and elevations, as provided in Appendix B, so that water surface elevation measurements could be easily translated to prototype locations.

A correction for the piezometers was also created for converting piezometer readings to prototype water surface elevations. Four discharges (ranging from 0.10 to 1.38 cfs, equivalent to 337 to 4,321 cfs prototype) were tested, resulting in low velocities and low energy losses in the model. The tailwater gate was sealed as much as possible, creating nearly horizontal water surface profiles in the model for the four depths. For these flows, the piezometers were expected to all have the same (or similar) readings. Piezometer 36 was used as the datum piezometer, and other piezometer readings were compared to it. The corrections over all four flow depths were averaged for each piezometer. Differences between the piezometers did not exceed 2 mm for any of the tests, and the corrections for all but three of the piezometers are 1 mm or less, which is the estimated uncertainty of the piezometers. Nevertheless, the established corrections were applied to the piezometers for all later tests in the model.

The point gauge above piezometer 36 provided direct measurement of flow depths. These could be subtracted from the readings of piezometer 36 to establish a bed level depth, allowing flow depths to be determined for all piezometer readings.

Using this information, a set of piezometer readings can be converted to prototype water surface profiles. All piezometer readings are first corrected to account for measurement bias. Then all piezometer readings are corrected to give water surface elevations relative to the datum established by piezometer 36. The water surface elevations are then scaled to prototype values, using the equivalent prototype bed

elevation of piezometer 36 to aid in the conversion to NAVD 88 water surface elevations. For all tests, corrected and converted water surface elevations are presented in the appendices, alongside the raw data used to create them.

4.4. Pre-calibration – Bridge Drag Tests

After improvements to the model were made, tests were run with and without both bridges. While the model was not calibrated, these tests enabled the development of methodology to analyze the losses due to drag from the bridges. Appendices D and E contain the data collected for these tests. These data were used to estimate bridge loss coefficients by applying the momentum equation (Finnemore and Franzini 2001):

$$P_1 - P_2 - F = \rho Q(V_2 - V_1) \tag{4.1}$$

Where P is the force from hydrostatic pressure, F is the drag force on the bridges, V is the bulk average velocity, ρ is the density of water, and Q is the discharge. Point 1 is upstream and Point 2 is downstream. This assumes that wall shear stress is negligible in comparison to form drag. Pressure force and bulk average velocity can be expressed in terms of the channel cross sectional area, A_c:

$$P = \gamma \bar{h} A_c \tag{4.2}$$

$$V = Q/A_c \tag{4.3}$$

Where γ is the specific weight of water and $\bar{h}$ is depth of the centroid, a function of depth. Substituting 4.2 and 4.3 into 4.1 and solving for F yields:

$$F = \gamma \overline{h_1} A_{c1} - \gamma \overline{h_2} A_{c2} - \rho Q \left(\frac{1}{A_{c2}} - \frac{1}{A_{c1}} \right) \tag{4.4}$$

From depth measurements, $\bar{h}$ and A_c can be calculated. Discharge is measured. Fluid properties γ and ρ are known for water. This means that from experimental data, the force exerted on the flow by the model bridges can be determined, which can be related to a drag coefficient, C_D:

$$F = C_D A_f \frac{\rho V^2}{2} \tag{4.5}$$

Where A_f is the effective frontal area. Drag coefficients and frontal area are well-established for common geometries. However, the current bridge geometry is not simple. Additional drag from multiple sequential columns and beams augment the effective frontal area. The following form accommodates the added frontal area with a multiplier coefficient, C_M:

$$F = C_D C_M A_f{}' \frac{\rho V^2}{2} \tag{4.6}$$

Where $A_f{}'$ is the frontal area of the bridge based on its cross section and is a function of the flow depth and bridge geometry. For bridge elements with multiple sequential members, $A_f{}'$ is based on the upstream-most member. C_M increases the frontal area but is not a simple integer multiplier since downstream members are in the wake of the first member. In parts of this thesis, C_D is assumed to be the same as that of the upstream-most member (for sequential members having the same shape) and all changes in drag are associated with the area multiplier. Nevertheless, the combined coefficients ($C_D C_M$) are difficult to separate using experimental data.

Combining equations (4.4) and (4.6) yields equation (4.7), which can be rearranged to equation (4.8):

$$C_D C_M A_f{}' \frac{\rho V^2}{2} = \gamma \overline{h_1} A_{c1} - \gamma \overline{h_2} A_{c2} - \rho Q \left(\frac{1}{A_{c2}} - \frac{1}{A_{c1}} \right) \quad (4.7)$$

$$\overline{h_2} A_{c2} + \frac{Q^2}{g A_{c2}} = \overline{h_1} A_{c1} + \frac{Q^2}{g A_{c1}} + C_D C_M A_f' \frac{1}{2g} \left(\frac{Q}{A_{c1}} \right)^2 \quad (4.8)$$

For the pre-calibration tests, the only configurations tested were both bridges and no bridges. The spur bridge is above piezometer 16, and the main line bridge spans approximately from piezometers 18 to 19. Piezometers 1 through 15 are upstream, and 20 through 39 are downstream.

For pairs of model tests with the same discharges and tailwater gate height, piezometer readings for the tests with bridges were subtracted from corresponding readings for the tests without bridges. The resulting head differences are caused by the bridges (and measurement uncertainties). The average head differences for upstream (1-15) and downstream (20-36) piezometers were determined. The difference between the two averages was the observed head drop due to the bridges. These head drops are plotted in Figure 4.1, along with head drops predicted using equation (4.6) with $C_D C_M = 7$. For this initial analysis, it was assumed that head losses caused by the spur bridge would be much greater than those caused by the main line, so only the submerged frontal area of the spur bridge was used in Equation 4.6. $C_D C_M$ was estimated without regression for this preliminary example, but clearly, the momentum equation will do a reasonable job of estimating head losses for the bridges if $C_D C_M$ is properly determined.

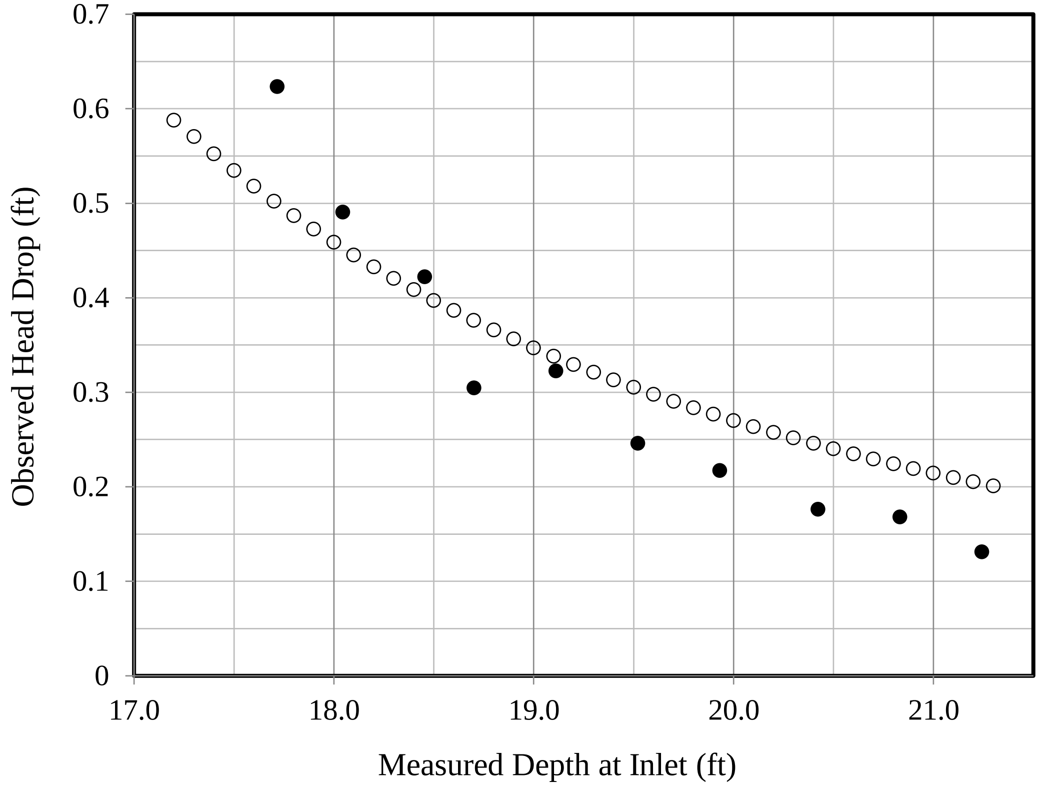


Figure 4.1 Measured (filled) and predicted (hollow) head losses at prototype scale due to bridges in uncalibrated model.

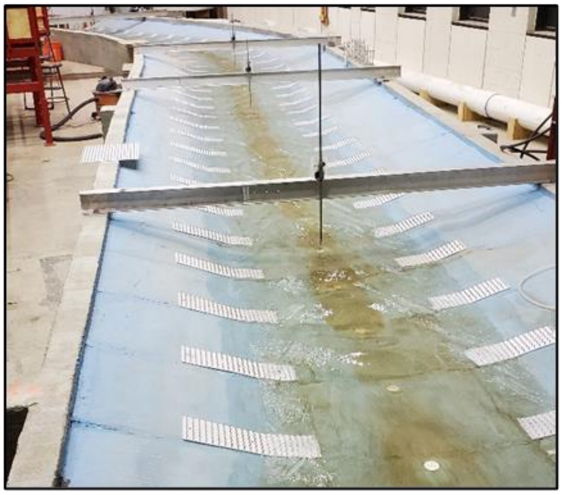
This methodology with the momentum equation has a very useful characteristic. The drag and frontal area multiplier coefficients found in the model are potentially applicable for the existing bridges for computer modeling purposes. The model is based on proposed cross sections, not existing cross sections, meaning that the model bridges have different submerged frontal areas than the existing prototype bridges. Nevertheless, this difference is accounted for by the drag equation, such that measured drag and area multiplier coefficients can be applied to different geometries with some confidence.

Section 4.6 provides more extensive bridge drag results and includes results with the two bridges tested independently.

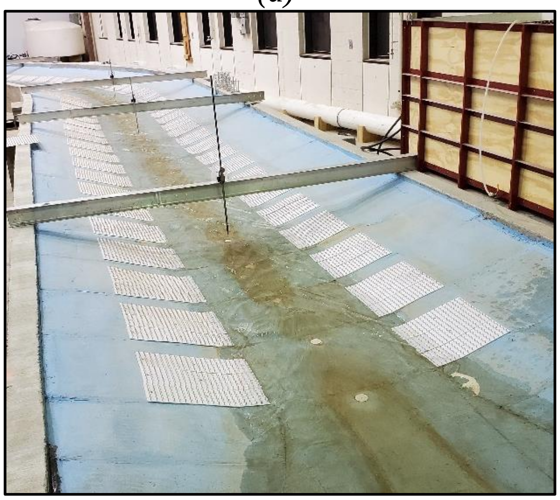
4.5. Calibration

Calibrating the model involved adding roughness panels until model results reasonably matched a set of target results. The target results were created using a HEC-RAS (Hydraulic Engineering Center – River Analysis System) computer model. Two models were created, one at prototype scale and one at model scale, which gave near identical results. Each model used the geometry discussed in Section 3.3.2, with the flow depth at the section of piezometer 36 set to a fixed depth outlet boundary condition. To simplify the HEC-RAS model used to calibrate the physical model, the bridges were not installed for any calibration tests.

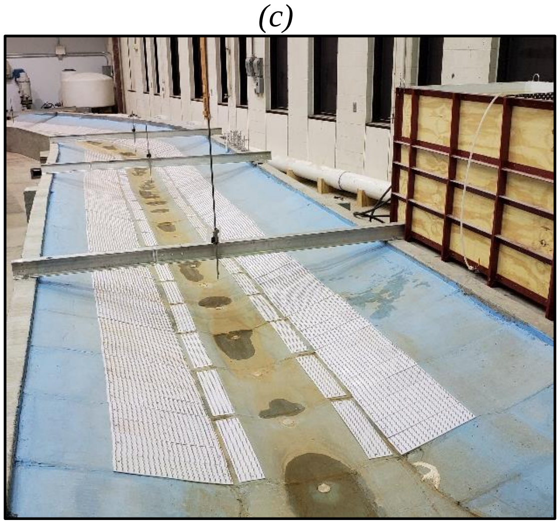
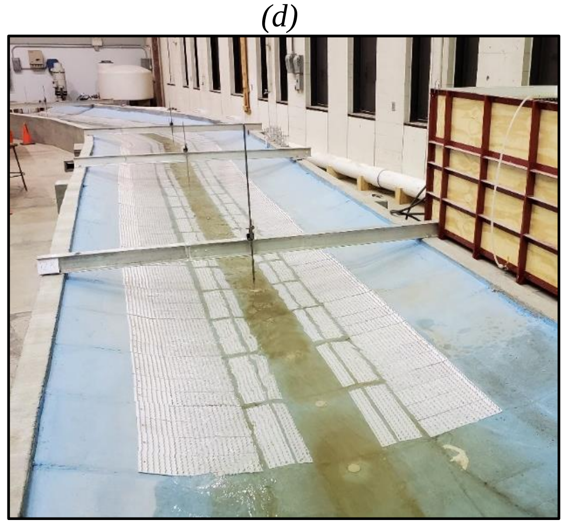
Six-inch wide panels of roughness elements were cut from the assembled boards and fastened to the banks of the model in intervals. A set of tests, one each at 8,000, 10,000, and 12,000 cfs prototype equivalent discharges, was run. The process was repeated for incremental installations of the panels as shown in Figure 4.2(a) through (f). These figures also show a reduction in the standing waves present in the model as more roughness panels are added.




(a) *(b)*




(c) *(d)*

(e) *(f)*

Figure 4.2(a)-(f) Incremental installation of roughness panels.

The calibration process was primarily focused on the 12,000 cfs equivalent; but the other discharges were run to check the capability of the model to produce reliable results at lower flows.

Figure 4.3, below, shows the corrected water surface elevations (relative to the bed datum at Piezometer 36) collected for the three calibration tests in comparison to the target water surface elevations determined using a non-uniform model of HEC-RAS. Data from all tests are provided in Appendix F. Note that the water surface profile changes very little between 2/6 and 4/6 roughness panel installations, despite doubling the roughness elements in the model. Adding additional roughness panels on the sides of the channel was less effective for increasing flow resistance after preliminary roughness panels were installed. Installing additional roughness panels near the center of the channel, however, had a significant effect on increasing the flow resistance, as shown by the fully paneled water surface elevation profiles. The fully paneled model does a reasonably good job of reproducing the results observed in the non-uniform HEC-RAS model used for the calibration. Note that Piezometer 27 appears to have functioned poorly for these tests (this could be due to an obstruction in the piezometer, for example).

Figure 4.3 is plotted at model scale rather than prototype scale because the HEC-RAS model used to calibrate the physical model was also done at model scale. All other figures are plotted at prototype scale.

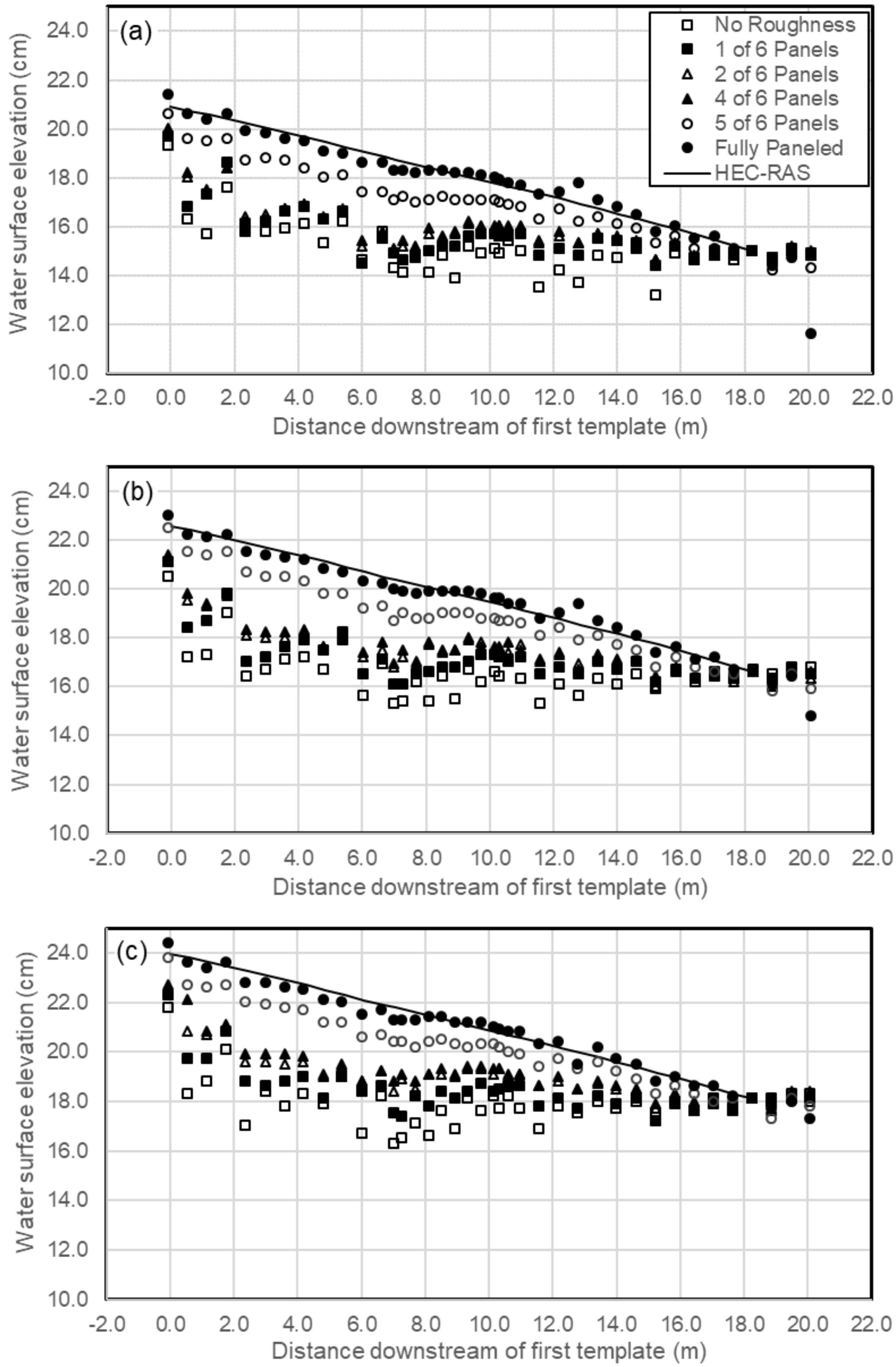


Figure 4.3 Calibration water surface elevations relative to Piezometer 36 datum for prototype discharges of (a) 8000 cfs, (b) 10000 cfs, and (c) 12000 cfs.

4.6. Post-calibration – Bridge Drag Tests

With the model calibration complete, the initial tests with and without bridges were rerun. Tests were also run with each bridge independently, but only at the highest flow. These results are in Appendices G through I. The results from independent bridge tests were used to estimate loss coefficients and used to predict experimental results, as described below.

4.6.1. Main Line Bridge Only – No Spur Bridge

To separate the head drop caused by roughness elements from the head drop associated with the bridge, multiple test pairs were run with and without the bridge in place; each test pair had the same discharge and the same water surface elevation at Piezometer 36. As previously mentioned, the main line bridge approximately spans from piezometer 18 to 19. The head drop from piezometer 17 to 20 is thus the best measurement of head loss due to the bridge. For each test pair, linear regressions were run for the head differentials of the upstream piezometers (1 through 17) and downstream piezometers (20 through 36). From the regressions, the inlet head difference at piezometer 17 and outlet head difference at piezometer 20 were estimated, and the head drop between them was calculated. The linear regression method was used to improve the estimation of the upstream and downstream head differentials over what can be obtained by relying on just two piezometers (i.e., piezometers 17 and 20)

Using the inlet depth and the geometry of the bridge, the inlet area, centroid, and effective frontal area were calculated. The submerged pier and column pile frontal areas

are calculated separately then added to become the effective frontal area, as the coefficient for multiple members (C_M) is only applied to the column piles. The pier is monolithic, meaning the value of C_M can be presumed to be 1. The drag coefficient (C_D) was assumed to be 2 for both the pier and column piles, as provided by Finnemore and Franzini (2001) for a blunt rectangular object.

Using equation 4.8, the assumptions above, and the measured discharge, the outlet depth and head drop were predicted. The value of C_M for the piles was optimized to minimize the root-mean-square error between the measured head drops and the predicted head drops for all test pairs. The resulting C_M value from this was 2.315. As they are technically inseparable, the product $C_M C_D$ for the column piles is 4.63. The results from this, at prototype scale, are shown in Figure 4.4.

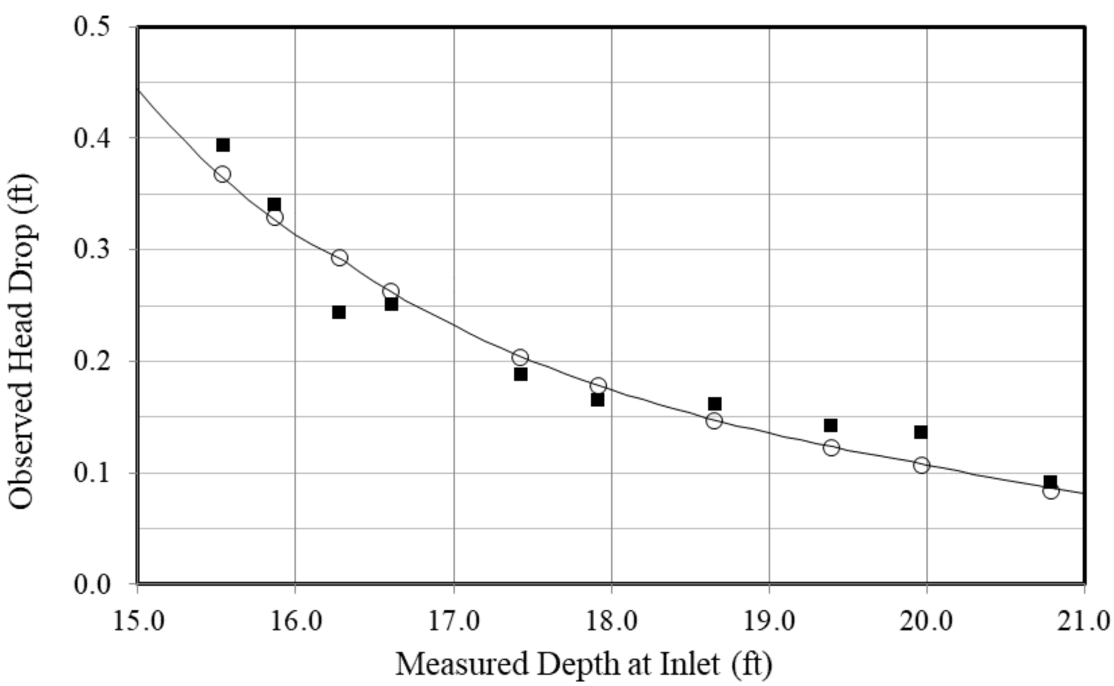


Figure 4.4 Main line bridge head loss as a function of depth upstream. Filled squares show measured head drops, open circles show predicted head drops.

4.6.2. Spur Bridge Only – No Main Line Bridge

The process described above was repeated for tests with only the spur bridge. For these tests, piezometers 1 through 15 are considered upstream and 17 through 36 are downstream. The drag coefficient (C_D) for the I-beams was still assumed to be 2, as estimated in Consolazio et al. (2013), but C_M applies to all members. Using the same root-mean-square error optimization, C_M was calculated to be 1.835, meaning $C_M C_D$ is 3.67. The optimization results are shown, at prototype scale, in Figure 4.5.

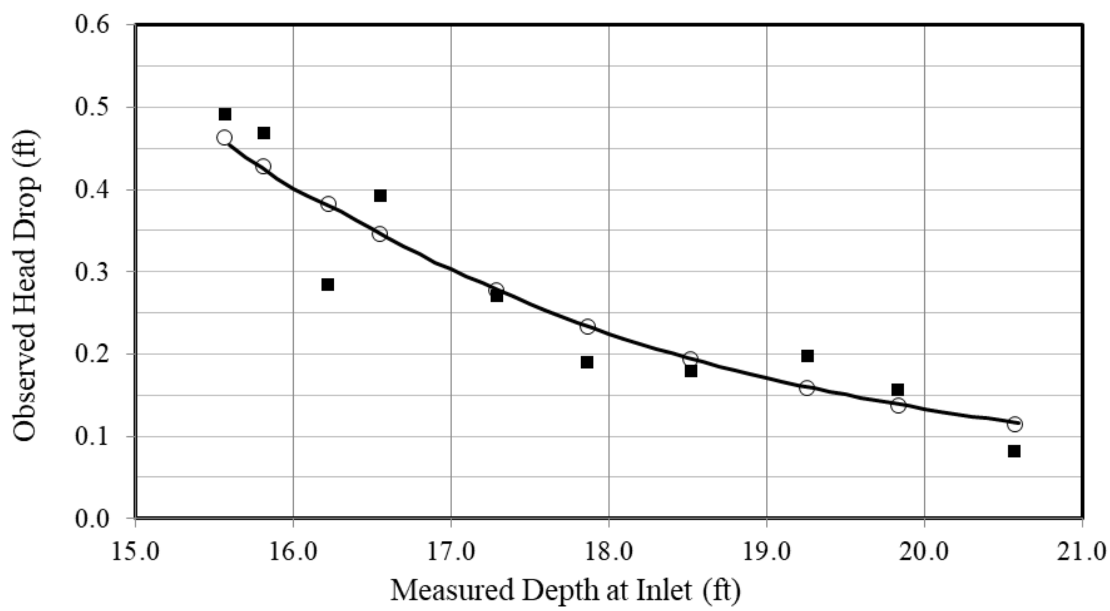


Figure 4.5 Spur bridge head loss as a function of depth upstream. Filled squares show measured head drops, open circles show predicted head drops.

4.6.3. Both Bridges

Similar calculations were done for data collected with both bridges, using values determined from the individual bridges. The combined bridge tests were run at three different target discharges (8000, 10000, and 12000 cfs prototype equivalent) to check

the validity of calculations. Upstream piezometers were 1 through 15, downstream were 20 through 36.

Predicted head drops were calculated sequentially. That is, for an inlet head at piezometer 15, the head drop over the spur bridge was calculated, also yielding the head at piezometer 17. This head was used as the inlet for the main line bridge, with the head drop and head at piezometer 20 calculated from it. Both predicted and measured head drops from piezometer 15 to piezometer 20 are shown in Figure 4.6, at prototype scale. The coefficients determined from the independent bridge tests appear to predict head losses well, though they slightly underestimate the observed head drops at the highest discharge.

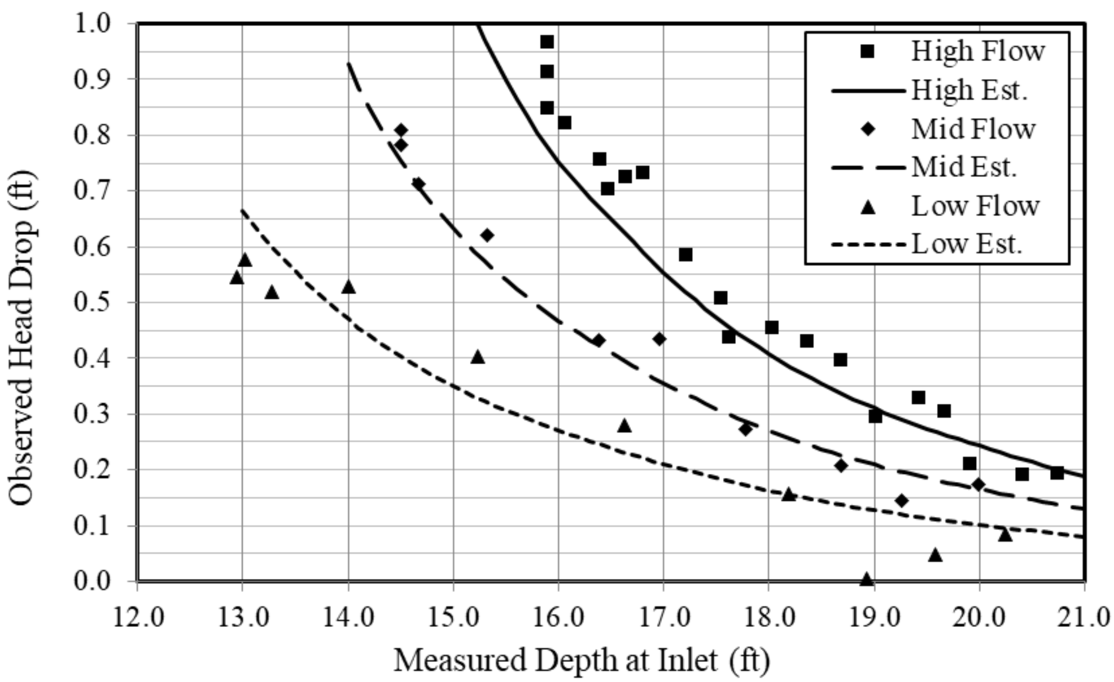


Figure 4.6 Head losses across both bridges as a function of depth upstream. Symbols show measured head drops, and lines show head drops predicted using Equation 4.8 and coefficients determined from independent bridge tests.

One clear conclusion from the analysis of the individual and combined bridges provided in Section 4.6 is that the head losses associated with the main line bridge are not negligible and are similar in size to the head losses associated with the spur bridge. Note, however, that all the flow tests were deep enough so that both bridges resulted in head loss. For much lower flows, only the spur bridge will come into contact with the flow.

4.7. Flume Results

Tests with the flume in place established a new baseline for comparison and highlighted the combination of the constriction and the bridges as a bottleneck. Most notably, with the tailwater low, a hydraulic jump formed at the flume outlet, as shown in Figure 4.7 and Figure 4.9. If this jump was present, changing the tailwater did not notably affect the upstream water surface profile. The full data for these tests are in Appendix J.

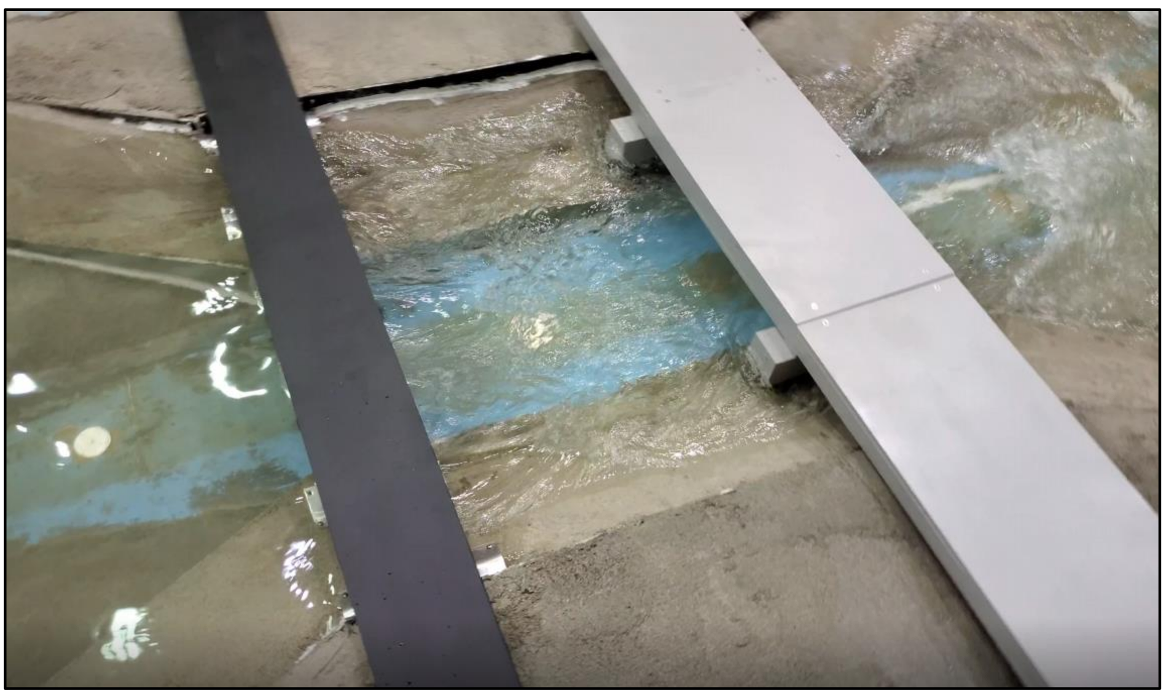
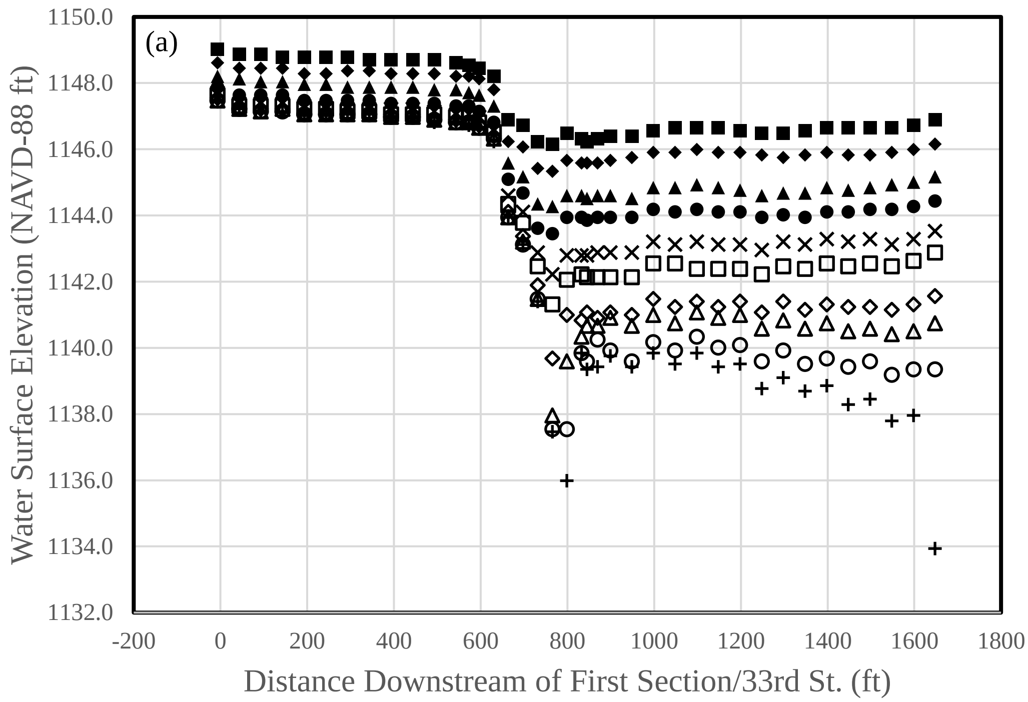


Figure 4.7 Flow overview from flume testing. Hydraulic jump apparent at right.



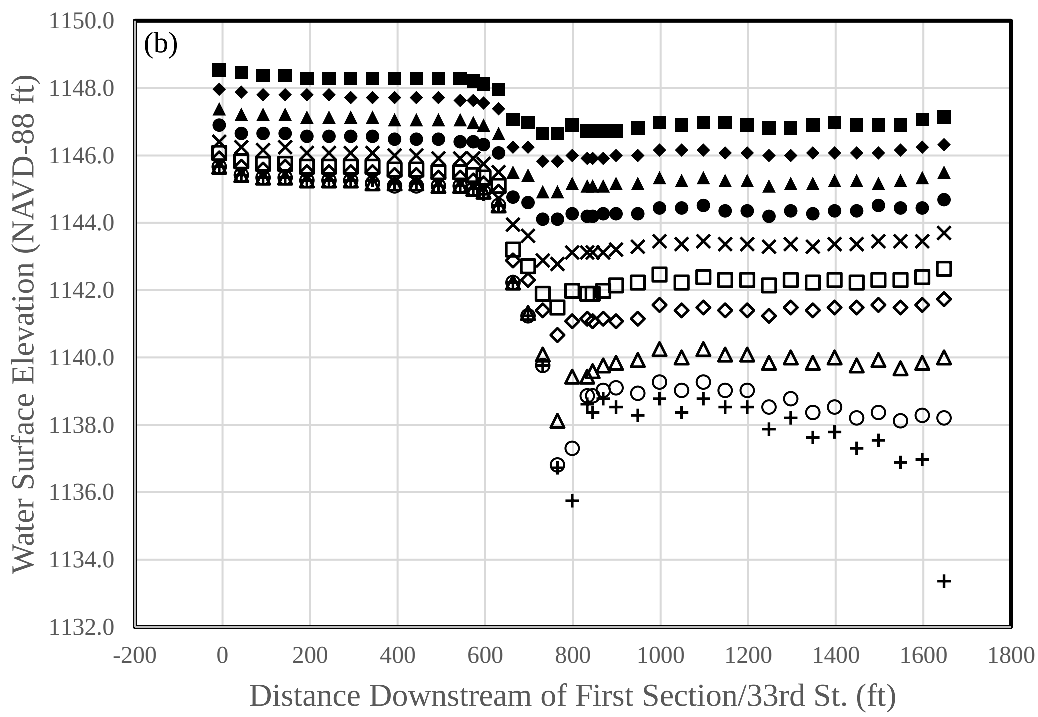


Figure 4.8 Prototype water surface profiles for flume test data at (a) 12,000, (b) 10,000 and (c) 8,000 cfs.

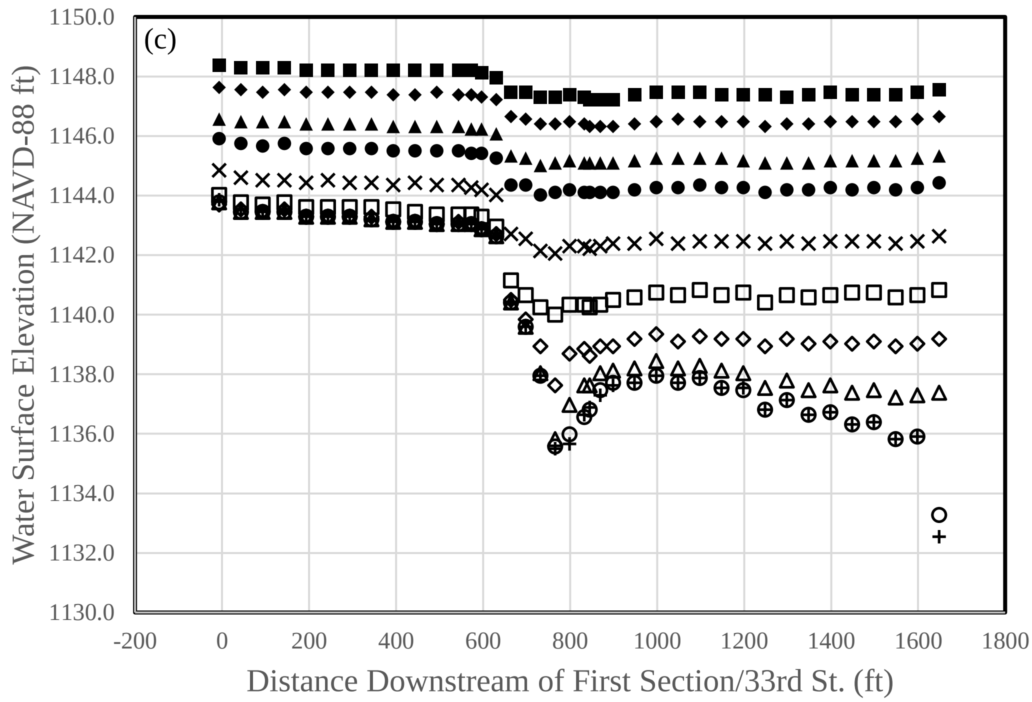


Figure 4.9 (cont.)

Figure 4.10 shows the total head loss over the bridges due to the bridges, flume, and hydraulic jump, if present. At very high downstream depths, the hydraulic jump is not present, meaning that all losses are associated with the bridges and the flume. The hydraulic jump is not present for downstream flow depths (as measured at Piezometer 36) greater than approximately 20.9 ft, 19.5 ft, and 18.6 ft for flows of 12,000 cfs, 10,000 cfs, and 8,000 cfs, respectively.

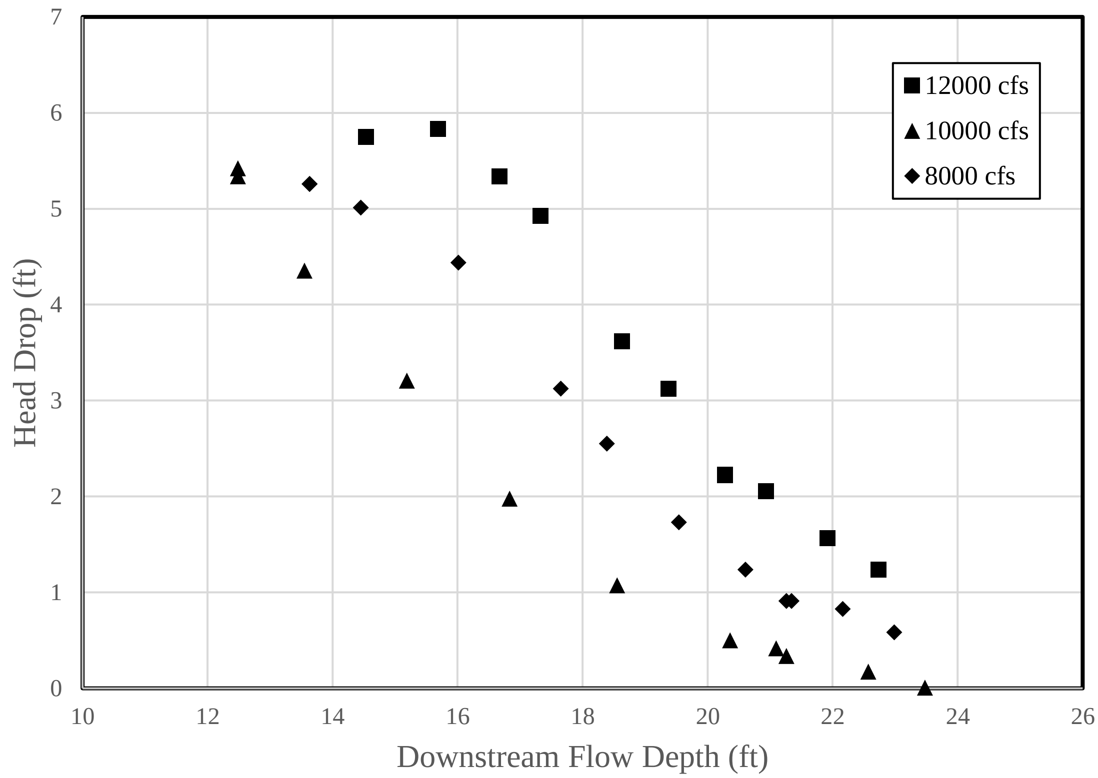


Figure 4.10 Total head losses due to flume and bridges (Piezometer 15 to 21). Downstream flow depth determined from Piezometer 36 reading.

4.8. Flume Results – Pier Extensions

The United States Corps of Engineers (USACE) provided a set of pier extensions for the spur bridge piers that would be in the flume. In theory, this would reduce the loss coefficient for the piers in the highest velocity part of the flow, improving conveyance through the bridges. These are shown in Figure 4.11, along with the elliptical inlets created for the tests described in Section 4.10. Note, however, that the pier extensions and elliptical inlets were tested independently.

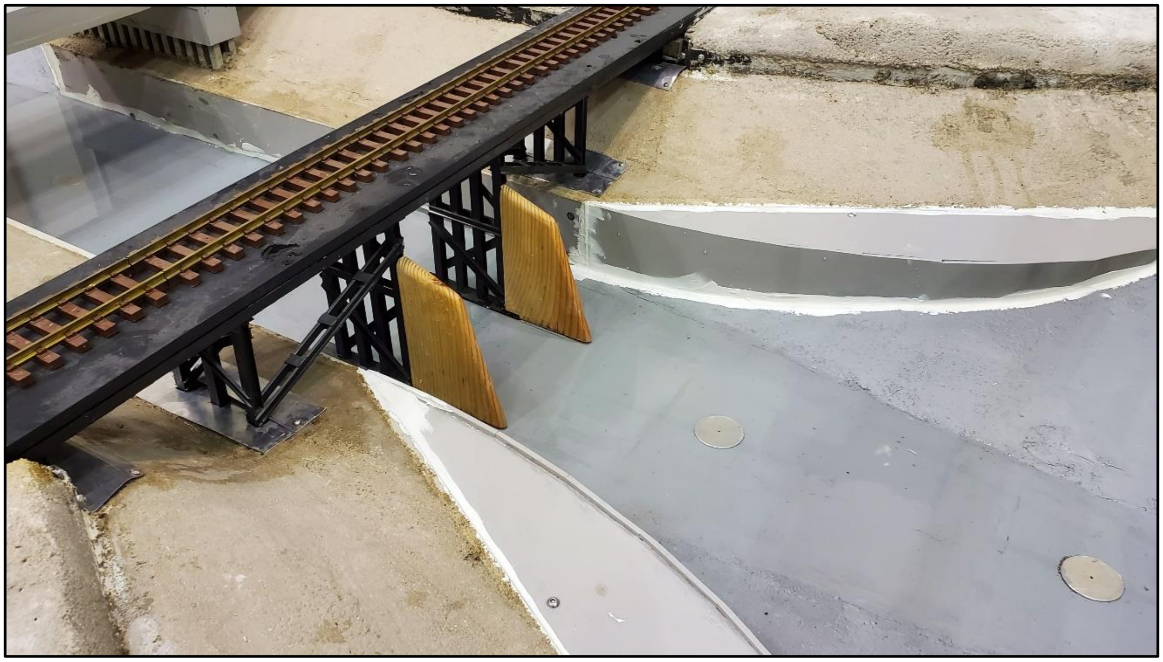


Figure 4.11 Spur bridge pier extensions in place. Elliptical inlet also in place. Not tested together.

Tests using the pier extensions required careful matching of discharges and tailwater depths from previous tests, as measured head differentials were at the limits of model measurement at 1 mm (1 inch in the prototype). All discharges for pairs of tests with and without the pier extension were kept within 1%, and all test pair tailwater depths were replicated within the 1 mm uncertainty of the piezometers. Figure 4.12 shows the changes in the upstream water surface elevation observed when the pier extensions are installed. For tests with low tailwater, the pier extensions were ineffective and even caused the upstream water surface to increase. For higher tailwater, the pier extensions did appear to reduce the water surface elevation. It is possible that for lower inlet depths, the model pier extensions slightly reduce the effective flow area at the flume inlet. All pier extension measurements approached the accuracy limit of the piezometers. The complete set of data is in Appendix K.

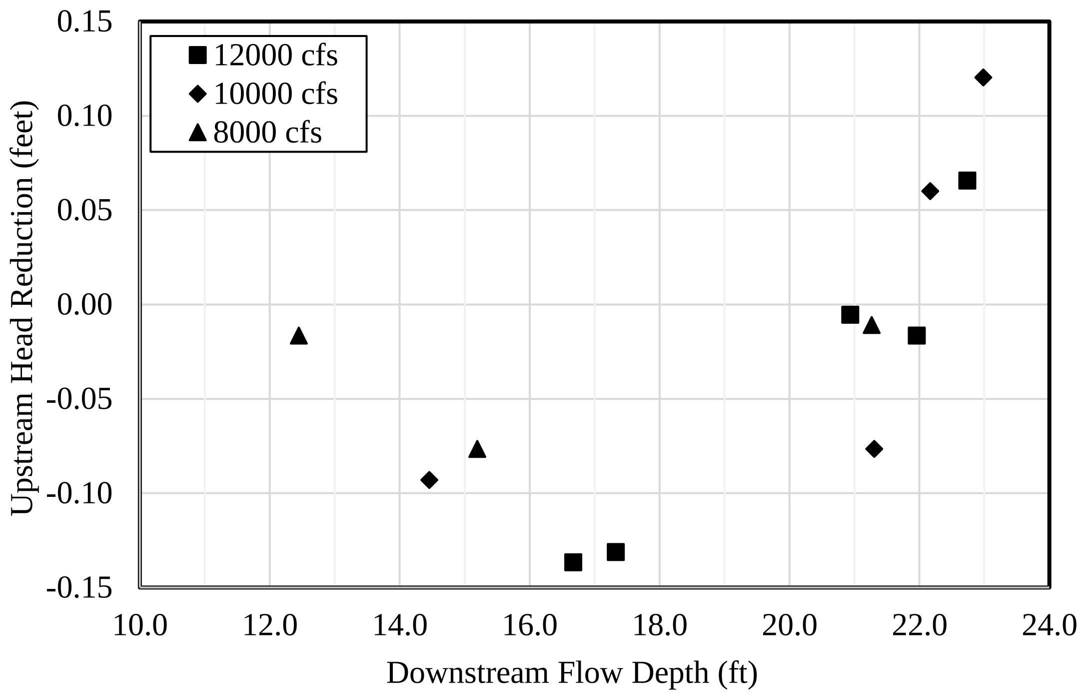


Figure 4.12 Reduction in upstream water surface elevation in the prototype realized for an equivalent prototype discharge of 12000, 10000, and 8000 cfs when pier extensions are added. Downstream flow depth determined from Piezometer 36 reading.

4.9. Flume Results – Removal of Spur Bridge

One alternative the USACE and railroads are considering is adding the spur line onto the main line bridge, or otherwise removing the spur bridge. This test used the flume as constructed for both bridges, but with the spur bridge removed and with metal plates covering the holes where the model spur bridge piers are placed, as shown in Figure 4.13. Test data were again collected as pairs, with discharges and tailwaters matching those of tests for which the spur bridge was in place. The data from the spur bridge removal tests are in Appendix L.

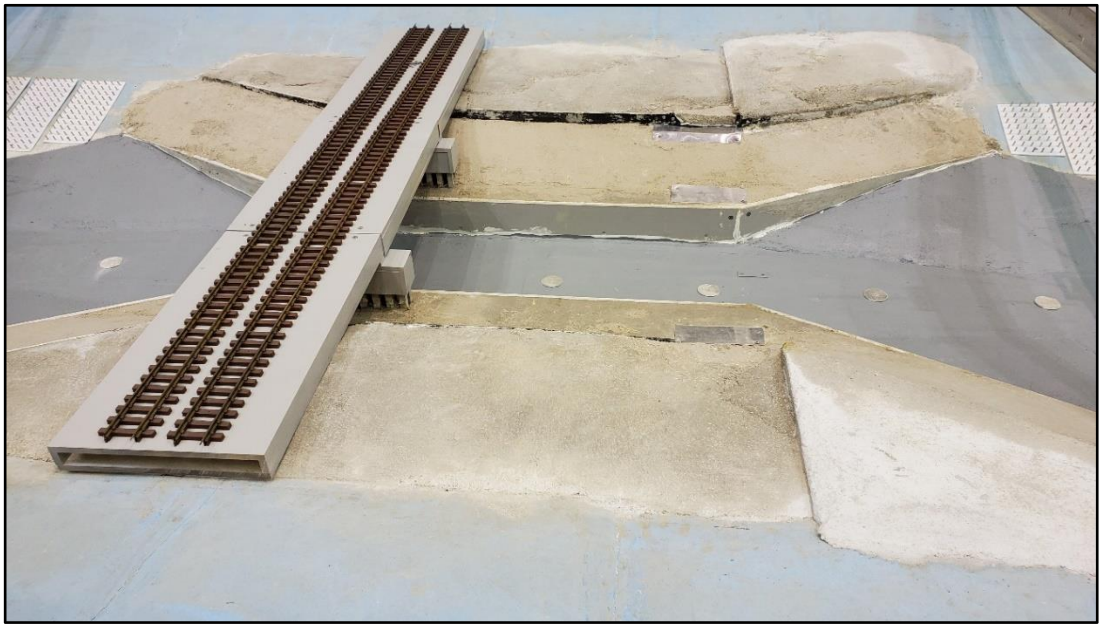


Figure 4.13 Flume test with only main line bridge. Note metal plates covering spur bridge pier boxes.

Water surface elevations collected with the spur bridge removed were subtracted from water surface elevations with the spur bridge in place for each matched pair of data. The resulting reductions in upstream flow depth associated with bridge removal are shown in Figure 4.14. At the lowest tailwater tested, the depth at which the downstream hydraulic jump begins to form, the reduction in upstream flow depth is more than 1 cm, equivalent to approximately 10 inches in the prototype. This is the greatest reduction in upstream depth that can be achieved, as further reductions in tailwater will not impact the upstream flow depth (due to the formation of the hydraulic jump).

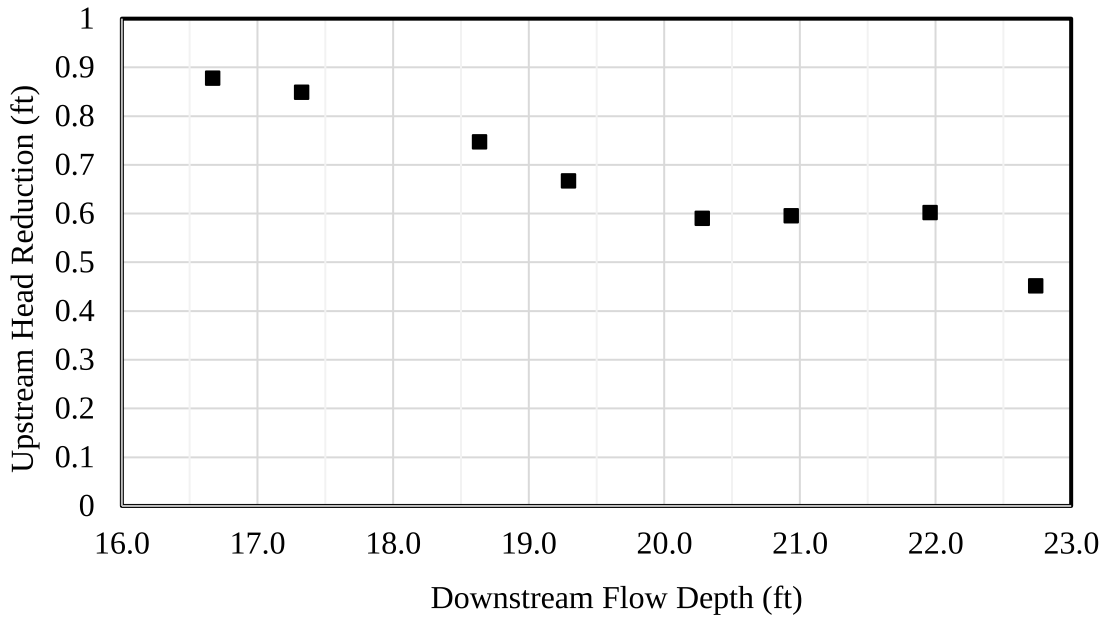


Figure 4.14 Reduction in water surface elevation in the model realized for an equivalent prototype discharge of 12000 cfs when the spur bridge is removed. Downstream flow depth determined from Piezometer 36 reading.

4.10. Flume Results – Elliptical Entrance

Another alternative the USACE wanted to test was an elliptical inlet into the flume, with both bridges, as shown in Figure 4.11. These tests were run at 12000 and 10000 cfs equivalents. Appendix M contains the data from these tests, with results shown in Figure 4.15. For tests with the highest tailwaters, the upstream flow depth was unchanged or slightly reduced. For other tests, the upstream flow depth increased. The exact cause of this increase is undetermined. Possible explanations include: (1) the sharp top edge of the elliptical forms may cause additional losses and a reduction of the upstream cross section flow area, and (2) the ellipticals may direct more flow into the central region of the channel, where the central piers of the spur bridge cause additional head losses. At higher tailwaters, increases in the upstream water depth likely reduce the velocity through

the flume, thereby reducing any head adjustments caused by the elliptical entrance. In any case, the head adjustments observed due to the addition of elliptical entrances are relatively small (~0.1 ft at prototype scales).

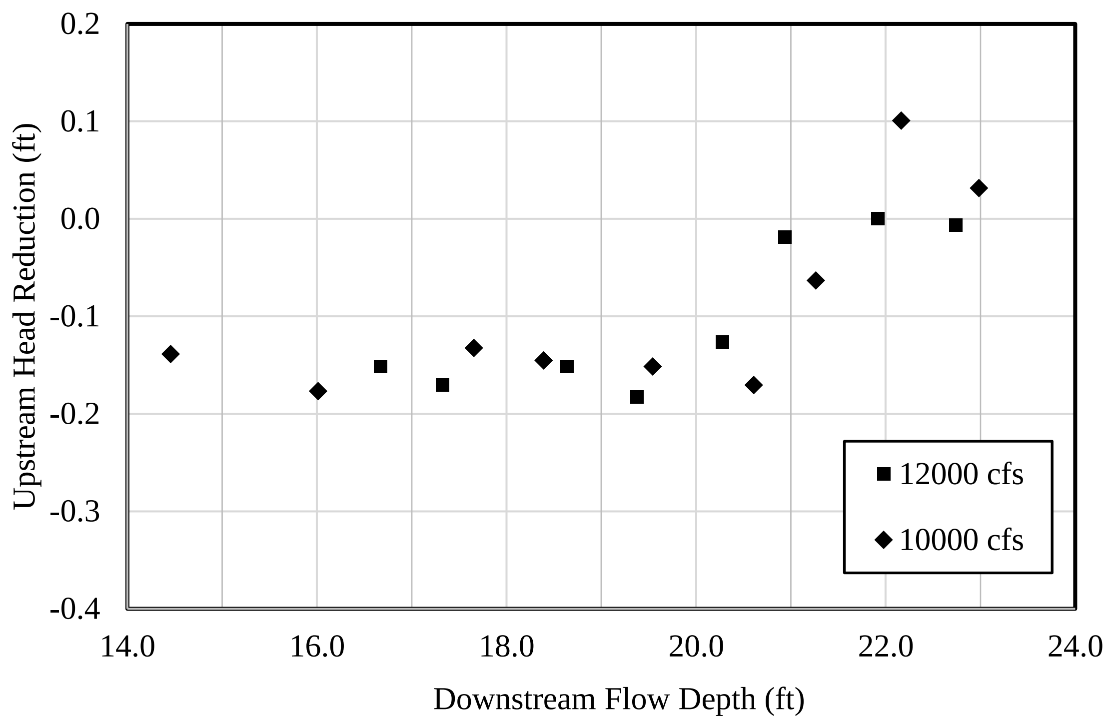


Figure 4.15 Reduction in upstream water surface elevation in the prototype realized for an equivalent prototype discharge of 12000 and 10000 cfs when elliptical entrance is added. Downstream flow depth determined from Piezometer 36 reading. Note that a negative measurement indicates an increase in head loss for the elliptical entrance.

Chapter 5. Conclusions and Future Work

5.1. Summary of Work

A physical model of Deadmans Run was designed and constructed based on principles of Froude number modeling. Several scales were assessed for suitability, with 1:25 being selected due to space and pump flow rate limitations. The selected scale was determined to be independent of Reynolds number effects.

The model was constructed with steel templates used to reproduce cross sections of proposed channel modifications. The templates were surveyed to the correct location and elevation based on the 1:25 model scale. The gaps between sections were filled with lightweight Vermiculite concrete. A piezometer was installed at each cross section to read the water elevation at that section.

The main line and spur line rail bridges were also replicated at scale using aluminum and acrylic. These were also surveyed into location.

To account for roughness at model scale, wood dowels were cut to length and press fit into pegboard sheets to create roughness panels. During calibration, the panels were incrementally added to the physical model so that water depths observed in the model agreed with results observed in a HEC-RAS model of the proposed channel.

To install the proposed flume, portions of the model were marked and cut away. Plastic forms were positioned and filled with Vermiculite concrete to form the flume profile. Tests were performed in the model both before and after installation of the flume.

5.2. Conclusions

Using the momentum equation, a method of estimating the head losses for the bridges was developed. This was compared to results from tests before the model was calibrated and showed reasonable predictive ability. The methodology is also flexible in that it can be applied to different geometries.

After calibrating the model, this methodology was refined to consider the bridges independently, using tests with the individual bridges to determine drag coefficients of each bridge. Using the independent drag coefficients in sequential calculations to predict total head losses yielded results very similar to measured results, improving confidence in the drag calculation method. At the highest flow measured, the method underpredicted head loss by approximately 0.1 feet at prototype scale.

After the flume was constructed, a hydraulic jump was evident in the outlet of the flume at low tailwater depths. Water surface profiles were measured and reported for a range of tailwater conditions at three flow rates (prototype: 8000, 10000, and 12000 cfs) for most structural modifications. Only when the jump was drowned by the tailwater was the upstream water surface profile impacted by the tailwater.

The pier extensions seemed to have little to no impact on the flow. At low tailwater depths, the upstream head slightly increased. At high tailwater depths, the upstream head slightly decreased. Both changes were near the limits of detection, equivalent to approximately one inch at prototype scale.

Removing the spur bridge significantly reduced upstream head. The reduction was up to 10 inches at prototype scale. The flume was not shortened for these tests; redesigning it for only the main line bridge would provide additional head reduction.

The elliptical inlet performed similarly to the pier extensions, causing a slight increase in upstream head at low tailwater depths. Neither the addition of pier extensions nor the addition of elliptical entrances resulted in desired head reductions. The flume and the spur line bridge have complex shapes and complex overflow characteristics, so the observed performance of these two added structural components, while unexpected, is not unreasonable.

5.3. Possible Future Model Measurements

Several additional measurements could be valuable:

1) An alternate flume geometry could be assessed, such as a flume with higher walls.
2) Velocity profiles in the channel and flume could be determined with acoustic doppler velocimetry. This could highlight potential problems with scour or deposition, especially downstream of the flume.
3) There is a culvert located immediately upstream of the bridges. A pipe was installed in the model to allow the effects of the culvert on flume performance to be observed, but the scaled culvert was never utilized in existing model runs. Although the flow in the culvert is small compared to the flow in Deadmans Run, the jet at the culvert outlet may impact the flow in the channel, justifying some additional tests.
4) The spur bridge may be modified to reduce lateral flow between the members of each pier set, potentially reducing the losses caused by sequential pier set members.

5) Simultaneously removing both the main line bridge and the spur bridge will help to determine the performance of the flume, independent of bridge effects.

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Strickler, A. (1923). "Beiträge zur Frage der Geschwindigkeitsformel und der Rauhigkeitszahlen fur Ströme, Kanäle und Geschlossene Leitungen," (Some contributions to the problem of the velocity formula and roughness factors for rivers, canals, and closed conduits), Mitteilungen des eidgenössischen Amtes für Wasserwirtschaft, Bern, Switzerland, no. 16.

Appendices

Appendix A. Prototype Scale Bridge Drawings

All drawings have dimensions of feet unless otherwise stated.

Steel members roughly correspond as follows

8x2.5 Channel – C 8x11.5

10x3 Channel – C 10x30

Any steel members not labeled are I-beams roughly equivalent to W 12x65.

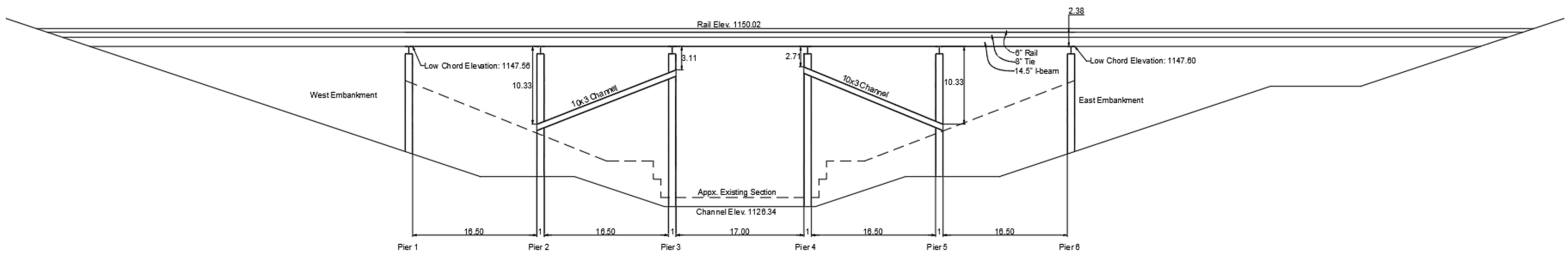


Figure A.1 View from upstream of the Spur Bridge. See Figure A.3 through Figure A.8 for individual pier details.

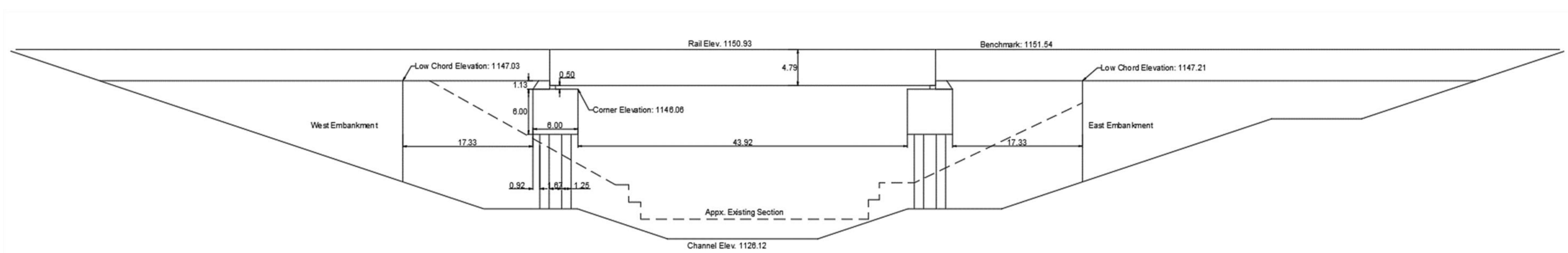
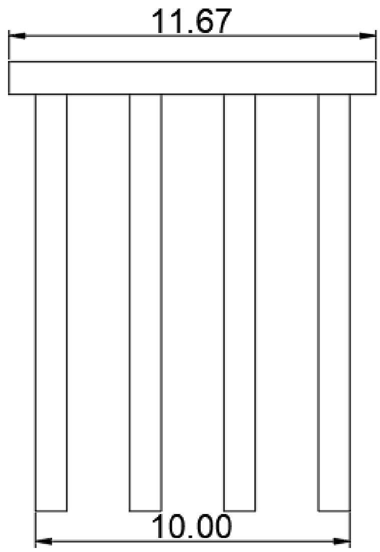


Figure A.2 View from upstream of the Main Line Bridge. See Figure A.9 for pier detail.



1

Figure A.3 Detail of the spur bridge Pier 1 (embankment pier) on the left bank.

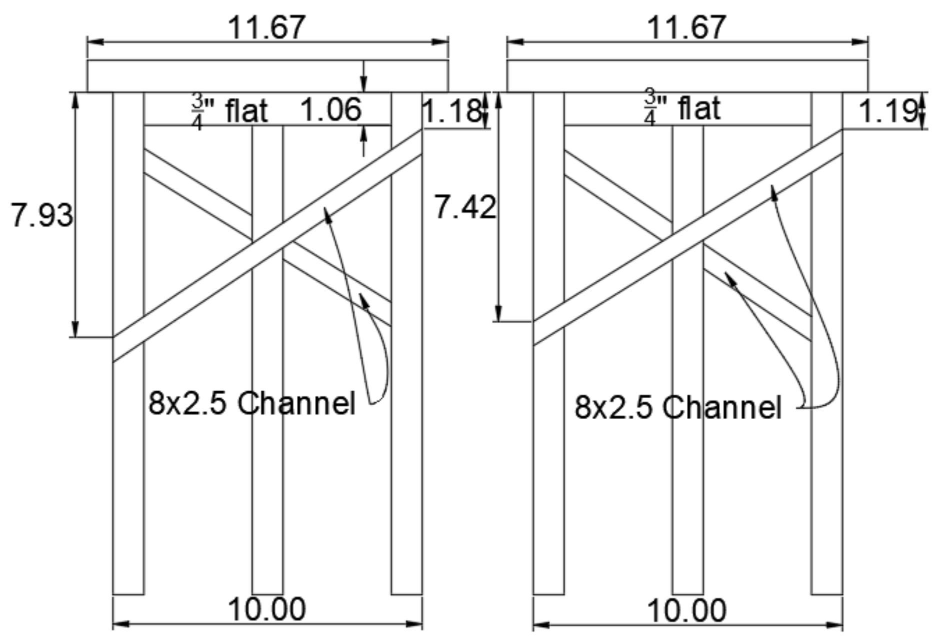


Figure A.4 Details of the spur bridge Pier 2 (central pier) on the left bank. The left detail is the side closer to the embankment, the right closer to the channel. Note that this is the only pier with three vertical I-beams instead of four.

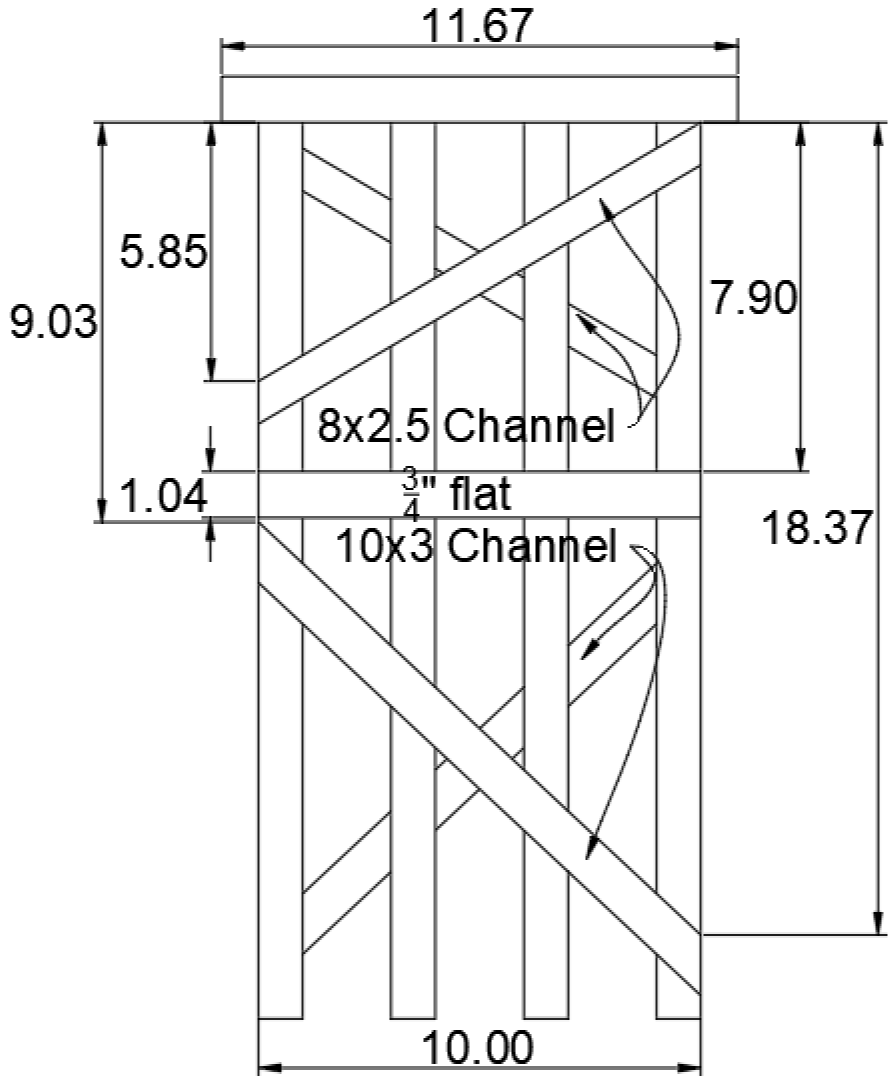


Figure A.5 Detail of the spur bridge Pier 3 (pier closest to the centerline of the channel) on the left bank.

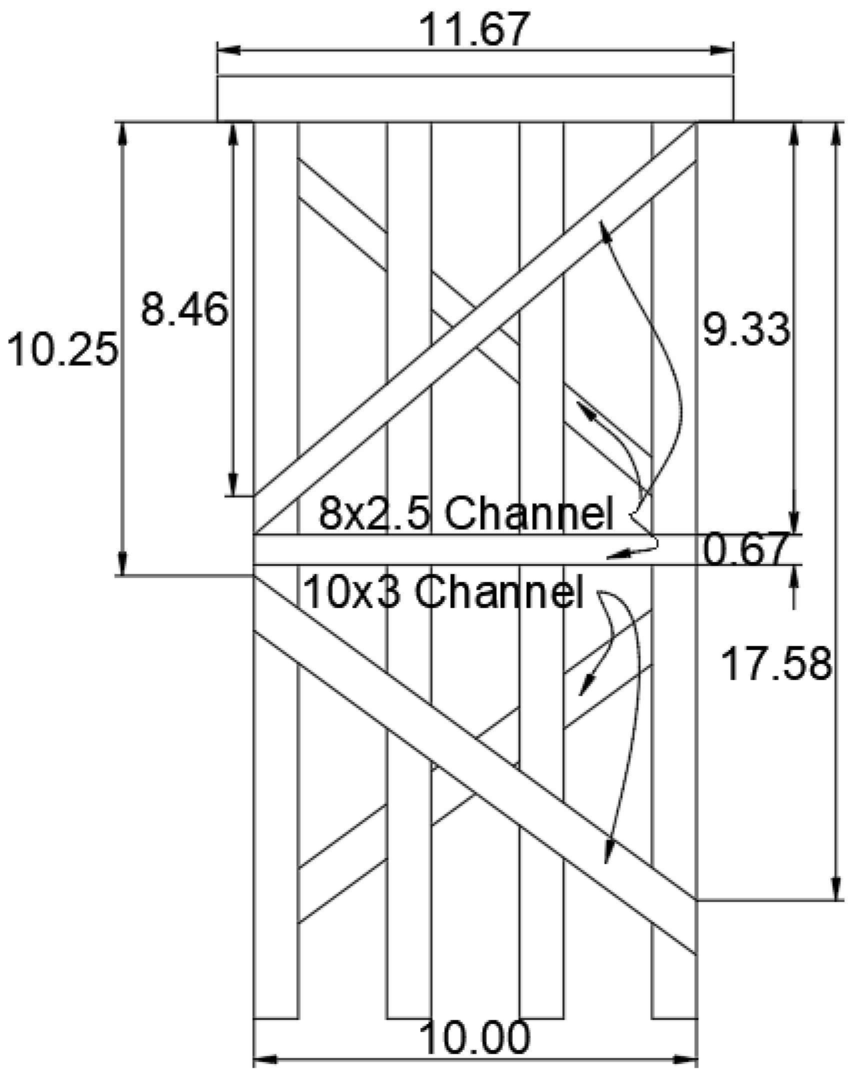


Figure A.6 Detail of the spur bridge Pier 4 (pier closest to the centerline of the channel) on the right bank.

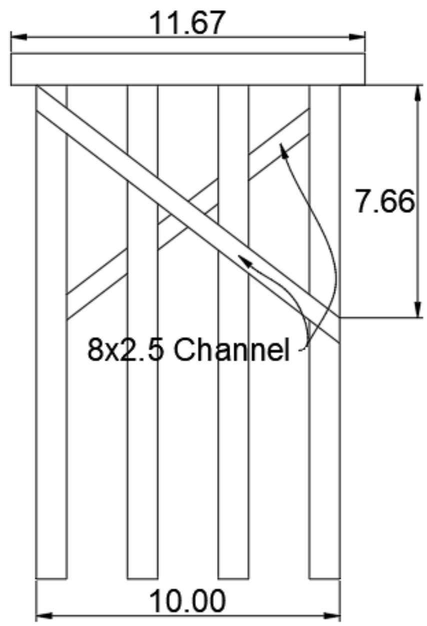


Figure A.7 Detail of the spur bridge Pier 5 (central pier) on the right bank.

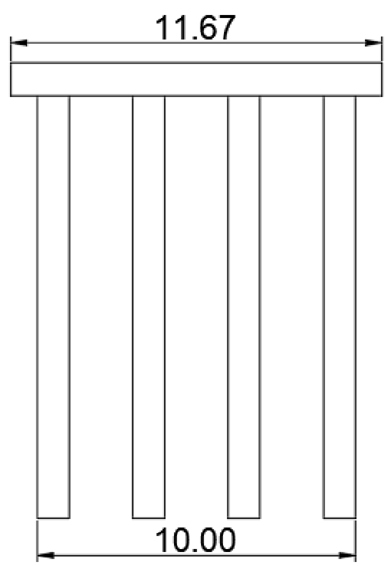


Figure A.8 Detail of the spur bridge Pier 6 (embankment pier) on the left bank.

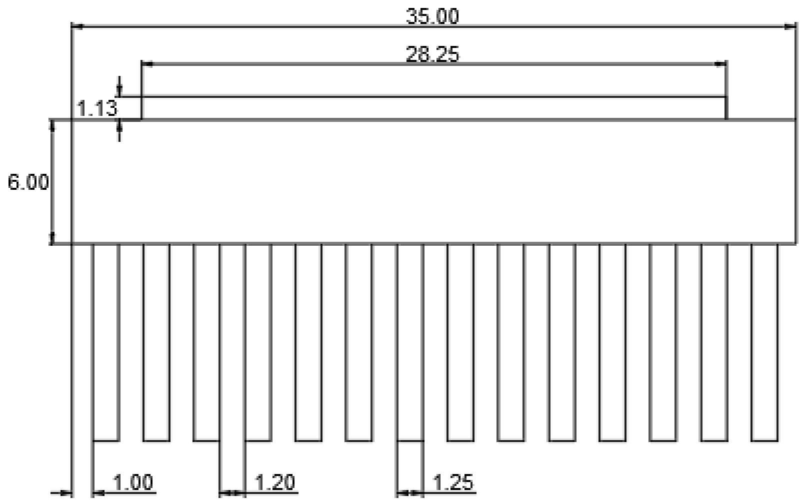


Figure A.9 Detail of concrete bridge pier pile spacing.

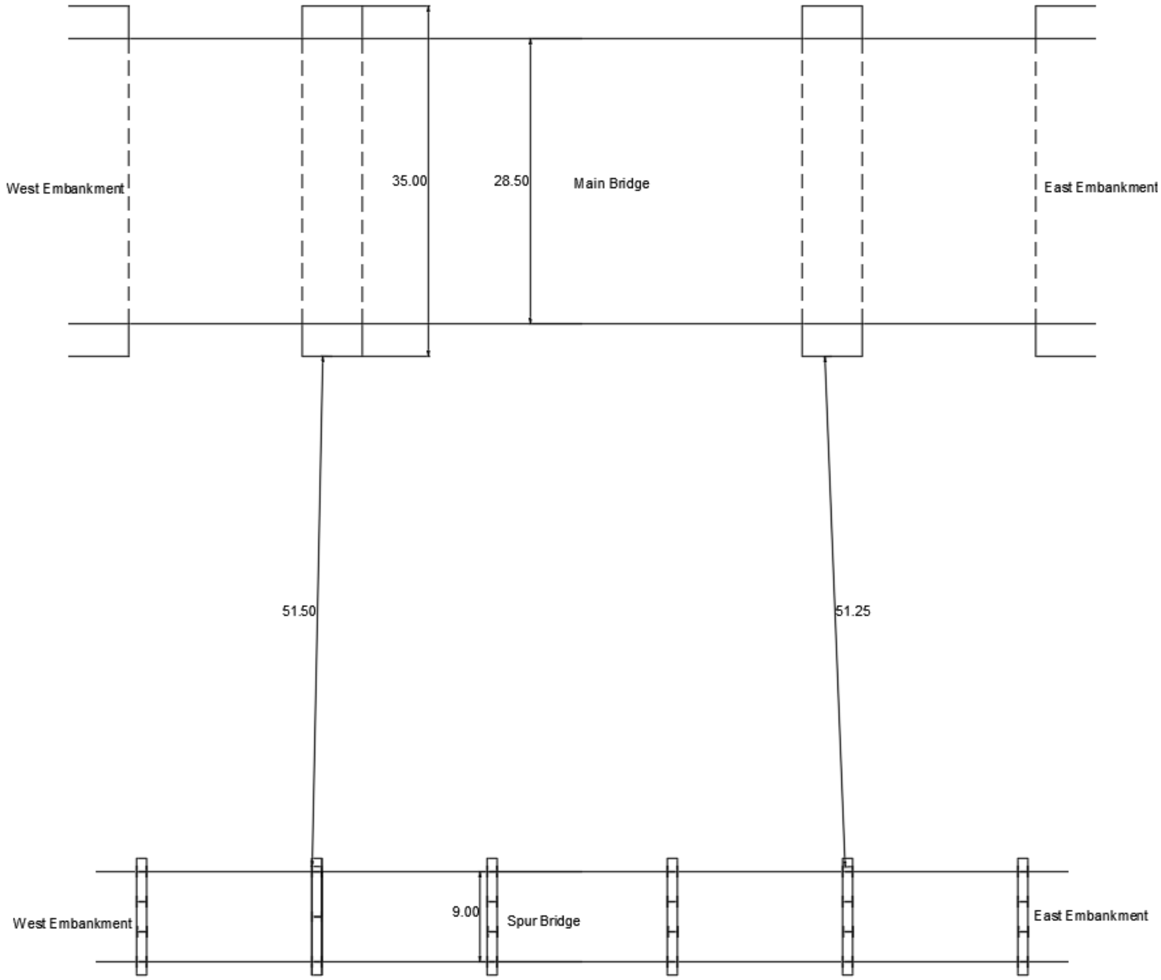


Figure A.10 Plan view showing bridge decks and spacing between bridges. Note that the decks do not include walkways.

Appendix B. Template and Piezometer Locations and Elevation Data

NE NAD 83 and NAVD 88

Table B.1 Template locations and thalweg elevations.

Template	Centerline (thalweg) Northing (ft)	Easting (ft)	Elevation (ft-msl)	Approximate Corresponding Piezometer
1	383824.24	2560536.76	1127.99	1
2	383864.34	2560506.89	1127.87	2
3	383904.44	2560477.02	1127.75	3
4	383944.53	2560447.15	1127.64	4
5	383984.63	2560417.28	1127.52	5
6	384024.73	2560387.41	1127.40	6
7	384064.89	2560357.62	1127.28	7
8	384105.11	2560327.93	1127.17	8
9	384145.34	2560298.23	1127.05	9
10	384185.57	2560268.54	1126.93	10
11	384225.79	2560238.84	1126.82	11
12	384266.02	2560209.15	1126.70	12
13	384290.08	2560191.39	1126.60	13
14	384533.12	2560021.98	1125.65	23
15	384558.09	2560006.45	1125.57	24
16	384594.98	2559973.36	1125.43	25
17	384628.61	2559936.36	1125.29	26
18	384660.49	2559897.89	1125.15	27
19	384691.40	2559858.58	1125.01	28
20	384719.30	2559817.33	1124.87	29
21	384742.44	2559773.01	1124.73	30
22	384765.58	2559728.69	1124.59	31
23	384784.54	2559682.44	1124.45	32
24	384803.12	2559636.02	1124.31	33
25	384821.07	2559589.36	1124.17	34
26	384838.62	2559542.54	1124.03	35
27	384856.18	2559495.72	1123.89	36
28	384873.19	2559448.71	1123.75	37
29	384889.43	2559401.42	1123.61	38
30	384905.67	2559354.13	1123.47	39

Table B.2 Piezometer locations and thalweg elevations.

Piezometer	Centerline (thalweg) Northing (ft)	Easting (ft)	Elevation (ft-msl)	Approximate Corresponding Template
1	383818.81	2560540.80	1128.01	1
2	383858.91	2560510.93	1127.89	2
3	383899.01	2560481.06	1127.77	3
4	383939.10	2560451.20	1127.65	4
5	383979.20	2560421.32	1127.54	5
6	384019.30	2560391.45	1127.42	6
7	384059.45	2560361.65	1127.30	7
8	384099.66	2560331.95	1127.18	8
9	384139.89	2560302.25	1127.07	9
10	384180.12	2560272.56	1126.95	10
11	384220.34	2560242.86	1126.83	11
12	384260.57	2560213.17	1126.71	12
13	384284.63	2560195.41	1126.62	13
14	384303.64	2560182.14	1126.55	**Test Section** These Piezometers were located using lab survey data and interpolation
15	384331.54	2560162.67	1126.44	
16	384358.95	2560143.54	1126.33	
17	384386.95	2560124.00	1126.22	
18	384414.53	2560104.75	1126.12	
19	384442.28	2560085.38	1126.01	
20	384469.87	2560066.12	1125.90	
21	384497.57	2560046.79	1125.79	
22	384507.85	2560039.61	1125.75	
23	384527.57	2560025.85	1125.68	14
24	384552.34	2560010.03	1125.59	15
25	384589.94	2559977.88	1125.45	16
26	384624.06	2559941.37	1125.31	17
27	384656.17	2559903.10	1125.17	18
28	384687.21	2559863.90	1125.03	19
29	384715.51	2559822.94	1124.89	20
30	384739.31	2559779.01	1124.75	21
31	384762.45	2559734.69	1124.61	22
32	384781.97	2559688.70	1124.47	23
33	384800.60	2559642.31	1124.33	24
34	384818.64	2559595.68	1124.19	25
35	384836.24	2559548.88	1124.05	26
36	384853.80	2559502.06	1123.91	27
37	384870.89	2559455.08	1123.77	28
38	384887.23	2559407.82	1123.63	29
39	384903.47	2559360.53	1123.49	30

Appendix C. Preliminary Model Data – Unused Data

Appendix C.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table C.1 Preliminary raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges. Set I. Piezometer units are cm.

Test	10A	10B	10C	10D	10E	10F	10G	10H
Pump Freq. (Hz)	50.2	50.2	50.2	50.2	50.2	60.6	40.4	30.1
Weir (cm)	82.05	82.07	81.68	81.29	80.38	89.24	70.65	50.74
Discharge (ft^3/s)	2.763	2.766	2.716	2.667	2.553	3.785	1.521	0.309
Water Temp (C)	19.5	19	19	19.5	19.5	19.5	19.5	19.5
Gate Height (in)	0.00	2.00	4.00	6.00	10.00	0.00	0.00	0.00
Gate Height (cm)	0.00	5.08	10.16	15.24	25.40	0.00	0.00	0.00
Piezometer								
1	17.3	17.3	17.7	21.8	28.3	19.3	14.3	9.8
2	14.3	14.3	17.0	21.6	28.2	15.8	12.2	7.8
3	14.1	14.0	17.3	21.7	28.2	16.2	11.3	7.4
4	15.6	15.6	17.7	21.8	28.2	17.5	13.0	8.3
5	13.9	13.9	17.4	21.7	28.1	14.7	11.5	7.1
6	13.7	13.6	17.6	21.7	28.2	16.0	11.1	6.1
7	13.8	13.8	17.8	21.8	28.2	15.4	11.4	7.1
8	14.2	14.3	17.5	21.8	28.3	15.4	11.6	7.2
9	13.4	13.5	17.6	21.8	28.2	15.4	11.5	6.9
10	14.3	14.2	17.6	21.8	28.2	16.6	11.7	7.3
11	12.5	12.4	17.3	21.5	28.1	14.1	9.7	5.7
12	13.6	13.5	17.2	21.3	28.1	15.2	10.8	6.8
13	12.3	12.2	17.5	21.7	28.1	14.0	9.7	5.2
14	12.2	12.2	17.6	21.6	28.1	14.1	8.9	4.2
15	12.6	12.6	17.6	21.7	28.1	14.3	9.8	4.4
16	12.0	12.1	17.7	21.7	28.1	13.3	9.6	4.9
17	12.6	12.5	17.8	21.7	28.1	14.2	9.8	5.1
18	11.9	12.1	17.8	21.7	28.2	14.0	9.1	5.3
19	13.1	13.1	17.8	21.7	28.1	14.9	10.0	5.5
20	12.7	12.7	17.8	21.7	28.1	14.8	9.8	5.6
21	13.4	13.4	17.8	21.8	28.2	15.6	10.0	5.7
22	13.2	13.2	17.8	21.8	28.2	15.6	10.3	5.7
23	13.7	13.7	17.8	21.8	28.2	15.2	10.2	5.8
24	13.4	13.4	17.8	21.8	28.1	15.3	10.1	5.8
25	11.0	11.1	17.8	21.8	28.0	13.2	8.6	4.6
26	12.5	12.4	17.8	21.8	28.1	14.5	9.5	5.1
27	11.8	11.9	17.7	21.8	28.3	12.5	8.9	4.9
28	12.5	12.6	17.8	21.8	28.1	12.9	10.0	4.9
29	12.1	12.2	17.7	21.6	28.1	13.0	9.3	4.9
30	12.4	12.7	17.8	21.8	28.1	13.4	9.9	5.0
31	10.5	10.6	17.6	21.5	28.0	12.2	7.8	3.4
32	11.4	11.7	17.6	21.5	28.0	13.6	8.8	4.1
33	11.1	11.0	16.8	20.7	27.5	11.7	7.7	3.6
34	11.6	11.8	17.6	21.6	28.0	12.1	8.8	4.0
35	10.7	11.0	17.5	21.5	28.0	12.5	8.4	2.9
36	11.8	12.0	17.7	21.6	28.0	13.4	8.8	3.7
37	11.5	11.7	17.8	21.7	28.0	13.3	8.3	3.8
38	12.1	12.2	17.8	21.6	28.1	13.7	8.8	3.9
39	8.3	11.3	17.8	21.8	28.1	8.3	5.4	1.5

Table C.2 Preliminary raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges. Set II. Piezometer units are cm.

Test	11A	11B	11C	11D	11E	11F	11G	11H
Pump Freq. (Hz)	61.1	61	61.1	61.1	61	61	61	55.5
Weir (cm)	89.20	89.15	89.32	89.38	89.49	89.53	89.44	85.61
Discharge (ft^3/s)	3.778	3.771	3.797	3.806	3.824	3.830	3.816	3.245
Water Temp (C)	19.5	19.5	19.5	19.5	20	20	20	20
Gate Height (in)	7.38	6.50	5.50	4.50	3.50	2.50	1.50	7.50
Gate Height (cm)	18.73	16.51	13.97	11.43	8.89	6.35	3.81	19.05
Piezometer								
1	25.5	23.6	21.3	19.3	19.3	19.3	19.3	24.5
2	25.4	23.3	21.0	17.3	15.8	15.9	15.9	24.5
3	25.3	23.4	21.2	18.3	16.2	16.3	16.2	24.5
4	25.3	23.5	21.3	19.2	17.6	17.7	17.5	24.5
5	25.3	23.4	21.2	18.4	14.5	14.8	14.6	24.4
6	25.3	23.6	21.3	19.2	16.0	16.0	16.0	24.5
7	25.3	23.6	21.3	19.1	15.4	15.5	15.4	24.5
8	25.3	23.6	21.3	19.4	15.5	15.5	15.4	24.5
9	25.3	23.6	21.2	19.1	15.4	15.4	15.4	24.5
10	25.4	23.6	21.4	19.3	16.7	16.6	16.6	24.5
11	25.3	23.4	21.2	19.0	14.6	14.2	14.2	24.4
12	25.2	23.6	21.4	19.3	15.8	15.8	15.7	24.4
13	25.3	23.4	21.2	19.1	15.8	14.1	14.0	24.4
14	25.3	23.5	21.1	19.2	16.0	14.2	14.1	24.4
15	25.3	23.6	21.2	19.3	16.0	14.3	14.2	24.4
16	25.3	23.6	21.4	19.4	16.4	12.5	13.3	24.5
17	25.3	23.6	21.3	19.5	16.7	14.6	14.3	24.5
18	25.3	23.6	21.3	19.5	16.8	14.3	14.0	24.5
19	25.4	23.6	21.4	19.6	17.0	15.2	14.9	24.5
20	25.4	23.6	21.4	19.6	17.0	15.0	14.9	24.5
21	25.4	23.7	21.6	19.7	17.2	15.9	15.6	24.5
22	25.5	23.7	21.5	19.7	17.1	15.6	15.6	24.5
23	25.5	23.7	21.5	19.7	17.2	15.7	15.2	24.4
24	25.5	23.7	21.4	19.6	17.1	15.4	15.5	24.5
25	25.5	23.6	21.5	19.5	16.8	13.9	13.5	24.6
26	25.4	23.7	21.5	19.6	17.0	14.7	14.4	24.5
27	25.3	23.6	21.5	19.5	16.7	13.8	12.6	24.5
28	25.4	23.7	21.5	19.6	17.2	14.8	14.2	24.6
29	25.4	23.6	21.3	19.5	17.0	14.5	14.1	24.5
30	25.4	23.6	21.4	19.5	17.2	14.8	14.5	24.5
31	25.3	23.4	21.2	19.2	16.7	13.4	12.5	24.4
32	25.3	23.6	21.2	19.4	17.1	14.5	14.0	24.4
33	25.3	23.5	21.1	19.4	16.6	13.9	13.0	24.4
34	25.3	23.5	21.3	19.4	17.1	14.6	13.7	24.4
35	25.3	23.5	21.2	19.4	16.8	14.0	12.8	24.4
36	25.5	23.6	21.3	19.5	17.2	14.9	13.8	24.5
37	25.4	23.5	21.4	19.4	17.1	14.7	13.7	24.5
38	25.6	23.7	21.4	19.5	17.3	15.2	14.1	24.5
39	25.6	23.7	21.7	19.7	17.5	14.9	10.4	24.7

Table C.2 (Cont.) Preliminary raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges. Set II. Piezometer units are cm.

Test	11I	11J	11K	11L	11M
Pump Freq. (Hz)	55.5	55.5	55.5	55.5	55.5
Weir (cm)	85.56	85.63	85.78	85.89	85.97
Discharge (ft^3/s)	3.238	3.248	3.269	3.285	3.296
Water Temp (C)	20.5	20.5	20	20	20
Gate Height (in)	6.50	5.50	4.50	3.50	2.50
Gate Height (cm)	16.51	13.97	11.43	8.89	6.35
Piezometer					
1	22.8	20.6	18.4	18.4	18.4
2	22.6	20.3	16.9	15.0	14.9
3	22.7	20.4	17.8	15.2	15.1
4	22.8	20.7	18.2	16.9	16.8
5	22.7	20.5	18.1	14.1	14.0
6	22.7	20.5	18.2	14.6	14.5
7	22.7	20.5	18.3	14.9	14.6
8	22.7	20.6	18.4	15.2	14.6
9	22.7	20.5	18.2	15.0	14.4
10	22.7	20.5	18.4	15.8	15.4
11	22.7	20.4	18.2	15.2	13.3
12	23.0	20.6	18.2	15.6	14.6
13	22.7	20.4	18.2	15.8	13.2
14	22.7	20.4	18.2	16.1	13.2
15	22.7	20.5	18.3	15.7	13.4
16	22.7	20.6	18.4	16.1	13.1
17	22.7	20.7	18.5	16.2	14.0
18	22.8	20.6	18.5	16.3	13.4
19	22.7	20.6	18.5	16.5	14.5
20	22.7	20.6	18.6	16.6	14.3
21	22.9	20.7	18.6	16.8	14.7
22	22.9	20.7	18.6	16.8	14.6
23	22.8	20.7	18.6	16.7	14.9
24	22.8	20.7	18.6	16.6	14.6
25	22.8	20.6	18.6	16.4	13.1
26	22.8	20.6	18.5	16.6	13.7
27	22.8	20.6	18.5	16.3	13.3
28	22.8	20.6	18.7	16.7	14.1
29	22.8	20.6	18.5	16.6	14.1
30	22.7	20.6	18.5	16.6	14.4
31	22.7	20.5	18.3	16.3	13.7
32	22.7	20.6	18.4	16.7	14.2
33	22.6	20.5	18.3	16.2	13.7
34	22.6	20.5	18.4	16.6	14.2
35	22.5	20.5	18.3	16.4	13.9
36	22.7	20.6	18.5	16.6	14.3
37	22.8	20.6	18.5	16.4	14.2
38	22.8	20.7	18.6	16.7	14.5
39	22.9	20.8	18.8	16.8	14.5

Table C.3 Preliminary raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges. Set III. Piezometer units are cm.

Test	12A	12B	12C	12D	12E	12F	12G	12H
Pump Freq. (Hz)	50.1	50.1	50.1	50.1	50.1	55.0	55.0	55.0
Weir (cm)	81.07	81.26	81.42	81.63	81.8	85.68	85.55	85.32
Discharge (ft^3/s)	2.639	2.663	2.683	2.710	2.731	3.255	3.237	3.204
Water Temp (C)	20	-	-	-	-	-	-	-
Gate Height (in)	7.50	6.50	5.50	4.50	3.50	3.50	4.50	5.50
Gate Height (cm)	19.05	16.51	13.97	11.43	8.89	8.89	11.43	13.97
Piezometer								
1	24.3	21.5	19.7	17.6	16.2	18.3	18.8	21.1
2	24.3	21.4	19.4	17.2	14.1	15.0	18.2	20.8
3	24.3	21.4	19.5	17.5	13.8	15.1	18.7	21.0
4	24.3	21.4	19.8	17.8	15.5	16.8	18.8	21.0
5	24.2	21.4	19.6	17.4	15.1	16.0	18.5	20.8
6	24.2	21.5	19.7	17.7	15.3	16.7	18.8	21.1
7	24.4	21.9	20.0	18.0	16.3	16.9	18.8	20.8
8	24.3	21.5	19.9	17.9	16.1	16.9	18.9	21.1
9	24.2	21.4	19.8	17.7	16.1	17.0	18.8	21.0
10	24.2	21.6	20.2	18.3	16.4	17.4	18.9	21.0
11	24.2	21.4	19.5	17.5	15.8	16.8	18.6	20.9
12	24.2	21.4	19.5	17.7	16.1	17.1	18.7	21.0
13	24.2	21.3	19.6	17.6	15.9	17.0	18.7	20.9
14	24.3	21.3	19.6	17.7	16.1	17.1	18.9	20.9
15	24.1	21.4	19.7	17.9	16.2	17.2	18.8	20.9
16	24.2	21.4	19.6	17.7	16.1	16.5	18.2	20.0
17	24.2	21.3	19.4	17.7	16.0	16.9	18.7	20.8
18	24.2	21.3	19.3	17.4	15.6	16.4	18.4	20.7
19	24.1	21.2	19.3	17.4	15.5	16.3	18.3	20.5
20	24.2	21.3	19.4	17.5	15.8	16.6	18.4	20.6
21	24.2	21.4	19.5	17.7	16.0	16.9	18.5	20.8
22	24.1	21.1	19.2	17.5	16.0	16.6	18.4	20.5
23	24.1	21.2	19.4	17.4	15.8	16.7	18.5	20.8
24	24.2	21.3	19.4	17.5	15.7	16.6	18.6	20.8
25	24.2	21.3	19.3	17.4	15.6	16.3	18.5	20.8
26	24.2	21.3	19.6	17.5	15.8	16.4	18.5	20.7
27	24.2	21.3	19.5	17.4	15.7	16.3	18.3	20.6
28	24.2	21.4	19.7	17.5	15.8	16.6	18.5	20.7
29	24.1	21.4	19.6	17.4	15.7	16.5	18.3	20.7
30	24.2	21.3	19.5	17.4	15.8	16.5	18.4	20.8
31	24.0	21.2	19.3	17.2	15.2	16.1	18.1	20.5
32	24.0	21.3	19.4	17.3	15.5	16.5	18.3	20.6
33	24.0	21.1	19.3	17.2	15.2	16.1	18.1	20.4
34	24.1	21.1	19.4	17.3	15.5	16.4	18.3	20.6
35	24.0	21.1	19.4	17.3	15.3	16.2	18.2	20.5
36	24.0	21.2	19.4	17.4	15.7	16.5	18.4	20.7
37	24.1	21.2	19.3	17.4	15.5	16.4	18.3	20.6
38	24.1	21.2	19.4	17.5	15.6	16.5	18.5	20.7
39	24.2	21.5	19.6	17.7	15.8	16.7	18.7	20.8

Table C.3 (Cont.) Preliminary raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges. Set III. Piezometer units are cm.

Test	12I	12J	12K	12L	12M	12N	12O
Pump Freq. (Hz)	55.0	55.0	57.4	57.4	57.4	57.4	57.4
Weir (cm)	85.19	84.98	86.84	86.97	87.12	87.19	87.35
Discharge (ft^3/s)	3.186	3.156	3.422	3.441	3.463	3.474	3.497
Water Temp (C)	-	-	-	-	-	-	-
Gate Height (in)	6.50	7.50	7.50	6.50	5.50	4.50	3.50
Gate Height (cm)	16.51	19.05	19.05	16.51	13.97	11.43	8.89
Piezometer							
1	23.0	25.0	25.4	23.4	21.5	19.5	18.8
2	22.8	24.8	25.3	23.3	21.4	19.0	15.3
3	22.9	24.9	25.3	23.4	21.5	19.4	15.7
4	23.0	25.0	25.3	23.5	21.7	19.6	17.3
5	22.8	24.8	25.1	23.3	21.6	19.3	15.9
6	22.8	25.0	25.3	23.4	21.6	19.5	16.8
7	22.7	24.5	25.0	23.4	21.8	19.8	17.6
8	22.8	24.9	25.2	23.4	21.8	19.7	17.8
9	22.8	24.9	25.2	23.4	21.6	19.6	17.3
10	22.6	24.7	25.1	23.3	21.7	20.0	18.0
11	22.8	24.8	25.2	23.3	21.4	19.4	17.4
12	22.9	24.8	25.2	23.3	21.5	19.5	17.5
13	22.8	24.8	25.2	23.3	21.5	19.4	17.4
14	22.8	24.8	25.3	23.4	21.4	19.6	17.7
15	22.7	24.5	25.1	23.4	21.6	19.8	17.8
16	22.4	24.4	24.9	23.4	21.5	19.5	17.4
17	22.7	24.8	25.2	23.3	21.3	19.4	17.3
18	22.6	24.6	25.1	23.2	21.2	19.1	17.0
19	22.5	24.6	25.0	23.2	21.2	19.0	16.7
20	22.7	24.7	25.2	23.2	21.2	19.2	16.9
21	22.8	24.8	25.2	23.3	21.4	19.3	17.2
22	22.6	24.6	25.0	23.1	21.1	19.0	17.1
23	22.7	24.7	25.1	23.2	21.2	19.2	17.0
24	22.7	24.8	25.2	23.2	21.3	19.2	16.9
25	22.7	24.8	25.2	23.2	21.3	19.1	16.5
26	22.8	24.8	25.1	23.2	21.3	19.2	16.7
27	22.8	24.8	25.1	23.2	21.3	19.0	16.5
28	22.9	24.8	25.2	23.3	21.3	19.3	16.9
29	22.7	24.7	25.1	23.2	21.3	19.1	16.7
30	22.8	24.8	25.2	23.2	21.2	19.1	16.8
31	22.6	24.6	25.0	23.1	21.0	18.7	16.3
32	22.7	24.7	25.0	23.2	21.2	19.0	16.6
33	22.6	24.6	25.0	23.1	21.0	18.8	16.3
34	22.7	24.7	25.0	23.1	21.2	19.0	16.7
35	22.6	24.6	25.1	23.1	21.2	18.8	16.5
36	22.7	24.8	25.1	23.2	21.3	19.1	16.7
37	22.6	24.8	25.2	23.2	21.2	18.9	16.6
38	22.7	24.9	25.2	23.3	21.2	19.1	16.9
39	22.8	24.9	25.3	23.4	21.4	19.3	17.0

Appendix C.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table C.4 Preliminary Scaled/Corrected data collected in modified cross-section with no roughness and no bridges. Set I. Piezometer units are ft-msl NAVD 88.

Test	10A	10B	10C	10D	10E	10F	10G	10H
Q (ft^3/s)	8636	8644	8488	8333	7979	11827	4752	966
Piezometer								
1	1140.1	1140.1	1140.4	1143.8	1149.1	1141.7	1137.6	1133.9
2	1137.6	1137.6	1139.8	1143.6	1149.0	1138.9	1135.9	1132.3
3	1137.5	1137.4	1140.1	1143.7	1149.0	1139.2	1135.2	1132.0
4	1138.7	1138.7	1140.4	1143.8	1149.0	1140.3	1136.6	1132.7
5	1137.3	1137.3	1140.2	1143.7	1148.9	1138.0	1135.3	1131.7
6	1137.1	1137.1	1140.3	1143.7	1149.0	1139.0	1135.0	1130.9
7	1137.2	1137.2	1140.5	1143.8	1149.0	1138.5	1135.2	1131.7
8	1137.5	1137.6	1140.3	1143.8	1149.1	1138.5	1135.4	1131.8
9	1136.9	1137.0	1140.3	1143.8	1149.0	1138.5	1135.3	1131.6
10	1137.6	1137.5	1140.3	1143.8	1149.0	1139.5	1135.5	1131.9
11	1136.2	1136.2	1140.2	1143.6	1149.0	1137.5	1133.9	1130.7
12	1137.1	1137.1	1140.1	1143.5	1149.0	1138.4	1134.8	1131.6
13	1136.1	1136.0	1140.3	1143.8	1149.0	1137.5	1133.9	1130.2
14	1135.9	1135.9	1140.3	1143.6	1148.9	1137.5	1133.2	1129.3
15	1136.2	1136.2	1140.3	1143.7	1148.9	1137.6	1133.9	1129.5
16	1135.7	1135.8	1140.4	1143.7	1148.9	1136.8	1133.8	1129.9
17	1136.2	1136.2	1140.5	1143.7	1148.9	1137.5	1133.9	1130.1
18	1135.7	1135.8	1140.5	1143.7	1149.0	1137.4	1133.4	1130.2
19	1136.6	1136.6	1140.5	1143.7	1148.9	1138.1	1134.1	1130.4
20	1136.3	1136.3	1140.5	1143.7	1148.9	1138.0	1133.9	1130.5
21	1136.7	1136.7	1140.3	1143.6	1148.9	1138.5	1133.9	1130.4
22	1136.6	1136.6	1140.3	1143.6	1148.9	1138.5	1134.2	1130.4
23	1137.0	1137.0	1140.3	1143.6	1148.9	1138.2	1134.1	1130.5
24	1136.7	1136.7	1140.3	1143.6	1148.8	1138.3	1134.0	1130.5
25	1134.8	1134.9	1140.4	1143.7	1148.8	1136.6	1132.9	1129.6
26	1136.1	1136.0	1140.4	1143.7	1148.9	1137.7	1133.6	1130.0
27	1135.5	1135.6	1140.3	1143.7	1149.0	1136.1	1133.1	1129.8
28	1136.1	1136.2	1140.4	1143.7	1148.9	1136.4	1134.0	1129.8
29	1135.7	1135.8	1140.3	1143.5	1148.9	1136.5	1133.4	1129.8
30	1136.0	1136.2	1140.4	1143.7	1148.9	1136.8	1133.9	1129.9
31	1134.5	1134.6	1140.3	1143.5	1148.9	1135.9	1132.3	1128.7
32	1135.2	1135.5	1140.3	1143.5	1148.9	1137.1	1133.1	1129.3
33	1135.0	1134.9	1139.7	1142.9	1148.5	1135.5	1132.2	1128.9
34	1135.4	1135.6	1140.3	1143.6	1148.9	1135.8	1133.1	1129.2
35	1134.7	1134.9	1140.3	1143.5	1148.9	1136.2	1132.8	1128.3
36	1135.5	1135.7	1140.3	1143.5	1148.8	1136.8	1133.0	1128.9
37	1135.2	1135.4	1140.4	1143.6	1148.8	1136.7	1132.6	1128.9
38	1135.7	1135.8	1140.4	1143.5	1148.9	1137.1	1133.0	1129.0
39	1132.6	1135.1	1140.4	1143.7	1148.9	1132.6	1130.2	1127.0

Table C.5 Preliminary Scaled/Corrected data collected in modified cross-section with no roughness and no bridges. Set II. Piezometer units are ft-msl NAVD 88.

Test	11A	11B	11C	11D	11E	11F	11G	11H
Q (ft^3/s)	11807	11783	11866	11895	11949	11968	11924	10141
Piezometer								
1	1146.8	1145.3	1143.4	1141.7	1141.7	1141.7	1141.7	1146.0
2	1146.7	1145.0	1143.1	1140.1	1138.9	1138.9	1138.9	1146.0
3	1146.6	1145.1	1143.3	1140.9	1139.2	1139.3	1139.2	1146.0
4	1146.6	1145.2	1143.4	1141.6	1140.3	1140.4	1140.3	1146.0
5	1146.6	1145.1	1143.3	1141.0	1137.8	1138.0	1137.9	1145.9
6	1146.6	1145.3	1143.4	1141.6	1139.0	1139.0	1139.0	1146.0
7	1146.6	1145.3	1143.4	1141.6	1138.5	1138.6	1138.5	1146.0
8	1146.6	1145.3	1143.4	1141.8	1138.6	1138.6	1138.5	1146.0
9	1146.6	1145.3	1143.3	1141.6	1138.5	1138.5	1138.5	1146.0
10	1146.7	1145.3	1143.5	1141.7	1139.6	1139.5	1139.5	1146.0
11	1146.7	1145.2	1143.4	1141.6	1138.0	1137.6	1137.6	1146.0
12	1146.6	1145.3	1143.5	1141.8	1138.9	1138.9	1138.9	1146.0
13	1146.7	1145.2	1143.4	1141.6	1138.9	1137.5	1137.5	1146.0
14	1146.6	1145.2	1143.2	1141.6	1139.0	1137.5	1137.5	1145.9
15	1146.6	1145.3	1143.3	1141.7	1139.0	1137.6	1137.5	1145.9
16	1146.6	1145.3	1143.5	1141.8	1139.3	1136.2	1136.8	1146.0
17	1146.6	1145.3	1143.4	1141.9	1139.6	1137.9	1137.6	1146.0
18	1146.6	1145.3	1143.4	1141.9	1139.7	1137.6	1137.4	1146.0
19	1146.7	1145.3	1143.5	1142.0	1139.8	1138.4	1138.1	1146.0
20	1146.7	1145.3	1143.5	1142.0	1139.8	1138.2	1138.1	1146.0
21	1146.6	1145.2	1143.5	1141.9	1139.8	1138.8	1138.5	1145.8
22	1146.6	1145.2	1143.4	1141.9	1139.8	1138.5	1138.5	1145.8
23	1146.6	1145.2	1143.4	1141.9	1139.8	1138.6	1138.2	1145.7
24	1146.6	1145.2	1143.3	1141.8	1139.8	1138.4	1138.4	1145.8
25	1146.7	1145.2	1143.5	1141.8	1139.6	1137.2	1136.9	1146.0
26	1146.6	1145.3	1143.5	1141.9	1139.8	1137.9	1137.6	1145.9
27	1146.6	1145.2	1143.5	1141.8	1139.5	1137.1	1136.2	1145.9
28	1146.6	1145.3	1143.5	1141.9	1139.9	1138.0	1137.5	1146.0
29	1146.6	1145.2	1143.3	1141.8	1139.8	1137.7	1137.4	1145.9
30	1146.6	1145.2	1143.4	1141.8	1139.9	1138.0	1137.7	1145.9
31	1146.6	1145.1	1143.3	1141.6	1139.6	1136.9	1136.2	1145.9
32	1146.6	1145.3	1143.3	1141.8	1139.9	1137.8	1137.4	1145.9
33	1146.6	1145.2	1143.2	1141.8	1139.5	1137.3	1136.6	1145.9
34	1146.6	1145.2	1143.4	1141.8	1139.9	1137.9	1137.1	1145.9
35	1146.6	1145.2	1143.3	1141.8	1139.7	1137.4	1136.4	1145.9
36	1146.7	1145.2	1143.3	1141.8	1139.9	1138.0	1137.1	1145.9
37	1146.6	1145.1	1143.4	1141.7	1139.8	1137.9	1137.1	1145.9
38	1146.8	1145.3	1143.4	1141.8	1140.0	1138.3	1137.4	1145.9
39	1146.8	1145.3	1143.6	1142.0	1140.2	1138.0	1134.3	1146.1

Table C.5 (Cont.) Preliminary Scaled/Corrected data collected in modified cross-section with no roughness and no bridges. Set II. Piezometer units are ft-msl NAVD 88.

Test	11I	11J	11K	11L	11M
Q (ft^3/s)	10119	10150	10216	10265	10301
Piezometer					
1	1144.6	1142.8	1141.0	1141.0	1141.0
2	1144.4	1142.5	1139.8	1138.2	1138.1
3	1144.5	1142.6	1140.5	1138.4	1138.3
4	1144.6	1142.9	1140.8	1139.8	1139.7
5	1144.5	1142.7	1140.7	1137.5	1137.4
6	1144.5	1142.7	1140.8	1137.9	1137.8
7	1144.5	1142.7	1140.9	1138.1	1137.9
8	1144.5	1142.8	1141.0	1138.4	1137.9
9	1144.5	1142.7	1140.8	1138.2	1137.7
10	1144.5	1142.7	1141.0	1138.9	1138.5
11	1144.6	1142.7	1140.9	1138.4	1136.9
12	1144.8	1142.9	1140.9	1138.8	1138.0
13	1144.6	1142.7	1140.9	1138.9	1136.8
14	1144.5	1142.6	1140.8	1139.1	1136.7
15	1144.5	1142.7	1140.9	1138.8	1136.9
16	1144.5	1142.8	1141.0	1139.1	1136.6
17	1144.5	1142.9	1141.1	1139.2	1137.4
18	1144.6	1142.8	1141.1	1139.3	1136.9
19	1144.5	1142.8	1141.1	1139.4	1137.8
20	1144.5	1142.8	1141.2	1139.5	1137.6
21	1144.5	1142.7	1141.0	1139.5	1137.8
22	1144.5	1142.7	1141.0	1139.5	1137.7
23	1144.4	1142.7	1141.0	1139.4	1138.0
24	1144.4	1142.7	1141.0	1139.3	1137.7
25	1144.5	1142.7	1141.1	1139.3	1136.6
26	1144.5	1142.7	1141.0	1139.4	1137.1
27	1144.5	1142.7	1141.0	1139.2	1136.7
28	1144.5	1142.7	1141.2	1139.5	1137.4
29	1144.5	1142.7	1141.0	1139.4	1137.4
30	1144.4	1142.7	1141.0	1139.4	1137.6
31	1144.5	1142.7	1140.9	1139.3	1137.2
32	1144.5	1142.8	1141.0	1139.6	1137.5
33	1144.4	1142.7	1140.9	1139.2	1137.1
34	1144.4	1142.7	1141.0	1139.5	1137.5
35	1144.4	1142.7	1140.9	1139.3	1137.3
36	1144.4	1142.7	1141.0	1139.4	1137.5
37	1144.5	1142.7	1141.0	1139.3	1137.5
38	1144.5	1142.8	1141.1	1139.5	1137.7
39	1144.6	1142.9	1141.2	1139.6	1137.7

Table C.6 Preliminary Scaled/Corrected data collected in modified cross-section with no roughness and no bridges. Set III. Piezometer units are ft-msl NAVD 88.

Test	12A	12B	12C	12D	12E	12F	12G	12H
Q (ft^3/s)	8247	8321	8384	8468	8536	10172	10114	10013
Piezometer								
1	1145.8	1143.5	1142.1	1140.3	1139.2	1140.9	1141.3	1143.2
2	1145.8	1143.5	1141.8	1140.0	1137.5	1138.2	1140.8	1143.0
3	1145.8	1143.5	1141.9	1140.3	1137.2	1138.3	1141.2	1143.1
4	1145.8	1143.5	1142.1	1140.5	1138.6	1139.7	1141.3	1143.1
5	1145.7	1143.5	1142.0	1140.2	1138.3	1139.0	1141.1	1143.0
6	1145.7	1143.5	1142.1	1140.4	1138.4	1139.6	1141.3	1143.2
7	1145.9	1143.9	1142.3	1140.7	1139.3	1139.8	1141.3	1143.0
8	1145.8	1143.5	1142.2	1140.6	1139.1	1139.8	1141.4	1143.2
9	1145.7	1143.5	1142.1	1140.4	1139.1	1139.8	1141.3	1143.1
10	1145.7	1143.6	1142.5	1140.9	1139.3	1140.2	1141.4	1143.1
11	1145.8	1143.5	1142.0	1140.3	1138.9	1139.8	1141.2	1143.1
12	1145.8	1143.5	1142.0	1140.5	1139.2	1140.0	1141.3	1143.2
13	1145.8	1143.5	1142.1	1140.4	1139.0	1139.9	1141.3	1143.1
14	1145.8	1143.4	1142.0	1140.4	1139.1	1139.9	1141.4	1143.0
15	1145.7	1143.5	1142.1	1140.6	1139.2	1140.0	1141.3	1143.0
16	1145.7	1143.5	1142.0	1140.4	1139.1	1139.4	1140.8	1142.3
17	1145.7	1143.4	1141.8	1140.4	1139.0	1139.8	1141.2	1143.0
18	1145.7	1143.4	1141.7	1140.2	1138.7	1139.3	1141.0	1142.9
19	1145.7	1143.3	1141.7	1140.2	1138.6	1139.3	1140.9	1142.7
20	1145.7	1143.4	1141.8	1140.3	1138.9	1139.5	1141.0	1142.8
21	1145.6	1143.3	1141.7	1140.3	1138.9	1139.6	1140.9	1142.8
22	1145.5	1143.0	1141.5	1140.1	1138.9	1139.3	1140.8	1142.5
23	1145.5	1143.1	1141.6	1140.0	1138.7	1139.4	1140.9	1142.8
24	1145.6	1143.2	1141.6	1140.1	1138.6	1139.3	1141.0	1142.8
25	1145.7	1143.3	1141.6	1140.1	1138.6	1139.2	1141.0	1142.9
26	1145.7	1143.3	1141.9	1140.2	1138.8	1139.3	1141.0	1142.8
27	1145.7	1143.3	1141.8	1140.1	1138.7	1139.2	1140.8	1142.7
28	1145.7	1143.4	1142.0	1140.2	1138.8	1139.4	1141.0	1142.8
29	1145.6	1143.4	1141.9	1140.1	1138.7	1139.3	1140.8	1142.8
30	1145.7	1143.3	1141.8	1140.1	1138.8	1139.3	1140.9	1142.9
31	1145.6	1143.3	1141.7	1140.0	1138.4	1139.1	1140.7	1142.7
32	1145.6	1143.4	1141.8	1140.1	1138.6	1139.4	1140.9	1142.8
33	1145.6	1143.2	1141.7	1140.0	1138.4	1139.1	1140.7	1142.6
34	1145.7	1143.2	1141.8	1140.1	1138.6	1139.3	1140.9	1142.8
35	1145.6	1143.2	1141.8	1140.1	1138.4	1139.2	1140.8	1142.7
36	1145.5	1143.2	1141.7	1140.1	1138.7	1139.3	1140.9	1142.8
37	1145.6	1143.2	1141.6	1140.1	1138.5	1139.3	1140.8	1142.7
38	1145.6	1143.2	1141.7	1140.2	1138.6	1139.3	1141.0	1142.8
39	1145.7	1143.5	1141.9	1140.3	1138.8	1139.5	1141.2	1142.9

Table C.6 (Cont.) Preliminary Scaled/Corrected data collected in modified cross-section with no roughness and no bridges. Set III. Piezometer units are ft-msl NAVD 88.

Test	12I	12J	12K	12L	12M	12N	12O
Q (ft^3/s)	9956	9864	10695	10754	10823	10855	10929
Piezometer							
1	1144.8	1146.4	1146.7	1145.1	1143.5	1141.9	1141.3
2	1144.6	1146.2	1146.6	1145.0	1143.5	1141.5	1138.4
3	1144.7	1146.3	1146.6	1145.1	1143.5	1141.8	1138.8
4	1144.8	1146.4	1146.6	1145.2	1143.7	1142.0	1140.1
5	1144.6	1146.2	1146.5	1145.0	1143.6	1141.7	1138.9
6	1144.6	1146.4	1146.6	1145.1	1143.6	1141.9	1139.7
7	1144.5	1146.0	1146.4	1145.1	1143.8	1142.1	1140.3
8	1144.6	1146.3	1146.6	1145.1	1143.8	1142.1	1140.5
9	1144.6	1146.3	1146.6	1145.1	1143.6	1142.0	1140.1
10	1144.4	1146.2	1146.5	1145.0	1143.7	1142.3	1140.7
11	1144.7	1146.3	1146.6	1145.1	1143.5	1141.9	1140.3
12	1144.8	1146.3	1146.6	1145.1	1143.6	1142.0	1140.3
13	1144.7	1146.3	1146.6	1145.1	1143.6	1141.9	1140.3
14	1144.6	1146.2	1146.6	1145.1	1143.5	1142.0	1140.4
15	1144.5	1146.0	1146.5	1145.1	1143.6	1142.1	1140.5
16	1144.3	1145.9	1146.3	1145.1	1143.5	1141.9	1140.2
17	1144.5	1146.2	1146.6	1145.0	1143.4	1141.8	1140.1
18	1144.4	1146.1	1146.5	1144.9	1143.3	1141.6	1139.8
19	1144.4	1146.1	1146.4	1144.9	1143.3	1141.5	1139.6
20	1144.5	1146.2	1146.6	1144.9	1143.3	1141.6	1139.8
21	1144.4	1146.1	1146.4	1144.8	1143.3	1141.6	1139.8
22	1144.3	1145.9	1146.2	1144.7	1143.0	1141.3	1139.8
23	1144.4	1146.0	1146.3	1144.8	1143.1	1141.5	1139.7
24	1144.4	1146.1	1146.4	1144.8	1143.2	1141.5	1139.6
25	1144.4	1146.2	1146.5	1144.8	1143.3	1141.5	1139.3
26	1144.5	1146.2	1146.4	1144.8	1143.3	1141.6	1139.5
27	1144.5	1146.2	1146.4	1144.8	1143.3	1141.4	1139.3
28	1144.6	1146.2	1146.5	1144.9	1143.3	1141.6	1139.7
29	1144.4	1146.1	1146.4	1144.8	1143.3	1141.5	1139.5
30	1144.5	1146.2	1146.5	1144.8	1143.2	1141.5	1139.6
31	1144.4	1146.1	1146.4	1144.8	1143.1	1141.2	1139.3
32	1144.5	1146.2	1146.4	1144.9	1143.3	1141.5	1139.5
33	1144.4	1146.1	1146.4	1144.8	1143.1	1141.3	1139.3
34	1144.5	1146.2	1146.4	1144.8	1143.3	1141.5	1139.6
35	1144.4	1146.1	1146.5	1144.8	1143.3	1141.3	1139.4
36	1144.4	1146.2	1146.4	1144.8	1143.3	1141.5	1139.5
37	1144.4	1146.2	1146.5	1144.8	1143.2	1141.3	1139.4
38	1144.4	1146.2	1146.5	1144.9	1143.2	1141.5	1139.7
39	1144.5	1146.2	1146.6	1145.0	1143.4	1141.6	1139.8

Appendix D. Pre-Calibration Model Data – Without Bridges

Appendix D.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table D.1 Raw experimental data collected in the physical model with modified cross-section with no roughness and no bridges for a high flow. Piezometer units are cm.

Test	20A	20B	20C	20D	20E	20F	20G	20H	20I	20J	20K
Pump Freq (Hz)	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Weir (cm)	89.43	89.32	89.36	89.48	89.38	89.42	89.41	89.47	89.47	89.55	89.39
Discharge (ft^3/s)	3.814	3.797	3.803	3.822	3.806	3.813	3.811	3.820	3.820	3.833	3.808
Water Temp (C)	20.6	20.7	20.7	20.8	20.8	20.8	20.8	20.8	20.9	20.9	20.7
Gate Height (in)	7.25	7.00	6.75	6.50	6.25	6.00	5.75	5.50	5.25	5.00	7.50
Gate Height(cm)	18.42	17.78	17.15	16.51	15.88	15.24	14.61	13.97	13.34	12.70	19.05
Piezometer											
1	25.2	24.7	24.1	23.6	23.1	22.5	22.1	21.5	21.0	20.2	25.2
2	25.1	24.7	23.9	23.4	22.8	22.3	21.8	21.1	20.4	19.7	25.0
3	25.2	24.7	24.0	23.5	23.0	22.4	22.0	21.3	20.7	20.1	25.1
4	25.2	24.8	24.0	23.6	23.1	22.5	22.1	21.4	20.9	20.3	25.2
5	25.2	24.7	23.9	23.5	22.9	22.4	21.9	21.4	20.7	20.0	25.1
6	25.2	24.6	24.1	23.6	23.0	22.5	22.0	21.5	20.9	20.2	25.0
7	25.2	24.8	24.1	23.7	23.1	22.6	22.1	21.6	21.0	20.3	25.1
8	25.2	24.9	24.2	23.7	23.2	22.5	22.2	21.6	20.9	20.2	25.1
9	25.2	24.8	24.1	23.5	23.0	22.5	22.0	21.5	20.9	20.2	25.1
10	25.2	24.7	24.1	23.6	23.1	22.6	22.1	21.6	20.9	20.3	25.2
11	25.1	24.7	24.0	23.4	22.9	22.4	22.0	21.4	20.8	20.1	25.0
12	25.2	24.7	23.9	23.5	23.0	22.4	22.1	21.4	20.9	20.2	25.1
13	25.1	24.6	24.0	23.4	22.9	22.4	21.9	21.3	20.8	20.1	25.0
14	25.0	24.7	24.0	23.4	23.0	22.5	22.0	21.4	20.8	20.2	24.9
15	25.0	24.6	24.0	23.5	23.0	22.5	21.9	21.4	20.9	20.2	25.0
16	25.1	24.8	24.1	23.5	23.1	22.6	22.1	21.5	21.0	20.4	24.6
17	25.1	24.7	24.0	23.5	23.0	22.6	22.0	21.5	21.0	20.5	24.7
18	25.0	24.7	24.0	23.6	23.1	22.6	22.1	21.6	21.1	20.4	24.4
19	25.1	24.8	24.1	23.6	23.1	22.6	22.1	21.6	21.1	20.5	24.4
20	25.1	24.8	24.1	23.6	23.1	22.6	22.1	21.6	21.1	20.5	24.5
21	25.2	24.8	24.1	23.7	23.2	22.7	22.2	21.6	21.2	20.5	24.6
22	25.2	24.8	24.1	23.7	23.2	22.7	22.2	21.7	21.2	20.6	24.6
23	25.2	24.7	24.1	23.6	23.1	22.7	22.2	21.7	21.1	20.4	24.5
24	25.2	24.8	24.0	23.6	23.1	22.7	22.1	21.6	21.1	20.5	24.5
25	25.2	24.7	24.0	23.4	23.1	22.5	22.1	21.6	21.0	20.3	24.5
26	25.2	24.7	24.1	23.5	23.1	22.7	22.2	21.6	21.0	20.5	24.6
27	25.2	24.8	24.1	23.5	23.1	22.7	22.2	21.6	21.0	20.4	24.5
28	25.2	24.8	24.1	23.5	23.1	22.7	22.2	21.6	21.1	20.5	24.5
29	25.2	24.7	24.1	23.6	23.0	22.6	22.2	21.5	21.0	20.4	24.5
30	25.2	24.8	24.1	23.5	23.0	22.6	22.1	21.5	20.9	20.4	24.7
31	24.9	24.5	23.8	23.3	22.8	22.4	21.8	21.4	20.8	20.2	24.5
32	25.0	24.6	24.0	23.4	22.9	22.6	22.0	21.5	20.9	20.3	24.4
33	25.0	24.6	24.0	23.4	22.8	22.5	21.9	21.4	20.8	20.3	24.3
34	25.1	24.6	24.0	23.4	22.9	22.5	22.0	21.5	20.9	20.3	24.4
35	25.0	24.5	24.0	23.4	22.9	22.4	22.0	21.5	20.9	20.3	24.4
36	25.1	24.6	24.0	23.4	22.9	22.6	22.0	21.5	21.0	20.4	24.5
37	25.1	24.6	24.0	23.4	22.9	22.5	22.1	21.5	20.9	20.4	24.5
38	25.1	24.7	24.1	23.5	23.0	22.6	22.1	21.6	21.0	20.5	24.5
39	25.2	24.8	24.2	23.7	23.2	22.7	22.4	21.7	21.3	20.6	24.7

Appendix D.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table D.4 Scaled/Corrected data collected in modified cross-section with no roughness and no bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	20A	20B	20C	20D	20E	20F	20G	20H	20I	20J	20K
Q (ft^3/s)	11919	11866	11885	11944	11895	11914	11910	11939	11939	11978	11900
Piezometer											
1	1146.6	1146.2	1145.7	1145.3	1144.8	1144.4	1144.0	1143.5	1143.1	1142.5	1146.6
2	1146.5	1146.2	1145.5	1145.1	1144.6	1144.2	1143.8	1143.2	1142.6	1142.1	1146.4
3	1146.6	1146.2	1145.6	1145.2	1144.8	1144.3	1143.9	1143.4	1142.9	1142.4	1146.5
4	1146.6	1146.2	1145.6	1145.3	1144.8	1144.4	1144.0	1143.5	1143.0	1142.5	1146.6
5	1146.6	1146.2	1145.5	1145.2	1144.7	1144.3	1143.9	1143.5	1142.9	1142.3	1146.5
6	1146.6	1146.1	1145.7	1145.3	1144.8	1144.4	1143.9	1143.5	1143.0	1142.5	1146.4
7	1146.6	1146.2	1145.7	1145.3	1144.8	1144.4	1144.0	1143.6	1143.1	1142.5	1146.5
8	1146.6	1146.3	1145.7	1145.3	1144.9	1144.4	1144.1	1143.6	1143.0	1142.5	1146.5
9	1146.6	1146.2	1145.7	1145.2	1144.8	1144.4	1143.9	1143.5	1143.0	1142.5	1146.5
10	1146.6	1146.2	1145.7	1145.3	1144.8	1144.4	1144.0	1143.6	1143.0	1142.5	1146.6
11	1146.6	1146.2	1145.7	1145.2	1144.8	1144.4	1144.0	1143.5	1143.0	1142.5	1146.5
12	1146.6	1146.2	1145.6	1145.3	1144.8	1144.4	1144.1	1143.5	1143.1	1142.5	1146.6
13	1146.6	1146.2	1145.7	1145.2	1144.8	1144.4	1143.9	1143.5	1143.0	1142.5	1146.5
14	1146.4	1146.2	1145.6	1145.1	1144.8	1144.4	1143.9	1143.5	1143.0	1142.5	1146.3
15	1146.4	1146.1	1145.6	1145.2	1144.8	1144.4	1143.9	1143.5	1143.0	1142.5	1146.4
16	1146.5	1146.2	1145.7	1145.2	1144.8	1144.4	1144.0	1143.5	1143.1	1142.6	1146.1
17	1146.5	1146.2	1145.6	1145.2	1144.8	1144.4	1143.9	1143.5	1143.1	1142.7	1146.2
18	1146.4	1146.2	1145.6	1145.3	1144.8	1144.4	1144.0	1143.6	1143.2	1142.6	1145.9
19	1146.5	1146.2	1145.7	1145.3	1144.8	1144.4	1144.0	1143.6	1143.2	1142.7	1145.9
20	1146.5	1146.2	1145.7	1145.3	1144.8	1144.4	1144.0	1143.6	1143.2	1142.7	1146.0
21	1146.4	1146.1	1145.5	1145.2	1144.8	1144.4	1143.9	1143.5	1143.1	1142.5	1145.9
22	1146.4	1146.1	1145.5	1145.2	1144.8	1144.4	1143.9	1143.5	1143.1	1142.6	1145.9
23	1146.4	1146.0	1145.5	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.5	1145.8
24	1146.4	1146.1	1145.4	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.5	1145.8
25	1146.5	1146.1	1145.5	1145.0	1144.8	1144.3	1143.9	1143.5	1143.0	1142.5	1145.9
26	1146.5	1146.1	1145.6	1145.1	1144.8	1144.4	1144.0	1143.5	1143.0	1142.6	1146.0
27	1146.5	1146.2	1145.6	1145.1	1144.8	1144.4	1144.0	1143.5	1143.0	1142.5	1145.9
28	1146.5	1146.2	1145.6	1145.1	1144.8	1144.4	1144.0	1143.5	1143.1	1142.6	1145.9
29	1146.5	1146.1	1145.6	1145.2	1144.7	1144.4	1144.0	1143.5	1143.0	1142.5	1145.9
30	1146.5	1146.2	1145.6	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.5	1146.1
31	1146.3	1146.0	1145.4	1145.0	1144.6	1144.3	1143.8	1143.5	1143.0	1142.5	1146.0
32	1146.4	1146.1	1145.6	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.5	1145.9
33	1146.4	1146.1	1145.6	1145.1	1144.6	1144.4	1143.9	1143.5	1143.0	1142.5	1145.8
34	1146.5	1146.1	1145.6	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.5	1145.9
35	1146.4	1146.0	1145.6	1145.1	1144.7	1144.3	1143.9	1143.5	1143.0	1142.5	1145.9
36	1146.4	1146.0	1145.5	1145.0	1144.6	1144.4	1143.9	1143.5	1143.0	1142.5	1145.9
37	1146.4	1146.0	1145.5	1145.0	1144.6	1144.3	1143.9	1143.5	1143.0	1142.5	1145.9
38	1146.4	1146.1	1145.6	1145.1	1144.7	1144.4	1143.9	1143.5	1143.0	1142.6	1145.9
39	1146.5	1146.2	1145.7	1145.3	1144.8	1144.4	1144.2	1143.6	1143.3	1142.7	1146.1

Appendix E. Pre-calibration Model Data – With Bridges

Appendix E.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table E.1 Raw experimental data collected in the physical model with modified cross-section with no roughness but with bridges for a high flow. Piezometer units are cm.

Test	30A	30B	30C	30D	30E	30F	30G	30H	30I	30J
Pump Freq. (Hz)	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Weir (cm)	89.25	89.27	89.26	89.26	89.26	89.29	89.28	89.29	89.29	89.33
Discharge (ft^3/s)	3.786	3.789	3.788	3.788	3.788	3.792	3.791	3.792	3.792	3.799
Water Temp (C)	-	-	-	-	-	-	-	-	-	-
Gate Height (in)	7.25	7.00	6.75	6.50	6.25	6.00	5.75	5.50	5.25	5.00
Gate Height (cm)	18.42	17.78	17.15	16.51	15.88	15.24	14.61	13.97	13.34	12.70
Piezometer										
1	25.4	24.9	24.4	23.8	23.2	22.6	22.3	21.9	21.4	20.9
2	25.4	24.6	24.3	23.6	23.0	22.4	22.0	21.7	21.0	20.5
3	25.3	24.7	24.3	23.7	23.1	22.6	22.1	21.7	21.2	20.8
4	25.4	24.8	24.2	23.7	23.2	22.7	22.3	21.9	21.4	21.1
5	25.3	24.7	24.2	23.6	23.1	22.6	22.2	21.7	21.3	20.8
6	25.2	24.7	24.3	23.7	23.2	22.7	22.2	21.9	21.4	21.0
7	25.4	24.8	24.4	23.9	23.3	22.8	22.3	22.0	21.6	21.0
8	25.3	24.7	24.4	23.9	23.3	22.6	22.2	21.8	21.4	20.9
9	25.4	24.7	24.3	23.8	23.2	22.7	22.2	21.9	21.4	20.9
10	25.3	24.7	24.4	23.8	23.2	22.7	22.2	22.0	21.4	21.0
11	25.3	24.7	24.3	23.6	23.1	22.5	22.2	21.7	21.3	20.8
12	25.3	24.7	24.3	23.6	23.1	22.6	22.2	21.8	21.3	20.9
13	25.2	24.6	24.3	23.7	23.0	22.6	22.1	21.8	21.2	20.8
14	25.4	24.8	24.4	23.7	23.2	22.7	22.2	21.9	21.4	20.9
15	25.4	24.9	24.4	23.8	23.3	22.8	22.3	22.0	21.5	21.1
16	25.2	24.6	24.2	23.5	22.9	22.5	22.0	21.6	21.1	20.6
17	25.3	24.7	24.2	23.6	23.0	22.5	22.0	21.7	21.2	20.7
18	25.1	24.4	24.1	23.5	22.8	22.3	21.8	21.4	21.0	20.4
19	25.1	24.4	24.1	23.4	22.8	22.3	21.8	21.4	20.9	20.4
20	25.1	24.5	24.2	23.5	22.8	22.4	21.9	21.5	21.0	20.4
21	25.2	24.6	24.2	23.5	23.0	22.5	22.0	21.6	21.2	20.6
22	25.2	24.6	24.3	23.5	22.9	22.5	22.0	21.6	21.2	20.6
23	25.2	24.5	24.2	23.5	22.9	22.3	22.0	21.5	21.0	20.5
24	25.2	24.5	24.2	23.4	22.9	22.4	22.0	21.5	21.0	20.6
25	25.2	24.5	24.1	23.4	22.9	22.3	21.9	21.4	20.8	20.4
26	25.1	24.6	24.2	23.5	22.9	22.5	21.9	21.5	20.9	20.5
27	25.2	24.5	24.2	23.5	22.9	22.4	21.9	21.5	20.9	20.3
28	25.2	24.5	24.2	23.5	22.9	22.5	21.9	21.6	21.0	20.5
29	25.2	24.5	24.0	23.4	22.8	22.3	21.9	21.4	20.9	20.4
30	25.2	24.7	24.1	23.4	22.9	22.3	21.9	21.4	20.8	20.4
31	25.0	24.5	24.2	23.4	22.9	22.3	21.8	21.3	20.6	20.1
32	25.1	24.4	24.0	23.3	22.8	22.3	21.8	21.2	20.8	20.2
33	25.0	24.3	23.9	23.3	22.7	22.2	21.8	21.2	20.7	20.2
34	25.1	24.4	24.0	23.3	22.8	22.3	21.8	21.3	20.8	20.3
35	25.0	24.4	24.1	23.6	23.2	22.6	22.2	21.8	21.2	20.3
36	25.2	24.5	24.1	23.4	22.8	22.3	21.8	21.5	20.9	20.3
37	25.1	24.5	24.1	23.3	22.8	22.2	21.8	21.3	20.8	20.3
38	25.2	24.5	24.1	23.4	22.8	22.3	21.9	21.5	20.8	20.4
39	25.3	24.7	24.3	23.7	23.0	22.7	22.2	21.7	21.2	20.6

Appendix E.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table E.2 Scaled/Corrected data collected in modified cross-section with no roughness but with bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	30A	30B	30C	30D	30E	30F	30G	30H	30I	30J
Discharge (ft^3/s)	11832	11841	11837	11837	11837	11851	11846	11851	11851	11871
Piezometer										
1	1146.7	1146.3	1145.9	1145.4	1144.9	1144.4	1144.2	1143.9	1143.5	1143.0
2	1146.7	1146.1	1145.8	1145.3	1144.8	1144.3	1143.9	1143.7	1143.1	1142.7
3	1146.6	1146.2	1145.8	1145.3	1144.8	1144.4	1144.0	1143.7	1143.3	1143.0
4	1146.7	1146.2	1145.7	1145.3	1144.9	1144.5	1144.2	1143.9	1143.5	1143.2
5	1146.6	1146.2	1145.7	1145.3	1144.8	1144.4	1144.1	1143.7	1143.4	1143.0
6	1146.6	1146.2	1145.8	1145.3	1144.9	1144.5	1144.1	1143.9	1143.5	1143.1
7	1146.7	1146.2	1145.9	1145.5	1145.0	1144.6	1144.2	1143.9	1143.6	1143.1
8	1146.6	1146.2	1145.9	1145.5	1145.0	1144.4	1144.1	1143.8	1143.5	1143.0
9	1146.7	1146.2	1145.8	1145.4	1144.9	1144.5	1144.1	1143.9	1143.5	1143.0
10	1146.6	1146.2	1145.9	1145.4	1144.9	1144.5	1144.1	1143.9	1143.5	1143.1
11	1146.7	1146.2	1145.9	1145.3	1144.9	1144.4	1144.2	1143.8	1143.5	1143.0
12	1146.7	1146.2	1145.9	1145.3	1144.9	1144.5	1144.2	1143.9	1143.5	1143.1
13	1146.6	1146.2	1145.9	1145.4	1144.8	1144.5	1144.1	1143.9	1143.4	1143.0
14	1146.7	1146.2	1145.9	1145.3	1144.9	1144.5	1144.1	1143.9	1143.5	1143.0
15	1146.7	1146.3	1145.9	1145.4	1145.0	1144.6	1144.2	1143.9	1143.5	1143.2
16	1146.6	1146.1	1145.7	1145.2	1144.7	1144.4	1143.9	1143.6	1143.2	1142.8
17	1146.6	1146.2	1145.7	1145.3	1144.8	1144.4	1143.9	1143.7	1143.3	1142.9
18	1146.5	1145.9	1145.7	1145.2	1144.6	1144.2	1143.8	1143.5	1143.1	1142.6
19	1146.5	1145.9	1145.7	1145.1	1144.6	1144.2	1143.8	1143.5	1143.0	1142.6
20	1146.5	1146.0	1145.7	1145.2	1144.6	1144.3	1143.9	1143.5	1143.1	1142.6
21	1146.4	1145.9	1145.6	1145.0	1144.6	1144.2	1143.8	1143.5	1143.1	1142.6
22	1146.4	1145.9	1145.7	1145.0	1144.5	1144.2	1143.8	1143.5	1143.1	1142.6
23	1146.4	1145.8	1145.6	1145.0	1144.5	1144.0	1143.8	1143.4	1143.0	1142.5
24	1146.4	1145.8	1145.6	1144.9	1144.5	1144.1	1143.8	1143.4	1143.0	1142.6
25	1146.5	1145.9	1145.6	1145.0	1144.6	1144.1	1143.8	1143.4	1142.9	1142.5
26	1146.4	1146.0	1145.7	1145.1	1144.6	1144.3	1143.8	1143.5	1143.0	1142.6
27	1146.5	1145.9	1145.7	1145.1	1144.6	1144.2	1143.8	1143.5	1143.0	1142.5
28	1146.5	1145.9	1145.7	1145.1	1144.6	1144.3	1143.8	1143.5	1143.0	1142.6
29	1146.5	1145.9	1145.5	1145.0	1144.5	1144.1	1143.8	1143.4	1143.0	1142.5
30	1146.5	1146.1	1145.6	1145.0	1144.6	1144.1	1143.8	1143.4	1142.9	1142.5
31	1146.4	1146.0	1145.7	1145.1	1144.7	1144.2	1143.8	1143.4	1142.8	1142.4
32	1146.5	1145.9	1145.6	1145.0	1144.6	1144.2	1143.8	1143.3	1143.0	1142.5
33	1146.4	1145.8	1145.5	1145.0	1144.5	1144.1	1143.8	1143.3	1142.9	1142.5
34	1146.5	1145.9	1145.6	1145.0	1144.6	1144.2	1143.8	1143.4	1143.0	1142.5
35	1146.4	1145.9	1145.7	1145.3	1144.9	1144.4	1144.1	1143.8	1143.3	1142.5
36	1146.5	1145.9	1145.6	1145.0	1144.5	1144.1	1143.7	1143.5	1143.0	1142.5
37	1146.4	1145.9	1145.6	1144.9	1144.5	1144.0	1143.7	1143.3	1142.9	1142.5
38	1146.5	1145.9	1145.6	1145.0	1144.5	1144.1	1143.8	1143.5	1142.9	1142.5
39	1146.6	1146.1	1145.7	1145.3	1144.7	1144.4	1144.0	1143.6	1143.2	1142.7

Appendix F. Model Calibration Data

Appendix F.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table F.1 Calibration data collected in the physical model with modified cross-section with varying amounts of roughness and no bridges. High discharge. Piezometer units are cm.

	Test	40A	40B	40C	40D	40E	40F	40G
	Pump Freq. (Hz)	60.2	60.4	60.3	60.4	60.4	60.5	60.7
	Weir (cm)	89.42	89.42	89.41	89.32	89.39	89.35	89.41
	Discharge (ft^3/s)	3.813	3.813	3.811	3.797	3.808	3.802	3.811
	Water Temp (C)	19.9	20.2	20.3	20.3	20.3	20.3	20.4
	Gate Height (in)	2.88	2.50	2.38	2.50	2.75	2.50	2.50
	Gate Height (cm)	7.3025	6.35	6.0325	6.35	6.985	6.35	6.35
Location (m)	**Piezometer**	No rough	1/6 rough	2/6 rough	3/6 rough	4/6 rough	5/6 rough	full rough
-0.083	1	19.4	19.9	20.0	20.0	20.3	21.4	22.0
0.522	2	15.9	17.3	18.4	18.5	19.7	20.3	21.2
1.134	3	16.4	17.3	18.3	18.2	18.4	20.2	21.0
1.753	4	17.7	18.4	18.5	18.7	18.7	20.3	21.2
2.353	5	14.6	16.4	17.2	17.2	17.5	19.6	20.4
2.972	6	16.0	16.2	17.2	17.2	17.5	19.5	20.4
3.577	7	15.4	16.4	17.1	17.1	17.5	19.4	20.2
4.176	8	15.9	16.6	17.2	17.1	17.4	19.3	20.1
4.791	9	15.5	15.7	16.6	16.5	16.7	18.8	19.7
5.389	10	16.6	16.6	17.1	15.6	17.0	18.8	19.6
6.011	11	14.2	15.9	16.3	16.3	16.3	18.1	19.0
6.620	12	15.7	16.1	16.7	16.8	16.7	18.2	19.2
6.990	13	13.8	15.0	15.9	16.0	16.3	17.9	18.8
7.271	14	14.1	15.0	16.5	16.8	16.7	18.0	18.9
7.685	15	14.7	15.8	16.1	16.2	16.4	17.8	18.9
8.092	16	14.2	15.4	16.7	16.7	16.7	18.0	19.0
8.507	17	15.2	16.0	16.7	16.8	16.9	18.1	19.0
8.916	18	14.5	15.7	16.6	16.5	16.7	17.9	18.8
9.328	19	15.7	16.0	17.0	16.9	16.9	17.8	18.8
9.737	20	15.2	16.3	16.9	16.9	17.0	17.9	18.8
10.148	21	16.0	16.2	16.9	16.8	17.1	18.1	18.8
10.300	22	15.5	16.3	17.1	17.0	17.1	18.0	18.7
10.593	23	16.0	16.4	16.8	16.8	16.9	17.8	18.6
10.959	24	15.5	16.4	16.9	16.8	16.9	17.7	18.6
11.557	25	14.6	15.5	16.3	16.3	16.3	17.1	18.0
12.178	26	15.5	15.8	16.5	16.7	16.7	17.4	18.1
12.776	27	15.2	15.4	16.2	16.2	16.2	17.0	17.2
13.398	28	15.7	15.9	16.4	16.6	16.5	17.3	17.9
13.987	29	15.4	15.6	16.2	16.2	16.3	16.9	17.4
14.607	30	15.7	15.8	16.2	16.1	16.2	16.6	17.2
15.210	31	15.1	14.8	15.3	15.5	15.5	15.9	16.4
15.825	32	15.5	15.6	15.9	15.8	15.9	16.2	16.6
16.427	33	15.2	15.2	15.5	15.5	15.6	15.9	16.2
17.046	34	15.5	15.7	15.7	15.7	15.6	15.6	16.2
17.653	35	15.3	15.2	15.3	15.5	15.7	15.7	15.8
18.246	36	15.8	15.8	15.8	15.8	15.8	15.8	15.8
18.862	37	15.7	15.8	15.3	15.2	15.4	15.0	15.4
19.477	38	16.0	15.8	15.8	16.0	16.1	15.8	15.7
20.071	39	16.0	15.8	15.7	16.0	16.1	15.5	15.0

Table F.2 Calibration data collected in the physical model with modified cross-section with varying amounts of roughness and no bridges. Medium discharge. Piezometer units are cm.

	Test	41A	41B	41C	41D	41E	41F	41G
	Pump Freq. (Hz)	53.9	54.1	54.3	54.6	54.5	54.6	54.5
	Weir (cm)	85.14	85.18	85.28	85.43	85.38	85.43	85.23
	Discharge (ft^3/s)	3.179	3.184	3.198	3.220	3.212	3.220	3.191
	Water Temp (C)	19.9	20.2	20.4	20.3	20.3	20.4	20.5
	Gate Height (in)	2.56	2.25	2.13	2.25	2.25	2.13	2.06
	Gate Height (cm)	6.51	5.72	5.40	5.72	5.72	5.40	5.24
Location (m)	**Piezometer**	No rough	1/6 rough	2/6 rough	3/6 rough	4/6 rough	5/6 rough	full rough
-0.083	1	18.1	18.7	18.7	18.9	19.0	20.1	20.6
0.522	2	14.8	16.0	17.1	17.2	17.4	19.1	19.8
1.134	3	14.9	16.3	16.9	16.8	17.0	19.0	19.7
1.753	4	16.6	17.4	17.3	17.4	17.4	19.1	19.8
2.353	5	14.0	14.6	15.7	15.7	15.9	18.3	19.1
2.972	6	14.3	14.8	15.6	15.5	15.8	18.1	19.0
3.577	7	14.7	15.2	15.6	15.5	15.8	18.1	18.9
4.176	8	14.8	15.5	15.8	15.8	15.9	17.9	18.8
4.791	9	14.3	15.1	15.2	15.2	15.2	17.4	18.4
5.389	10	15.5	15.8	15.6	15.5	15.6	17.4	18.3
6.011	11	13.1	14.0	14.7	15.0	14.9	16.7	17.8
6.620	12	14.4	14.6	15.0	15.4	15.3	16.8	17.7
6.990	13	12.8	13.6	14.3	14.3	14.4	16.2	17.5
7.271	14	13.0	13.7	14.8	15.0	15.1	16.6	17.5
7.685	15	13.8	14.1	14.5	14.5	14.6	16.4	17.4
8.092	16	13.0	14.2	15.3	15.3	15.4	16.4	17.5
8.507	17	14.0	14.4	15.0	15.0	15.1	16.6	17.5
8.916	18	13.1	14.4	15.1	15.0	15.1	16.6	17.5
9.328	19	14.3	14.6	15.5	15.5	15.6	16.6	17.5
9.737	20	13.8	14.9	15.4	15.2	15.2	16.4	17.4
10.148	21	14.4	15.1	15.3	15.4	15.4	16.6	17.4
10.300	22	14.2	15.0	15.4	15.4	15.3	16.5	17.4
10.593	23	14.8	14.9	15.2	15.5	15.6	16.5	17.2
10.959	24	14.1	15.0	15.5	15.3	15.3	16.4	17.2
11.557	25	13.0	14.2	14.8	14.6	14.7	15.8	16.5
12.178	26	13.8	14.5	15.0	15.2	15.1	16.1	16.7
12.776	27	13.3	14.2	14.6	14.5	14.4	15.6	17.1
13.398	28	14.0	14.7	15.0	15.0	15.0	15.8	16.4
13.987	29	13.8	14.4	14.7	14.9	14.8	15.4	16.1
14.607	30	14.2	14.7	14.8	14.8	14.8	15.2	15.8
15.210	31	13.5	13.8	13.6	13.9	14.0	14.4	15.0
15.825	32	14.2	14.3	14.3	14.3	14.4	14.8	15.2
16.427	33	13.8	13.9	13.9	14.0	14.0	14.4	14.7
17.046	34	14.0	14.2	14.2	14.2	14.1	14.2	14.8
17.653	35	13.9	13.9	13.8	14.1	14.1	14.1	14.3
18.246	36	14.4	14.3	14.3	14.3	14.3	14.3	14.3
18.862	37	14.2	14.0	13.7	13.8	13.8	13.5	13.8
19.477	38	14.5	14.4	14.3	14.4	14.5	14.2	14.1
20.071	39	14.5	14.2	14.0	14.3	14.3	13.6	12.5

Table F.3 Calibration data collected in the physical model with modified cross-section with varying amounts of roughness and no bridges. Low discharge. Piezometer units are cm.

	Test	42A	42B	42C	42D	42E	42F	42G
	Pump Freq. (Hz)	48.2	48.1	48.3	48.2	48.5	48.4	48.6
	Weir (cm)	80.46	80.33	80.49	80.38	80.56	80.21	80.37
	Discharge (ft^3/s)	2.563	2.547	2.567	2.553	2.576	2.533	2.552
	Water Temp (C)	20	20.3	20.4	20.4	20.4	20.4	20.5
	Gate Height (in)	2.25	1.94	2.00	2.00	2.00	2.00	1.50
	Gate Height (cm)	5.72	4.92	5.08	5.08	5.08	5.08	3.81
Location (m)	**Piezometer**	No rough	1/6 rough	2/6 rough	3/6 rough	4/6 rough	5/6 rough	full rough
-0.083	1	16.9	17.3	17.4	17.3	17.6	18.2	19.0
0.522	2	13.9	14.4	15.6	15.5	15.8	17.2	18.2
1.134	3	13.3	14.9	15.0	14.9	15.1	17.1	18.0
1.753	4	15.2	16.2	16.0	16.0	16.0	17.2	18.2
2.353	5	13.7	13.4	14.0	13.7	13.8	16.3	17.5
2.972	6	13.4	13.8	14.1	13.9	13.9	16.4	17.4
3.577	7	13.5	14.2	14.3	14.3	14.3	16.3	17.2
4.176	8	13.7	14.4	14.5	14.5	14.5	16.0	17.1
4.791	9	12.9	13.9	13.9	13.9	14.0	15.6	16.7
5.389	10	13.8	14.2	14.2	14.3	14.3	15.7	16.6
6.011	11	12.1	12.0	12.7	12.6	12.9	14.9	16.1
6.620	12	13.3	13.0	13.2	13.2	13.3	14.9	16.1
6.990	13	11.8	12.4	12.5	12.5	12.6	14.6	15.8
7.271	14	11.7	12.2	12.8	13.1	13.0	14.8	15.9
7.685	15	12.4	12.3	12.7	12.7	12.8	14.6	15.8
8.092	16	11.7	12.6	13.3	13.4	13.5	14.7	15.9
8.507	17	12.4	12.8	13.1	13.3	13.2	14.8	15.9
8.916	18	11.5	12.8	13.3	13.2	13.4	14.7	15.8
9.328	19	12.8	13.2	13.7	13.8	13.8	14.7	15.8
9.737	20	12.5	13.3	13.6	13.7	13.5	14.7	15.7
10.148	21	12.9	13.5	13.8	13.7	13.7	14.9	15.8
10.300	22	12.7	13.4	13.8	13.9	13.8	14.8	15.7
10.593	23	13.2	13.4	13.7	13.6	13.8	14.7	15.6
10.959	24	12.8	13.5	13.8	13.7	13.7	14.6	15.5
11.557	25	11.2	12.5	13.0	13.2	13.1	14.0	15.0
12.178	26	11.9	12.8	13.3	13.4	13.5	14.4	15.1
12.776	27	11.4	12.5	13.0	12.9	13.0	13.9	15.5
13.398	28	12.5	13.2	13.4	13.4	13.4	14.1	14.8
13.987	29	12.4	13.1	13.1	13.2	13.3	13.8	14.5
14.607	30	12.8	13.0	13.1	13.0	12.9	13.6	14.2
15.210	31	10.8	12.0	12.2	12.3	12.2	12.9	13.4
15.825	32	12.5	12.8	12.9	12.9	12.8	13.2	13.6
16.427	33	12.2	12.3	12.3	12.5	12.4	12.7	13.1
17.046	34	12.4	12.6	12.6	12.7	12.4	12.7	13.2
17.653	35	12.2	12.4	12.4	12.6	12.4	12.6	12.7
18.246	36	12.7	12.7	12.7	12.7	12.7	12.7	12.7
18.862	37	12.4	12.4	12.3	12.3	12.3	11.9	12.1
19.477	38	12.8	12.7	12.8	12.9	12.9	12.6	12.4
20.071	39	12.6	12.5	12.6	12.8	12.7	12.0	9.3

Appendix F.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table F.4 Preliminary Scaled/Corrected data collected in modified cross-section with varying roughness and no bridges. High discharge. Piezometer units are ft-msl NAVD 88.

Test	40A	40B	40C	40D	40E	40F	40G
Q (ft^3/s)	11914	11914	11910	11866	11900	11880	11910
Piezometer							
1	1141.8	1142.2	1142.3	1142.3	1142.5	1143.5	1143.9
2	1138.9	1140.1	1141.0	1141.1	1142.1	1142.5	1143.3
3	1139.3	1140.1	1140.9	1140.8	1141.0	1142.5	1143.1
4	1140.4	1141.0	1141.1	1141.2	1141.2	1142.5	1143.3
5	1137.9	1139.3	1140.0	1140.0	1140.3	1142.0	1142.6
6	1139.0	1139.2	1140.0	1140.0	1140.3	1141.9	1142.6
7	1138.5	1139.3	1139.9	1139.9	1140.3	1141.8	1142.5
8	1138.9	1139.5	1140.0	1139.9	1140.2	1141.7	1142.4
9	1138.6	1138.8	1139.5	1139.4	1139.6	1141.3	1142.1
10	1139.5	1139.5	1139.9	1138.7	1139.8	1141.3	1142.0
11	1137.6	1139.0	1139.3	1139.3	1139.3	1140.8	1141.6
12	1138.9	1139.2	1139.7	1139.8	1139.7	1140.9	1141.7
13	1137.3	1138.3	1139.0	1139.1	1139.3	1140.7	1141.4
14	1137.5	1138.2	1139.4	1139.7	1139.6	1140.7	1141.4
15	1138.0	1138.9	1139.1	1139.2	1139.3	1140.5	1141.4
16	1137.5	1138.5	1139.6	1139.6	1139.6	1140.7	1141.5
17	1138.4	1139.0	1139.6	1139.7	1139.8	1140.7	1141.5
18	1137.8	1138.8	1139.5	1139.4	1139.6	1140.6	1141.3
19	1138.8	1139.0	1139.8	1139.8	1139.8	1140.5	1141.3
20	1138.4	1139.3	1139.8	1139.8	1139.8	1140.6	1141.3
21	1138.9	1139.0	1139.6	1139.5	1139.8	1140.6	1141.2
22	1138.4	1139.1	1139.8	1139.7	1139.8	1140.5	1141.1
23	1138.9	1139.2	1139.5	1139.5	1139.6	1140.3	1141.0
24	1138.4	1139.2	1139.6	1139.5	1139.6	1140.3	1141.0
25	1137.8	1138.5	1139.2	1139.2	1139.2	1139.8	1140.6
26	1138.5	1138.8	1139.3	1139.5	1139.5	1140.1	1140.7
27	1138.3	1138.4	1139.1	1139.1	1139.1	1139.8	1139.9
28	1138.7	1138.9	1139.3	1139.4	1139.3	1140.0	1140.5
29	1138.4	1138.6	1139.1	1139.1	1139.2	1139.7	1140.1
30	1138.7	1138.8	1139.1	1139.0	1139.1	1139.4	1139.9
31	1138.3	1138.0	1138.4	1138.6	1138.6	1138.9	1139.3
32	1138.6	1138.7	1138.9	1138.9	1138.9	1139.2	1139.5
33	1138.4	1138.4	1138.6	1138.6	1138.7	1138.9	1139.2
34	1138.6	1138.8	1138.8	1138.8	1138.7	1138.7	1139.2
35	1138.4	1138.4	1138.4	1138.6	1138.8	1138.8	1138.9
36	1138.8	1138.8	1138.8	1138.8	1138.8	1138.8	1138.8
37	1138.7	1138.8	1138.4	1138.3	1138.4	1138.1	1138.4
38	1138.9	1138.8	1138.8	1138.9	1139.0	1138.8	1138.7
39	1138.9	1138.8	1138.7	1138.9	1139.0	1138.5	1138.1

Table F.5 Preliminary Scaled/Corrected data collected in modified cross-section with varying roughness and no bridges. Medium discharge. Piezometer units are ft-msl NAVD 88.

Test	41A	41B	41C	41D	41E	41F	41G
Q (ft^3/s)	9934	9951	9995	10061	10039	10061	9973
Piezometer							
1	1140.7	1141.2	1141.2	1141.4	1141.5	1142.4	1142.8
2	1138.0	1139.0	1139.9	1140.0	1140.2	1141.6	1142.1
3	1138.1	1139.3	1139.8	1139.7	1139.8	1141.5	1142.1
4	1139.5	1140.2	1140.1	1140.2	1140.2	1141.6	1142.1
5	1137.4	1137.9	1138.8	1138.8	1138.9	1140.9	1141.6
6	1137.6	1138.0	1138.7	1138.6	1138.9	1140.7	1141.5
7	1138.0	1138.4	1138.7	1138.6	1138.9	1140.7	1141.4
8	1138.0	1138.6	1138.9	1138.9	1138.9	1140.6	1141.3
9	1137.6	1138.3	1138.4	1138.4	1138.4	1140.2	1141.0
10	1138.6	1138.9	1138.7	1138.6	1138.7	1140.2	1140.9
11	1136.7	1137.5	1138.0	1138.3	1138.2	1139.7	1140.6
12	1137.8	1138.0	1138.3	1138.6	1138.5	1139.8	1140.5
13	1136.5	1137.1	1137.7	1137.7	1137.8	1139.3	1140.3
14	1136.6	1137.1	1138.0	1138.2	1138.3	1139.5	1140.3
15	1137.2	1137.5	1137.8	1137.8	1137.9	1139.3	1140.2
16	1136.6	1137.5	1138.4	1138.4	1138.5	1139.3	1140.3
17	1137.4	1137.7	1138.2	1138.2	1138.3	1139.5	1140.3
18	1136.6	1137.7	1138.3	1138.2	1138.3	1139.5	1140.3
19	1137.6	1137.9	1138.6	1138.6	1138.7	1139.5	1140.3
20	1137.2	1138.1	1138.5	1138.4	1138.4	1139.3	1140.2
21	1137.5	1138.1	1138.3	1138.4	1138.4	1139.3	1140.0
22	1137.4	1138.0	1138.4	1138.4	1138.3	1139.3	1140.0
23	1137.9	1138.0	1138.2	1138.4	1138.5	1139.3	1139.8
24	1137.3	1138.0	1138.4	1138.3	1138.3	1139.2	1139.8
25	1136.5	1137.5	1138.0	1137.8	1137.9	1138.8	1139.3
26	1137.1	1137.7	1138.1	1138.3	1138.2	1139.0	1139.5
27	1136.7	1137.5	1137.8	1137.7	1137.6	1138.6	1139.8
28	1137.3	1137.9	1138.1	1138.1	1138.1	1138.8	1139.3
29	1137.1	1137.6	1137.9	1138.0	1138.0	1138.4	1139.0
30	1137.5	1137.9	1138.0	1138.0	1138.0	1138.3	1138.8
31	1137.0	1137.2	1137.1	1137.3	1137.4	1137.7	1138.2
32	1137.5	1137.6	1137.6	1137.6	1137.7	1138.0	1138.4
33	1137.2	1137.3	1137.3	1137.4	1137.4	1137.7	1138.0
34	1137.4	1137.5	1137.5	1137.5	1137.5	1137.5	1138.0
35	1137.3	1137.3	1137.2	1137.5	1137.5	1137.5	1137.6
36	1137.6	1137.5	1137.5	1137.5	1137.5	1137.5	1137.5
37	1137.5	1137.3	1137.1	1137.1	1137.1	1136.9	1137.1
38	1137.7	1137.6	1137.5	1137.6	1137.7	1137.5	1137.4
39	1137.7	1137.5	1137.3	1137.5	1137.5	1137.0	1136.1

Table F.6 Preliminary Scaled/Corrected data collected in modified cross-section with varying roughness and no bridges. Low discharge. Piezometer units are ft-msl NAVD 88.

Test	42A	42B	42C	42D	42E	42F	42G
Q (ft^3/s)	8010	7960	8022	7979	8049	7914	7975
Piezometer							
1	1139.8	1140.1	1140.2	1140.1	1140.3	1140.8	1141.5
2	1137.3	1137.7	1138.7	1138.6	1138.9	1140.0	1140.8
3	1136.8	1138.1	1138.2	1138.1	1138.3	1139.9	1140.7
4	1138.4	1139.2	1139.0	1139.0	1139.0	1140.0	1140.8
5	1137.1	1136.9	1137.4	1137.1	1137.2	1139.3	1140.3
6	1136.9	1137.2	1137.5	1137.3	1137.3	1139.3	1140.2
7	1137.0	1137.5	1137.6	1137.6	1137.6	1139.3	1140.0
8	1137.1	1137.7	1137.8	1137.8	1137.8	1139.0	1139.9
9	1136.5	1137.3	1137.3	1137.3	1137.4	1138.7	1139.6
10	1137.2	1137.5	1137.5	1137.6	1137.6	1138.8	1139.5
11	1135.9	1135.8	1136.4	1136.3	1136.6	1138.2	1139.2
12	1136.9	1136.6	1136.8	1136.8	1136.9	1138.2	1139.2
13	1135.7	1136.2	1136.2	1136.2	1136.3	1138.0	1138.9
14	1135.5	1135.9	1136.4	1136.6	1136.6	1138.0	1138.9
15	1136.1	1136.0	1136.3	1136.3	1136.4	1137.9	1138.9
16	1135.5	1136.2	1136.8	1136.9	1137.0	1138.0	1138.9
17	1136.1	1136.4	1136.6	1136.8	1136.7	1138.0	1138.9
18	1135.3	1136.4	1136.8	1136.7	1136.9	1138.0	1138.9
19	1136.4	1136.7	1137.1	1137.2	1137.2	1138.0	1138.9
20	1136.2	1136.8	1137.1	1137.1	1137.0	1138.0	1138.8
21	1136.3	1136.8	1137.1	1137.0	1137.0	1138.0	1138.7
22	1136.2	1136.7	1137.1	1137.1	1137.1	1137.9	1138.6
23	1136.6	1136.7	1137.0	1136.9	1137.1	1137.8	1138.5
24	1136.2	1136.8	1137.1	1137.0	1137.0	1137.7	1138.4
25	1135.0	1136.1	1136.5	1136.6	1136.6	1137.3	1138.1
26	1135.6	1136.3	1136.7	1136.8	1136.9	1137.6	1138.2
27	1135.2	1136.1	1136.5	1136.4	1136.5	1137.2	1138.5
28	1136.1	1136.6	1136.8	1136.8	1136.8	1137.4	1138.0
29	1136.0	1136.6	1136.6	1136.6	1136.7	1137.1	1137.7
30	1136.3	1136.5	1136.6	1136.5	1136.4	1137.0	1137.5
31	1134.8	1135.7	1135.9	1136.0	1135.9	1136.5	1136.9
32	1136.2	1136.4	1136.5	1136.5	1136.4	1136.7	1137.1
33	1135.9	1136.0	1136.0	1136.2	1136.1	1136.3	1136.6
34	1136.1	1136.2	1136.2	1136.3	1136.1	1136.3	1136.7
35	1135.9	1136.1	1136.1	1136.2	1136.1	1136.2	1136.3
36	1136.2	1136.2	1136.2	1136.2	1136.2	1136.2	1136.2
37	1136.0	1136.0	1135.9	1135.9	1135.9	1135.6	1135.7
38	1136.3	1136.2	1136.3	1136.4	1136.4	1136.2	1136.0
39	1136.2	1136.1	1136.2	1136.3	1136.2	1135.7	1133.4

Appendix G. Modified Cross Section Roughened – Without Bridges

Appendix G.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table G.1 Raw experimental data collected in the physical model with modified cross-section and with no bridges for a high flow. Piezometer units are cm.

Test	50A	50B	50C	50D	50E	50F	50G	50H	50I	50J
Pump Freq. (Hz)	60.7	60.7	60.7	60.7	60.7	60.7	60.7	60.7	60.7	60.6
Weir (cm)	89.21	89.28	89.30	89.36	89.42	89.43	89.43	89.48	89.48	89.38
Discharge (ft^3/s)	3.780	3.791	3.794	3.803	3.813	3.814	3.814	3.822	3.822	3.806
Water Temp (C)	20.5	20.5	20.5	20.6	20.7	20.8	20.8	20.8	20.8	20.9
Gate Height (in)	7.50	7.25	7.00	6.75	6.50	6.25	6.00	5.75	5.50	5.25
Gate Height (cm)	19.05	18.42	17.78	17.15	16.51	15.88	15.24	14.61	13.97	13.34
Piezometer										
1	26.5	26.1	25.6	25.3	25.0	24.6	24.2	23.8	23.5	23.3
2	26.3	25.9	25.4	25.2	24.8	24.3	23.9	23.4	23.1	22.9
3	26.2	25.8	25.4	25.1	24.7	24.2	23.8	23.3	23.0	22.7
4	26.3	25.9	25.5	25.1	24.8	24.3	23.9	23.4	23.2	22.9
5	26.1	25.7	25.2	24.9	24.5	24.0	23.5	23.0	22.7	22.4
6	26.1	25.7	25.2	24.9	24.5	23.9	23.5	23.0	22.7	22.4
7	26.1	25.7	25.2	24.9	24.5	23.9	23.6	23.0	22.7	22.4
8	26.0	25.6	25.1	24.8	24.4	23.9	23.5	23.0	22.7	22.4
9	26.0	25.6	25.0	24.7	24.3	23.8	23.3	22.8	22.5	22.1
10	26.0	25.6	25.0	24.7	24.3	23.8	23.3	22.8	22.4	22.1
11	25.8	25.4	24.9	24.5	24.1	23.5	23.0	22.5	22.2	21.8
12	25.8	25.4	24.9	24.5	24.0	23.6	23.1	22.6	22.2	21.9
13	25.7	25.3	24.8	24.5	24.0	23.5	23.0	22.5	22.1	21.7
14	25.8	25.4	24.9	24.5	24.1	23.6	23.0	22.6	22.2	21.7
15	25.8	25.4	24.8	24.5	24.0	23.5	23.0	22.5	22.1	21.7
16	25.8	25.4	24.9	24.5	24.1	23.6	23.1	22.5	22.2	21.8
17	25.8	25.3	24.8	24.5	24.0	23.5	23.0	22.5	22.1	21.7
18	25.8	25.4	24.9	24.5	24.1	23.5	23.0	22.5	22.1	21.7
19	25.8	25.3	24.8	24.5	24.0	23.6	23.0	22.5	22.1	21.7
20	25.7	25.3	24.8	24.5	24.1	23.5	23.0	22.5	22.1	21.6
21	25.9	25.4	24.9	24.5	24.1	23.5	23.0	22.6	22.2	21.7
22	25.8	25.4	24.9	24.5	24.0	23.5	23.0	22.6	22.1	21.7
23	25.8	25.4	24.8	24.5	24.0	23.6	23.0	22.5	22.1	21.7
24	25.8	25.3	24.9	24.5	24.0	23.5	23.0	22.5	22.0	21.6
25	25.7	25.2	24.7	24.3	23.9	23.3	22.8	22.3	21.9	21.4
26	25.7	25.2	24.8	24.3	24.0	23.3	22.9	22.3	21.9	21.5
27	25.6	25.2	24.7	24.2	23.8	23.3	22.7	22.2	21.8	21.3
28	25.7	25.2	24.7	24.3	23.9	23.3	22.8	22.3	21.8	21.3
29	25.4	25.1	24.7	24.2	23.8	23.2	22.7	22.2	21.7	21.2
30	25.6	25.0	24.6	24.2	23.7	23.1	22.6	22.1	21.6	21.1
31	25.3	24.8	24.3	23.9	23.4	22.8	22.2	21.8	21.2	20.7
32	25.4	24.9	24.3	23.9	23.5	23.0	22.4	21.8	21.4	20.9
33	25.3	24.8	24.2	23.9	23.4	22.8	22.3	21.7	21.2	20.7
34	25.4	24.9	24.3	23.9	23.5	22.9	22.3	21.7	21.2	20.6
35	25.4	24.8	24.3	23.9	23.4	22.8	22.3	21.6	21.1	20.6
36	25.4	25.0	24.3	23.9	23.5	22.9	22.4	21.8	21.3	20.7
37	25.4	24.8	24.3	23.8	23.4	22.8	22.2	21.6	21.1	20.5
38	25.5	25.1	24.5	24.1	23.5	23.0	22.4	21.8	21.3	20.8
39	25.7	25.2	24.7	24.2	23.7	23.2	22.7	22.1	21.6	21.0

Table G.1(Cont.) Raw experimental data collected in the physical model with modified cross-section and with no bridges for a high flow. Piezometer units are cm.

Test	50K	50L	50M	50N	50O	50P	50Q	50R	50S	50T
Pump Freq. (Hz)	60.7	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Weir (cm)	89.43	89.48	89.48	89.48	89.49	89.63	89.57	89.65	89.61	89.56
Discharge (ft^3/s)	3.814	3.822	3.822	3.822	3.824	3.846	3.836	3.849	3.842	3.835
Water Temp (C)	20.9	20.9	21.0	21.0	21.0	20.8	20.8	20.9	20.9	21.0
Gate Height (in)	5.00	4.75	4.50	4.25	4.00	3.50	3.00	2.50	2.00	0.00
Gate Height (cm)	12.70	12.07	11.43	10.80	10.16	8.89	7.62	6.35	5.08	0.00
Piezometer										
1	23.2	22.9	22.6	22.4	22.3	22.3	22.2	22.1	22.0	22.1
2	22.7	22.4	22.2	21.9	21.8	21.7	21.5	21.4	21.4	21.4
3	22.5	22.2	22.0	21.7	21.6	21.5	21.3	21.2	21.2	21.2
4	22.7	22.4	22.1	21.9	21.8	21.6	21.5	21.4	21.4	21.4
5	22.2	21.9	21.5	21.3	21.2	21.0	20.7	20.6	20.5	20.6
6	22.2	21.9	21.4	21.2	21.0	21.0	20.7	20.6	20.6	20.5
7	22.2	21.8	21.4	21.1	21.0	20.9	20.6	20.4	20.4	20.4
8	22.2	21.7	21.3	21.0	20.9	20.8	20.6	20.3	20.2	20.2
9	21.9	21.5	21.0	20.7	20.6	20.5	20.2	20.0	20.0	19.9
10	21.9	21.4	20.9	20.7	20.5	20.5	20.1	19.8	19.7	19.7
11	21.6	21.1	20.6	20.3	20.1	20.0	19.6	19.3	19.2	19.2
12	21.6	21.1	20.6	20.4	20.1	20.0	19.7	19.4	19.3	19.3
13	21.5	21.0	20.4	20.1	19.9	19.8	19.4	19.0	19.0	18.9
14	21.5	21.0	20.5	20.1	20.0	19.9	19.4	19.1	19.1	19.0
15	21.5	21.0	20.4	20.1	19.9	19.8	19.4	19.0	19.0	18.9
16	21.5	21.0	20.5	20.2	20.0	20.0	19.4	19.1	19.0	19.0
17	21.5	21.0	20.5	20.2	19.9	20.0	19.4	19.0	18.9	18.9
18	21.5	21.0	20.4	20.1	19.8	19.8	19.4	19.0	18.9	18.9
19	21.5	21.0	20.4	20.1	19.8	19.8	19.4	19.0	18.9	18.9
20	21.4	21.0	20.3	20.1	19.8	19.8	19.3	19.0	18.9	18.8
21	21.5	21.0	20.4	20.1	19.8	19.8	19.4	19.0	18.9	18.9
22	21.4	20.9	20.3	20.1	19.8	19.7	19.2	18.8	18.8	18.8
23	21.3	20.9	20.3	20.0	19.7	19.7	19.1	18.8	18.7	18.6
24	21.4	20.9	20.2	20.0	19.6	19.6	19.1	18.6	18.5	18.6
25	21.1	20.6	19.9	19.5	19.3	19.2	18.6	18.1	18.1	17.9
26	21.3	20.7	20.1	19.7	19.4	19.3	18.8	18.3	18.2	18.1
27	21.0	20.4	19.8	19.4	19.1	19.0	18.3	17.9	17.8	17.7
28	21.1	20.6	19.9	19.5	19.2	19.2	18.5	18.0	17.8	17.8
29	21.0	20.3	19.7	19.3	18.9	18.8	18.2	17.6	17.4	17.4
30	20.8	20.2	19.5	19.0	18.7	18.6	17.9	17.3	17.2	17.0
31	20.4	19.7	19.0	18.5	18.2	18.1	17.2	16.5	16.3	16.2
32	20.5	19.9	19.1	18.7	18.4	18.3	17.5	16.8	16.6	16.4
33	20.4	19.7	18.9	18.5	18.1	18.0	17.1	16.2	16.0	15.9
34	20.4	19.8	18.9	18.5	18.0	18.0	17.0	16.1	15.9	15.8
35	20.3	19.6	18.8	18.3	17.8	17.8	16.8	15.7	15.4	15.2
36	20.4	19.7	18.8	18.4	18.0	17.9	16.8	15.8	15.5	15.4
37	20.3	19.6	18.8	18.2	17.7	17.6	16.4	15.2	14.7	14.5
38	20.5	19.8	19.0	18.5	18.0	17.9	16.8	15.5	15.1	14.9
39	20.7	20.1	19.2	18.7	18.2	18.0	16.7	14.7	12.4	9.8

Table G.2 Raw experimental data collected in the physical model with modified cross-section and with no bridges for a medium flow. Piezometer units are cm.

Test	51A	51B	51C	51D	51E	51F	51G	51H	51I	51J
Pump Freq. (Hz)	54.5	54.5	54.5	54.5	54.5	54.2	54.2	54.0	54.0	54.0
Weir (cm)	85.12	85.25	85.34	85.39	85.47	85.32	85.43	85.34	85.46	85.49
Discharge (ft^3/s)	3.176	3.194	3.207	3.214	3.225	3.204	3.220	3.207	3.224	3.228
Water Temp (C)	21.1	21.1	21.0	21.0	21.0	20.9	20.9	20.9	21.0	21.0
Gate Height (in)	7.50	7.00	6.50	6.00	5.50	5.00	4.00	3.00	2.00	0.00
Gate Height (cm)	19.05	17.78	16.51	15.24	13.97	12.70	10.16	7.62	5.08	0.00
Piezometer										
1	25.6	24.8	24.0	23.1	22.3	21.7	21.0	20.6	20.6	20.6
2	25.6	24.6	23.9	22.9	22.0	21.3	20.4	20.0	19.9	19.9
3	25.5	24.5	23.8	22.8	21.8	21.2	20.2	19.8	19.7	19.7
4	25.6	24.6	23.9	22.9	22.0	21.3	20.4	19.9	19.9	19.9
5	25.4	24.4	23.6	22.6	21.6	20.8	19.8	19.2	19.2	19.1
6	25.4	24.5	23.6	22.6	21.6	20.8	19.8	19.2	19.1	19.1
7	25.4	24.4	23.6	22.5	21.6	20.8	19.7	19.1	19.0	19.0
8	25.3	24.4	23.6	22.5	21.6	20.7	19.6	19.0	18.9	18.9
9	25.2	24.3	23.5	22.4	21.4	20.5	19.3	18.6	18.6	18.5
10	25.2	24.2	23.5	22.4	21.3	20.4	19.3	18.5	18.3	18.3
11	25.1	24.2	23.3	22.1	21.1	20.2	18.8	18.0	17.8	17.8
12	25.1	24.1	23.3	22.2	21.1	20.2	18.9	18.0	17.8	17.8
13	25.0	24.1	23.2	22.1	21.0	20.1	18.7	17.8	17.5	17.5
14	25.1	24.2	23.3	22.1	21.0	20.1	18.7	17.8	17.6	17.6
15	25.1	24.1	23.3	22.1	21.0	20.1	18.6	17.8	17.5	17.5
16	25.1	24.1	23.3	22.1	21.1	20.1	18.8	17.8	17.6	17.6
17	25.1	24.1	23.2	22.1	21.0	20.1	18.7	17.8	17.6	17.6
18	25.1	24.2	23.2	22.1	21.0	20.1	18.7	17.7	17.5	17.5
19	25.1	24.1	23.3	22.1	21.0	20.0	18.6	17.7	17.5	17.5
20	25.1	24.1	23.2	22.0	21.0	20.0	18.7	17.6	17.4	17.4
21	25.2	24.2	23.3	22.1	21.1	20.2	18.7	17.8	17.5	17.5
22	25.2	24.1	23.3	22.1	21.0	20.0	18.5	17.6	17.3	17.5
23	25.1	24.1	23.3	22.1	21.0	20.0	18.6	17.5	17.3	17.3
24	25.1	24.1	23.2	22.1	21.0	20.0	18.5	17.5	17.2	17.1
25	25.0	24.0	23.1	21.9	20.8	19.8	18.2	17.0	16.6	16.6
26	25.0	24.0	23.2	22.0	20.9	19.9	18.3	17.1	16.7	16.7
27	25.0	24.0	23.1	21.9	20.7	19.7	18.0	16.7	16.3	16.3
28	25.0	24.0	23.1	21.9	20.8	19.8	18.2	16.9	16.4	16.4
29	24.9	23.9	23.0	21.8	20.7	19.6	17.9	16.5	16.0	16.0
30	24.9	23.9	23.0	21.7	20.6	19.5	17.7	16.3	15.8	15.8
31	24.7	23.7	22.7	21.4	20.2	19.2	17.3	15.6	15.0	14.9
32	24.7	23.7	22.8	21.5	20.3	19.3	17.4	15.8	15.2	15.1
33	24.7	23.7	22.8	21.5	20.2	19.2	17.2	15.4	14.7	14.6
34	24.7	23.7	22.7	21.5	20.2	19.1	17.2	15.4	14.5	14.4
35	24.7	23.6	22.7	21.4	20.2	19.0	17.0	15.1	14.1	14.0
36	24.7	23.7	22.8	21.5	20.3	19.2	17.2	15.3	14.2	14.1
37	24.7	23.7	22.7	21.5	20.1	19.0	16.9	14.8	13.5	13.3
38	24.8	23.8	22.8	21.6	20.4	19.2	17.2	15.1	13.8	13.6
39	25.0	23.9	23.0	21.8	20.6	19.5	17.4	15.0	11.2	8.8

Table G.3 Raw experimental data collected in the physical model with modified cross-section and with no bridges for a low flow. Piezometer units are cm.

Test	52A	52B	52C	52D	52E	52F	52G	52H	52I	52J
Pump Freq. (Hz)	48.9	48.9	48.9	48.9	48.4	48.4	48.0	48.0	48.0	48.0
Weir (cm)	80.22	80.32	80.46	80.59	80.29	80.53	80.32	80.43	80.39	80.50
Discharge (ft^3/s)	2.534	2.546	2.563	2.579	2.542	2.572	2.546	2.560	2.555	2.568
Water Temp (C)	20.9	20.9	20.9	20.9	20.8	20.8	20.8	20.8	20.8	20.8
Gate Height (in)	8.50	8.00	7.50	7.00	6.00	5.00	4.00	3.00	2.00	0.00
Gate Height (cm)	21.59	20.32	19.05	17.78	15.24	12.70	10.16	7.62	5.08	0.00
Piezometer										
1	25.8	25.0	24.2	23.4	21.7	20.4	19.4	19.1	19.0	19.0
2	25.7	25.0	24.1	23.2	21.4	20.0	18.8	18.3	18.2	18.2
3	25.6	24.9	24.0	23.2	21.3	19.9	18.7	18.1	18.0	18.0
4	25.7	24.9	24.1	23.3	21.4	20.0	18.8	18.3	18.2	18.1
5	25.6	24.8	24.0	23.0	21.2	19.6	18.3	17.6	17.4	17.4
6	25.6	24.8	24.0	23.0	21.2	19.6	18.2	17.6	17.4	17.4
7	25.6	24.8	24.0	23.1	21.1	19.5	18.2	17.5	17.3	17.3
8	25.6	24.8	24.0	23.1	21.1	19.5	18.1	17.3	17.2	17.1
9	25.5	24.8	24.0	23.0	21.0	19.4	17.8	17.1	16.8	16.7
10	25.5	24.8	24.0	23.0	21.0	19.3	17.8	17.0	16.8	16.7
11	25.4	24.7	23.8	22.7	20.8	19.1	17.4	16.5	16.1	16.1
12	25.4	24.6	23.8	22.8	20.8	19.1	17.5	16.5	16.2	16.2
13	25.3	24.6	23.8	22.8	20.8	19.0	17.3	16.2	15.8	15.8
14	25.4	24.6	23.8	22.8	20.7	19.0	17.3	16.3	16.0	16.0
15	25.3	24.6	23.8	22.8	20.7	18.9	17.2	16.3	15.9	15.9
16	25.4	24.6	23.8	22.8	20.8	19.0	17.4	16.4	16.0	15.9
17	25.3	24.6	23.7	22.8	20.7	19.0	17.3	16.3	16.0	15.9
18	25.3	24.6	23.8	22.8	20.8	19.0	17.3	16.2	15.8	15.8
19	25.3	24.6	23.8	22.8	20.8	19.0	17.3	16.3	15.8	15.8
20	25.3	24.6	23.7	22.8	20.8	19.0	17.3	16.2	15.7	15.7
21	25.4	24.7	23.8	22.8	20.9	19.1	17.4	16.3	15.9	15.8
22	25.4	24.6	23.8	22.8	20.8	19.0	17.3	16.1	15.6	15.6
23	25.4	24.6	23.7	22.7	20.8	19.0	17.3	16.1	15.7	15.7
24	25.4	24.6	23.7	22.8	20.7	18.9	17.2	15.9	15.4	15.4
25	25.4	24.6	23.6	22.7	20.7	18.8	17.0	15.7	15.0	15.0
26	25.4	24.6	23.7	22.8	20.8	18.9	17.1	15.7	15.2	15.2
27	25.3	24.5	23.6	22.7	20.6	18.7	16.8	15.4	14.8	14.8
28	25.3	24.5	23.7	22.7	20.7	18.8	16.9	15.5	14.8	14.8
29	25.3	24.5	23.6	22.7	20.6	18.6	16.8	15.3	14.6	14.5
30	25.3	24.5	23.6	22.6	20.5	18.6	16.6	15.1	14.3	14.2
31	25.0	24.2	23.3	22.4	20.2	18.2	16.2	14.4	13.5	13.4
32	25.1	24.3	23.4	22.4	20.3	18.3	16.3	14.7	13.7	13.6
33	25.1	24.3	23.4	22.4	20.3	18.2	16.1	14.3	13.2	13.1
34	25.1	24.3	23.4	22.4	20.3	18.2	16.1	14.3	13.1	13.0
35	25.2	24.3	23.4	22.4	20.2	18.2	16.1	14.1	12.8	12.7
36	25.2	24.4	23.4	22.5	20.3	18.2	16.2	14.2	12.8	12.8
37	25.1	24.3	23.4	22.4	20.3	18.2	15.9	13.9	12.2	11.9
38	25.2	24.5	23.5	22.5	20.4	18.3	16.2	14.2	12.5	12.4
39	25.3	24.5	23.6	22.6	20.5	18.5	16.3	14.1	10.7	7.9

Appendix G.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table G.4 Scaled/Corrected data collected in modified cross-section and with no bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	50A	50B	50C	50D	50E	50F	50G	50H	50I	50J
Discharge (ft^3/s)	11812	11846	11856	11885	11914	11919	11919	11944	11944	11895
Piezometer										
1	1147.6	1147.3	1146.9	1146.6	1146.4	1146.1	1145.7	1145.4	1145.2	1145.0
2	1147.5	1147.1	1146.7	1146.6	1146.2	1145.8	1145.5	1145.1	1144.8	1144.7
3	1147.4	1147.1	1146.7	1146.5	1146.2	1145.7	1145.4	1145.0	1144.8	1144.5
4	1147.5	1147.1	1146.8	1146.5	1146.2	1145.8	1145.5	1145.1	1144.9	1144.7
5	1147.3	1147.0	1146.6	1146.3	1146.0	1145.6	1145.2	1144.8	1144.5	1144.3
6	1147.3	1147.0	1146.6	1146.3	1146.0	1145.5	1145.2	1144.8	1144.5	1144.3
7	1147.3	1147.0	1146.6	1146.3	1146.0	1145.5	1145.3	1144.8	1144.5	1144.3
8	1147.2	1146.9	1146.5	1146.2	1145.9	1145.5	1145.2	1144.8	1144.5	1144.3
9	1147.2	1146.9	1146.4	1146.2	1145.8	1145.4	1145.0	1144.6	1144.4	1144.0
10	1147.2	1146.9	1146.4	1146.2	1145.8	1145.4	1145.0	1144.6	1144.3	1144.0
11	1147.1	1146.8	1146.4	1146.1	1145.7	1145.3	1144.8	1144.4	1144.2	1143.9
12	1147.1	1146.8	1146.4	1146.1	1145.7	1145.3	1144.9	1144.5	1144.2	1143.9
13	1147.1	1146.7	1146.3	1146.1	1145.7	1145.3	1144.8	1144.4	1144.1	1143.8
14	1147.1	1146.7	1146.3	1146.0	1145.7	1145.3	1144.8	1144.4	1144.1	1143.7
15	1147.1	1146.7	1146.2	1146.0	1145.6	1145.2	1144.8	1144.4	1144.0	1143.7
16	1147.1	1146.7	1146.3	1146.0	1145.7	1145.3	1144.8	1144.4	1144.1	1143.8
17	1147.1	1146.6	1146.2	1146.0	1145.6	1145.2	1144.8	1144.4	1144.0	1143.7
18	1147.1	1146.7	1146.3	1146.0	1145.7	1145.2	1144.8	1144.4	1144.0	1143.7
19	1147.1	1146.6	1146.2	1146.0	1145.6	1145.3	1144.8	1144.4	1144.0	1143.7
20	1147.0	1146.6	1146.2	1146.0	1145.7	1145.2	1144.8	1144.4	1144.0	1143.6
21	1147.0	1146.6	1146.2	1145.8	1145.5	1145.0	1144.6	1144.3	1143.9	1143.5
22	1146.9	1146.6	1146.2	1145.8	1145.4	1145.0	1144.6	1144.3	1143.9	1143.5
23	1146.9	1146.6	1146.1	1145.8	1145.4	1145.1	1144.6	1144.2	1143.9	1143.5
24	1146.9	1146.5	1146.2	1145.8	1145.4	1145.0	1144.6	1144.2	1143.8	1143.5
25	1146.9	1146.5	1146.1	1145.7	1145.4	1144.9	1144.5	1144.1	1143.8	1143.4
26	1146.9	1146.5	1146.2	1145.7	1145.5	1144.9	1144.6	1144.1	1143.8	1143.5
27	1146.8	1146.5	1146.1	1145.7	1145.3	1144.9	1144.4	1144.0	1143.7	1143.3
28	1146.9	1146.5	1146.1	1145.7	1145.4	1144.9	1144.5	1144.1	1143.7	1143.3
29	1146.6	1146.4	1146.1	1145.7	1145.3	1144.8	1144.4	1144.0	1143.6	1143.2
30	1146.8	1146.3	1146.0	1145.7	1145.3	1144.8	1144.4	1143.9	1143.5	1143.1
31	1146.6	1146.2	1145.8	1145.5	1145.1	1144.6	1144.1	1143.8	1143.3	1142.9
32	1146.7	1146.3	1145.8	1145.5	1145.2	1144.8	1144.3	1143.8	1143.5	1143.0
33	1146.6	1146.2	1145.7	1145.5	1145.1	1144.6	1144.2	1143.7	1143.3	1142.9
34	1146.7	1146.3	1145.8	1145.5	1145.2	1144.7	1144.2	1143.7	1143.3	1142.8
35	1146.7	1146.2	1145.8	1145.5	1145.1	1144.6	1144.2	1143.6	1143.2	1142.8
36	1146.6	1146.3	1145.7	1145.4	1145.1	1144.6	1144.2	1143.7	1143.3	1142.8
37	1146.6	1146.2	1145.7	1145.3	1145.0	1144.5	1144.0	1143.5	1143.1	1142.6
38	1146.7	1146.4	1145.9	1145.6	1145.1	1144.7	1144.2	1143.7	1143.3	1142.9
39	1146.9	1146.5	1146.1	1145.7	1145.3	1144.8	1144.4	1143.9	1143.5	1143.0

Table G.4(Cont.) Scaled/Corrected data collected in modified cross-section and with no bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	50K	50L	50M	50N	50O	50P	50Q	50R	50S	50T
Discharge (ft^3/s)	11919	11944	11944	11944	11949	12017	11988	12027	12007	11983
Piezometer										
1	1144.9	1144.7	1144.4	1144.3	1144.2	1144.2	1144.1	1144.0	1143.9	1144.0
2	1144.5	1144.3	1144.1	1143.9	1143.8	1143.7	1143.5	1143.5	1143.5	1143.5
3	1144.4	1144.1	1143.9	1143.7	1143.6	1143.5	1143.4	1143.3	1143.3	1143.3
4	1144.5	1144.3	1144.0	1143.9	1143.8	1143.6	1143.5	1143.5	1143.5	1143.5
5	1144.1	1143.9	1143.5	1143.4	1143.3	1143.1	1142.9	1142.8	1142.7	1142.8
6	1144.1	1143.9	1143.5	1143.3	1143.1	1143.1	1142.9	1142.8	1142.8	1142.7
7	1144.1	1143.8	1143.5	1143.2	1143.1	1143.0	1142.8	1142.6	1142.6	1142.6
8	1144.1	1143.7	1143.4	1143.1	1143.0	1143.0	1142.8	1142.5	1142.5	1142.5
9	1143.9	1143.5	1143.1	1142.9	1142.8	1142.7	1142.5	1142.3	1142.3	1142.2
10	1143.9	1143.5	1143.0	1142.9	1142.7	1142.7	1142.4	1142.1	1142.1	1142.1
11	1143.7	1143.3	1142.9	1142.6	1142.5	1142.4	1142.1	1141.8	1141.7	1141.7
12	1143.7	1143.3	1142.9	1142.7	1142.5	1142.4	1142.1	1141.9	1141.8	1141.8
13	1143.6	1143.2	1142.7	1142.5	1142.3	1142.2	1141.9	1141.6	1141.6	1141.5
14	1143.5	1143.1	1142.7	1142.4	1142.3	1142.2	1141.8	1141.6	1141.6	1141.5
15	1143.5	1143.1	1142.6	1142.4	1142.2	1142.1	1141.8	1141.5	1141.5	1141.4
16	1143.5	1143.1	1142.7	1142.5	1142.3	1142.3	1141.8	1141.6	1141.5	1141.5
17	1143.5	1143.1	1142.7	1142.5	1142.2	1142.3	1141.8	1141.5	1141.4	1141.4
18	1143.5	1143.1	1142.6	1142.4	1142.1	1142.1	1141.8	1141.5	1141.4	1141.4
19	1143.5	1143.1	1142.6	1142.4	1142.1	1142.1	1141.8	1141.5	1141.4	1141.4
20	1143.5	1143.1	1142.5	1142.4	1142.1	1142.1	1141.7	1141.5	1141.4	1141.3
21	1143.4	1143.0	1142.5	1142.2	1142.0	1142.0	1141.6	1141.3	1141.2	1141.2
22	1143.3	1142.9	1142.4	1142.2	1142.0	1141.9	1141.5	1141.2	1141.2	1141.2
23	1143.2	1142.9	1142.4	1142.1	1141.9	1141.9	1141.4	1141.2	1141.1	1141.0
24	1143.3	1142.9	1142.3	1142.1	1141.8	1141.8	1141.4	1141.0	1140.9	1141.0
25	1143.1	1142.7	1142.1	1141.8	1141.6	1141.6	1141.1	1140.7	1140.7	1140.5
26	1143.3	1142.8	1142.3	1142.0	1141.7	1141.6	1141.2	1140.8	1140.7	1140.7
27	1143.0	1142.5	1142.1	1141.7	1141.5	1141.4	1140.8	1140.5	1140.4	1140.3
28	1143.1	1142.7	1142.1	1141.8	1141.6	1141.6	1141.0	1140.6	1140.4	1140.4
29	1143.0	1142.5	1142.0	1141.6	1141.3	1141.2	1140.7	1140.3	1140.1	1140.1
30	1142.9	1142.4	1141.8	1141.4	1141.2	1141.1	1140.5	1140.0	1139.9	1139.8
31	1142.6	1142.1	1141.5	1141.1	1140.8	1140.7	1140.0	1139.4	1139.3	1139.2
32	1142.7	1142.2	1141.6	1141.2	1141.0	1140.9	1140.3	1139.7	1139.5	1139.3
33	1142.6	1142.1	1141.4	1141.1	1140.7	1140.7	1139.9	1139.2	1139.0	1138.9
34	1142.6	1142.1	1141.4	1141.1	1140.7	1140.7	1139.8	1139.1	1138.9	1138.9
35	1142.5	1142.0	1141.3	1140.9	1140.5	1140.5	1139.7	1138.8	1138.5	1138.4
36	1142.5	1142.0	1141.2	1140.9	1140.6	1140.5	1139.6	1138.8	1138.5	1138.4
37	1142.5	1141.9	1141.2	1140.7	1140.3	1140.3	1139.3	1138.3	1137.9	1137.7
38	1142.6	1142.1	1141.4	1141.0	1140.6	1140.5	1139.6	1138.5	1138.2	1138.0
39	1142.8	1142.3	1141.6	1141.2	1140.7	1140.6	1139.5	1137.9	1136.0	1133.9

Table G.5 Scaled/Corrected data collected in modified cross-section and with no bridges for a medium flow. Piezometer units are ft-msl NAVD 88.

Test	51A	51B	51C	51D	51E	51F	51G	51H	51I	51J
Discharge (ft^3/s)	9925	9982	10021	10043	10079	10013	10061	10021	10074	10088
Piezometer										
1	1146.9	1146.2	1145.6	1144.8	1144.2	1143.7	1143.1	1142.8	1142.8	1142.8
2	1146.9	1146.1	1145.5	1144.7	1143.9	1143.4	1142.6	1142.3	1142.2	1142.2
3	1146.8	1146.0	1145.4	1144.6	1143.8	1143.3	1142.5	1142.1	1142.1	1142.1
4	1146.9	1146.1	1145.5	1144.7	1143.9	1143.4	1142.6	1142.2	1142.2	1142.2
5	1146.7	1145.9	1145.3	1144.4	1143.6	1143.0	1142.1	1141.6	1141.6	1141.6
6	1146.7	1146.0	1145.3	1144.4	1143.6	1143.0	1142.1	1141.6	1141.6	1141.6
7	1146.7	1145.9	1145.3	1144.4	1143.6	1143.0	1142.1	1141.6	1141.5	1141.5
8	1146.6	1145.9	1145.3	1144.4	1143.6	1142.9	1142.0	1141.5	1141.4	1141.4
9	1146.6	1145.8	1145.2	1144.3	1143.5	1142.7	1141.7	1141.2	1141.2	1141.1
10	1146.6	1145.7	1145.2	1144.3	1143.4	1142.6	1141.7	1141.1	1140.9	1140.9
11	1146.6	1145.8	1145.1	1144.1	1143.3	1142.5	1141.4	1140.7	1140.6	1140.6
12	1146.6	1145.7	1145.1	1144.2	1143.3	1142.5	1141.5	1140.7	1140.6	1140.6
13	1146.5	1145.7	1145.0	1144.1	1143.2	1142.5	1141.3	1140.6	1140.3	1140.3
14	1146.5	1145.7	1145.0	1144.0	1143.1	1142.4	1141.2	1140.5	1140.3	1140.3
15	1146.5	1145.7	1145.0	1144.0	1143.1	1142.4	1141.2	1140.5	1140.3	1140.3
16	1146.5	1145.7	1145.0	1144.0	1143.2	1142.4	1141.3	1140.5	1140.3	1140.3
17	1146.5	1145.7	1144.9	1144.0	1143.1	1142.4	1141.2	1140.5	1140.3	1140.3
18	1146.5	1145.7	1144.9	1144.0	1143.1	1142.4	1141.2	1140.4	1140.3	1140.3
19	1146.5	1145.7	1145.0	1144.0	1143.1	1142.3	1141.2	1140.4	1140.3	1140.3
20	1146.5	1145.7	1144.9	1143.9	1143.1	1142.3	1141.2	1140.3	1140.2	1140.2
21	1146.4	1145.6	1144.8	1143.9	1143.0	1142.3	1141.1	1140.3	1140.1	1140.1
22	1146.4	1145.5	1144.8	1143.9	1143.0	1142.1	1140.9	1140.2	1139.9	1140.1
23	1146.3	1145.5	1144.8	1143.9	1143.0	1142.1	1141.0	1140.1	1139.9	1139.9
24	1146.3	1145.5	1144.8	1143.9	1143.0	1142.1	1140.9	1140.1	1139.8	1139.8
25	1146.3	1145.5	1144.8	1143.8	1142.9	1142.1	1140.7	1139.8	1139.4	1139.4
26	1146.3	1145.5	1144.8	1143.9	1143.0	1142.1	1140.8	1139.8	1139.5	1139.5
27	1146.3	1145.5	1144.8	1143.8	1142.8	1142.0	1140.6	1139.5	1139.2	1139.2
28	1146.3	1145.5	1144.8	1143.8	1142.9	1142.1	1140.7	1139.7	1139.3	1139.3
29	1146.2	1145.4	1144.7	1143.7	1142.8	1141.9	1140.5	1139.3	1138.9	1138.9
30	1146.2	1145.4	1144.7	1143.6	1142.7	1141.8	1140.3	1139.2	1138.8	1138.8
31	1146.2	1145.3	1144.5	1143.5	1142.5	1141.6	1140.1	1138.7	1138.2	1138.1
32	1146.2	1145.3	1144.6	1143.5	1142.5	1141.7	1140.2	1138.9	1138.4	1138.3
33	1146.2	1145.3	1144.6	1143.5	1142.5	1141.6	1140.0	1138.5	1138.0	1137.9
34	1146.2	1145.3	1144.5	1143.5	1142.5	1141.6	1140.0	1138.5	1137.8	1137.7
35	1146.2	1145.3	1144.5	1143.5	1142.5	1141.5	1139.8	1138.3	1137.5	1137.4
36	1146.1	1145.3	1144.5	1143.5	1142.5	1141.6	1139.9	1138.4	1137.5	1137.4
37	1146.1	1145.3	1144.4	1143.5	1142.3	1141.4	1139.7	1138.0	1136.9	1136.7
38	1146.2	1145.3	1144.5	1143.5	1142.5	1141.6	1139.9	1138.2	1137.1	1137.0
39	1146.3	1145.4	1144.7	1143.7	1142.7	1141.8	1140.1	1138.1	1135.0	1133.0

Table G.6 Scaled/Corrected data collected in modified cross-section and with no bridges for a low flow. Piezometer units are ft-msl NAVD 88.

Test	52A	52B	52C	52D	52E	52F	52G	52H	52I	52J
Discharge (ft^3/s)	7918	7956	8010	8060	7945	8037	7956	7998	7983	8025
Piezometer										
1	1147.1	1146.4	1145.7	1145.1	1143.7	1142.6	1141.8	1141.6	1141.5	1141.5
2	1147.0	1146.4	1145.7	1144.9	1143.5	1142.3	1141.3	1140.9	1140.8	1140.8
3	1146.9	1146.3	1145.6	1144.9	1143.4	1142.2	1141.2	1140.7	1140.7	1140.7
4	1147.0	1146.3	1145.7	1145.0	1143.5	1142.3	1141.3	1140.9	1140.8	1140.7
5	1146.9	1146.2	1145.6	1144.8	1143.3	1142.0	1140.9	1140.3	1140.2	1140.2
6	1146.9	1146.2	1145.6	1144.8	1143.3	1142.0	1140.8	1140.3	1140.2	1140.2
7	1146.9	1146.2	1145.6	1144.8	1143.2	1141.9	1140.8	1140.3	1140.1	1140.1
8	1146.9	1146.2	1145.6	1144.8	1143.2	1141.9	1140.7	1140.1	1140.0	1139.9
9	1146.8	1146.2	1145.6	1144.8	1143.1	1141.8	1140.5	1139.9	1139.7	1139.6
10	1146.8	1146.2	1145.6	1144.8	1143.1	1141.7	1140.5	1139.8	1139.7	1139.6
11	1146.8	1146.2	1145.5	1144.6	1143.0	1141.6	1140.3	1139.5	1139.2	1139.2
12	1146.8	1146.2	1145.5	1144.7	1143.0	1141.6	1140.3	1139.5	1139.3	1139.3
13	1146.7	1146.2	1145.5	1144.7	1143.0	1141.6	1140.2	1139.3	1138.9	1138.9
14	1146.7	1146.1	1145.4	1144.6	1142.9	1141.5	1140.1	1139.3	1139.0	1139.0
15	1146.6	1146.1	1145.4	1144.6	1142.9	1141.4	1140.0	1139.3	1138.9	1138.9
16	1146.7	1146.1	1145.4	1144.6	1143.0	1141.5	1140.2	1139.3	1139.0	1138.9
17	1146.6	1146.1	1145.3	1144.6	1142.9	1141.5	1140.1	1139.3	1139.0	1138.9
18	1146.6	1146.1	1145.4	1144.6	1143.0	1141.5	1140.1	1139.2	1138.9	1138.9
19	1146.6	1146.1	1145.4	1144.6	1143.0	1141.5	1140.1	1139.3	1138.9	1138.9
20	1146.6	1146.1	1145.3	1144.6	1143.0	1141.5	1140.1	1139.2	1138.8	1138.8
21	1146.6	1146.0	1145.3	1144.4	1142.9	1141.4	1140.0	1139.1	1138.8	1138.7
22	1146.6	1145.9	1145.3	1144.4	1142.8	1141.3	1139.9	1138.9	1138.5	1138.5
23	1146.6	1145.9	1145.2	1144.4	1142.8	1141.3	1139.9	1138.9	1138.6	1138.6
24	1146.6	1145.9	1145.2	1144.4	1142.7	1141.2	1139.8	1138.8	1138.4	1138.4
25	1146.6	1146.0	1145.2	1144.4	1142.8	1141.2	1139.8	1138.7	1138.1	1138.1
26	1146.6	1146.0	1145.3	1144.5	1142.9	1141.3	1139.8	1138.7	1138.3	1138.3
27	1146.6	1145.9	1145.2	1144.4	1142.7	1141.2	1139.6	1138.4	1138.0	1138.0
28	1146.6	1145.9	1145.3	1144.4	1142.8	1141.2	1139.7	1138.5	1138.0	1138.0
29	1146.6	1145.9	1145.2	1144.4	1142.7	1141.1	1139.6	1138.4	1137.8	1137.7
30	1146.6	1145.9	1145.2	1144.4	1142.6	1141.1	1139.4	1138.2	1137.5	1137.5
31	1146.4	1145.7	1145.0	1144.3	1142.5	1140.8	1139.2	1137.7	1137.0	1136.9
32	1146.5	1145.8	1145.1	1144.3	1142.5	1140.9	1139.3	1138.0	1137.1	1137.1
33	1146.5	1145.8	1145.1	1144.3	1142.5	1140.8	1139.1	1137.6	1136.7	1136.6
34	1146.5	1145.8	1145.1	1144.3	1142.5	1140.8	1139.1	1137.6	1136.6	1136.6
35	1146.6	1145.8	1145.1	1144.3	1142.5	1140.8	1139.1	1137.5	1136.4	1136.3
36	1146.5	1145.8	1145.0	1144.3	1142.5	1140.7	1139.1	1137.5	1136.3	1136.3
37	1146.4	1145.7	1145.0	1144.2	1142.5	1140.7	1138.9	1137.2	1135.8	1135.6
38	1146.5	1145.9	1145.1	1144.3	1142.5	1140.8	1139.1	1137.5	1136.1	1136.0
39	1146.6	1145.9	1145.2	1144.4	1142.6	1141.0	1139.2	1137.4	1134.6	1132.3

Appendix H. Modified Cross Section Roughened – With Bridges

Appendix H.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table H.1 Raw experimental data collected in the physical model with modified cross-section and with bridges for a high flow. Piezometer units are cm.

Test	60A	60B	60C	60D	60E	60F	60G	60H	60I	60J
Pump Freq. (Hz)	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Weir (cm)	89.35	89.27	89.30	89.30	89.34	89.32	89.39	89.39	89.41	89.41
Discharge (ft^3/s)	3.802	3.789	3.794	3.794	3.800	3.797	3.808	3.808	3.811	3.811
Water Temp (C)	21.0	21.1	21.1	21.2	21.0	21.1	21.1	21.1	21.2	21.2
Gate Height (in)	7.38	7.25	6.88	6.75	6.50	6.25	6.00	5.75	5.50	5.25
Gate Height (cm)	18.73	18.42	17.46	17.15	16.51	15.88	15.24	14.61	13.97	13.34
Piezometer										
1	26.7	26.4	25.9	25.5	25.3	24.9	24.6	24.2	24.0	23.8
2	26.6	26.2	25.7	25.4	25.1	24.7	24.4	24.0	23.7	23.4
3	26.5	26.1	25.5	25.3	25.0	24.6	24.2	23.8	23.6	23.3
4	26.6	26.2	25.6	25.4	24.9	24.7	24.3	24.0	23.7	23.4
5	26.3	26.0	25.4	25.1	24.9	24.4	24.0	23.6	23.3	22.9
6	26.4	26.0	25.4	25.1	24.9	24.4	24.0	23.6	23.3	22.9
7	26.3	26.0	25.4	25.0	24.8	24.4	24.0	23.6	23.3	22.9
8	26.3	26.0	25.3	25.0	24.8	24.3	23.9	23.5	23.2	22.9
9	26.2	25.9	25.2	24.9	24.7	24.2	23.9	23.4	23.1	22.7
10	26.2	25.8	25.2	24.9	24.7	24.2	23.8	23.4	23.1	22.7
11	26.1	25.7	25.1	24.8	24.5	24.0	23.6	23.1	22.8	22.4
12	26.1	25.7	25.0	24.8	24.5	24.0	23.7	23.1	22.9	22.4
13	26.0	25.6	25.0	24.7	24.4	23.9	23.6	23.0	22.8	22.3
14	26.1	25.7	25.0	24.8	24.5	24.0	23.6	23.1	22.8	22.4
15	26.1	25.7	25.1	24.8	24.5	24.0	23.6	23.2	22.8	22.3
16	25.9	25.5	24.9	24.6	24.3	23.7	23.3	22.8	22.5	22.1
17	26.0	25.6	24.9	24.6	24.3	23.7	23.3	22.8	22.6	22.1
18	25.8	25.4	24.7	24.4	24.1	23.6	23.1	22.6	22.3	21.8
19	25.8	25.4	24.7	24.4	24.1	23.6	23.1	22.6	22.2	21.7
20	25.9	25.4	24.8	24.4	24.1	23.6	23.1	22.6	22.2	21.7
21	25.9	25.4	24.8	24.4	24.2	23.6	23.2	22.7	22.3	21.8
22	25.8	25.4	24.8	24.4	24.1	23.6	23.1	22.6	22.2	21.8
23	25.8	25.4	24.8	24.4	24.1	23.6	23.1	22.6	22.2	21.7
24	25.7	25.4	24.7	24.3	24.1	23.5	23.0	22.5	22.1	21.6
25	25.7	25.3	24.6	24.2	23.9	23.3	22.9	22.3	22.0	21.4
26	25.7	25.3	24.7	24.3	24.1	23.5	23.0	22.5	22.1	21.6
27	25.6	25.2	24.7	24.2	23.9	23.3	22.8	22.2	21.9	21.3
28	25.7	25.3	24.6	24.2	23.9	23.3	22.8	22.3	21.9	21.4
29	25.6	25.2	24.5	24.1	23.8	23.2	22.8	22.2	21.8	21.2
30	25.5	25.1	24.4	24.0	23.7	23.1	22.7	22.1	21.6	21.0
31	25.2	24.8	24.1	23.7	23.4	22.8	22.3	21.7	21.3	20.6
32	25.3	24.9	24.2	23.9	23.6	22.9	22.4	21.9	21.4	20.8
33	25.3	24.8	24.2	23.8	23.5	22.8	22.3	21.7	21.3	20.5
34	25.3	24.9	24.1	23.8	23.5	22.8	22.3	21.8	21.2	20.6
35	25.3	24.9	24.2	23.7	23.5	22.7	22.3	21.7	21.2	20.6
36	25.4	25.0	24.3	23.9	23.5	22.9	22.4	21.8	21.3	20.7
37	25.3	24.9	24.2	23.8	23.5	22.8	22.3	21.7	21.2	20.5
38	25.5	25.0	24.4	24.0	23.7	23.0	22.4	21.9	21.4	20.8
39	25.6	25.2	24.6	24.2	23.9	23.2	22.7	22.2	21.8	21.1

Table H.1(Cont.) Raw experimental data collected in the physical model with modified cross-section and with bridges for a high flow. Piezometer units are cm.

Test	60K	60L	60M	60N	60O	60P	60Q	60R	60S	60T
Pump Freq. (Hz)	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Weir (cm)	89.51	89.44	89.44	89.44	89.49	89.38	89.39	89.43	89.44	89.41
Discharge (ft^3/s)	3.827	3.816	3.816	3.816	3.824	3.806	3.808	3.814	3.816	3.811
Water Temp (C)	21.1	21.1	21.2	21.2	21.2	21.3	21.4	21.4	21.4	21.5
Gate Height (in)	5.13	4.75	4.38	4.13	4.00	3.88	3.25	2.75	2.50	0.00
Gate Height (cm)	13.02	12.07	11.11	10.48	10.16	9.84	8.26	6.99	6.35	0.00
Piezometer										
1	23.6	23.3	23.0	22.9	22.9	22.8	22.7	22.5	22.5	22.5
2	23.2	22.9	22.6	22.4	22.3	22.3	22.0	21.9	21.9	21.9
3	23.0	22.8	22.5	22.3	22.2	22.1	21.9	21.7	21.7	21.7
4	23.1	22.7	22.5	22.3	22.1	22.1	21.9	21.7	21.7	21.7
5	22.7	22.3	22.1	21.9	21.7	21.7	21.4	21.3	21.2	21.2
6	22.7	22.4	22.1	21.9	21.7	21.7	21.4	21.2	21.2	21.2
7	22.7	22.4	22.1	21.9	21.7	21.7	21.4	21.2	21.1	21.1
8	22.7	22.3	22.0	21.8	21.6	21.5	21.3	21.1	21.0	21.0
9	22.5	22.2	21.8	21.6	21.4	21.3	21.0	20.8	20.7	20.7
10	22.6	22.2	21.8	21.6	21.4	21.3	21.0	20.8	20.7	20.7
11	22.2	21.8	21.4	21.1	21.0	20.8	20.5	20.2	20.2	20.2
12	22.3	21.9	21.5	21.2	21.0	20.9	20.6	20.3	20.3	20.3
13	22.1	21.7	21.3	21.0	20.8	20.7	20.4	20.1	20.1	20.1
14	22.2	21.8	21.4	21.0	20.8	20.8	20.4	20.1	20.0	20.1
15	22.2	21.8	21.3	21.1	20.9	20.8	20.4	20.2	20.2	20.2
16	21.9	21.4	20.9	20.7	20.4	20.4	20.0	19.7	19.7	19.7
17	21.9	21.5	21.0	20.8	20.6	20.5	20.1	19.8	19.8	19.7
18	21.6	21.2	20.6	20.3	20.1	20.0	19.6	19.2	19.2	19.1
19	21.5	21.1	20.5	20.2	20.0	19.8	19.4	19.0	18.9	19.0
20	21.5	21.1	20.5	20.2	19.9	19.8	19.4	19.0	19.0	18.9
21	21.6	21.2	20.5	20.3	20.0	19.9	19.4	19.1	19.1	19.0
22	21.5	21.1	20.4	20.2	19.9	19.8	19.3	18.9	18.8	18.8
23	21.5	20.9	20.3	20.1	19.8	19.7	19.2	18.9	18.8	18.7
24	21.3	20.8	20.2	19.9	19.6	19.5	18.9	18.6	18.5	18.4
25	21.1	20.7	20.0	19.6	19.4	19.2	18.6	18.1	18.1	18.0
26	21.3	20.8	20.1	19.8	19.5	19.5	18.9	18.3	18.3	18.2
27	21.0	20.5	19.8	19.4	19.1	19.0	18.3	17.8	17.7	17.6
28	21.1	20.6	19.9	19.5	19.2	19.1	18.5	17.9	17.8	17.7
29	21.0	20.4	19.7	19.3	19.0	18.9	18.2	17.6	17.5	17.4
30	20.8	20.2	19.5	19.1	18.8	18.6	17.8	17.3	17.1	16.9
31	20.3	19.7	18.9	18.5	18.1	18.0	17.2	16.4	16.2	16.0
32	20.5	20.0	19.2	18.8	18.3	18.3	17.5	16.7	16.6	16.4
33	20.3	19.8	18.9	18.5	18.1	18.0	17.0	16.1	16.0	15.8
34	20.3	19.7	18.8	18.4	18.0	17.9	16.9	16.0	15.7	15.5
35	20.3	19.6	18.8	18.3	17.9	17.8	16.8	15.8	15.3	15.1
36	20.4	19.7	18.8	18.4	18.0	17.9	16.8	15.8	15.5	15.4
37	20.2	19.6	18.7	18.2	17.7	17.6	16.5	15.3	14.7	14.5
38	20.5	19.9	19.0	18.5	18.1	18.0	16.9	15.7	15.2	14.8
39	20.8	20.2	19.3	18.8	18.3	18.2	16.9	15.1	13.1	9.8

Table H.2 Raw experimental data collected in the physical model with modified cross-section and with bridges for a medium flow. Piezometer units are cm.

Test	61A	61B	61C	61D	61E	61F	61G	61H	61I	61J
Pump Freq. (Hz)	54.6	54.6	54.6	54.7	54.7	54.7	54.6	54.4	54.4	54.4
Weir (cm)	85.08	85.12	85.14	85.31	85.34	85.37	85.46	85.33	85.30	85.36
Discharge (ft^3/s)	3.170	3.176	3.179	3.203	3.207	3.211	3.224	3.205	3.201	3.210
Water Temp (C)	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.8	21.8
Gate Height (in)	7.75	7.25	6.75	6.00	5.50	5.00	4.00	3.00	2.00	0.00
Gate Height (cm)	19.69	18.42	17.15	15.24	13.97	12.70	10.16	7.62	5.08	0.00
Piezometer										
1	25.8	24.9	24.4	23.3	22.6	22.2	21.4	21.0	21.0	21.0
2	25.6	24.8	24.2	23.1	22.3	21.8	21.0	20.4	20.3	20.3
3	25.6	24.7	24.1	23.0	22.2	21.7	20.8	20.3	20.1	20.1
4	25.6	24.7	24.1	23.0	22.2	21.7	20.7	20.2	20.1	20.1
5	25.5	24.6	23.9	22.8	21.9	21.4	20.4	19.8	19.6	19.6
6	25.5	24.6	23.9	22.8	22.0	21.4	20.4	19.8	19.6	19.6
7	25.5	24.6	23.9	22.8	21.9	21.4	20.3	19.7	19.5	19.6
8	25.5	24.6	23.9	22.8	21.8	21.3	20.2	19.6	19.4	19.4
9	25.4	24.5	23.8	22.7	21.7	21.2	20.0	19.3	19.2	19.2
10	25.3	24.5	23.8	22.7	21.7	21.2	20.0	19.3	19.1	19.1
11	25.2	24.3	23.7	22.4	21.5	20.8	19.6	18.8	18.6	18.6
12	25.2	24.3	23.7	22.5	21.5	20.8	19.6	18.8	18.7	18.6
13	25.1	24.3	23.6	22.4	21.4	20.8	19.5	18.7	18.4	18.4
14	25.2	24.3	23.6	22.5	21.4	20.8	19.5	18.7	18.5	18.5
15	25.2	24.3	23.6	22.5	21.5	20.8	19.5	18.7	18.5	18.5
16	25.1	24.2	23.4	22.2	21.1	20.5	19.2	18.3	18.1	18.1
17	25.1	24.2	23.5	22.3	21.2	20.6	19.3	18.3	18.1	18.1
18	25.0	24.1	23.4	22.1	21.0	20.3	18.9	18.0	17.7	17.7
19	25.0	24.1	23.3	22.1	20.9	20.2	18.7	17.8	17.5	17.4
20	25.0	24.1	23.3	22.1	20.9	20.2	18.7	17.7	17.4	17.4
21	25.1	24.2	23.4	22.2	21.0	20.3	18.9	17.8	17.5	17.5
22	25.1	24.1	23.3	22.1	20.9	20.2	18.7	17.7	17.4	17.4
23	25.0	24.1	23.3	22.1	20.9	20.2	18.6	17.6	17.3	17.3
24	25.0	24.1	23.3	22.1	20.8	20.1	18.5	17.4	17.1	17.1
25	25.0	24.0	23.2	21.9	20.7	20.0	18.2	17.1	16.6	16.5
26	25.0	24.1	23.3	22.0	20.8	20.1	18.4	17.2	16.9	16.8
27	24.9	23.9	23.2	21.8	20.5	19.8	18.0	16.8	16.3	16.3
28	24.9	24.0	23.2	21.9	20.7	19.9	18.2	16.8	16.4	16.3
29	24.9	23.9	23.1	21.8	20.6	19.8	18.0	16.6	16.1	16.1
30	24.8	23.8	23.0	21.7	20.4	19.6	17.7	16.3	15.8	15.7
31	24.6	23.5	22.7	21.4	20.1	19.2	17.2	15.6	14.8	14.8
32	24.7	23.6	22.8	21.5	20.2	19.3	17.4	15.8	15.2	15.1
33	24.6	23.6	22.8	21.4	20.1	19.2	17.2	15.4	15.1	14.6
34	24.6	23.6	22.8	21.5	20.1	19.1	17.1	15.3	14.4	14.3
35	24.7	23.6	22.7	21.3	20.0	19.1	17.0	15.1	14.1	14.0
36	24.7	23.7	22.8	21.5	20.1	19.2	17.2	15.3	14.2	14.1
37	24.7	23.6	22.8	21.4	20.0	19.1	16.9	14.8	13.4	13.3
38	24.8	23.8	22.9	21.5	20.2	19.3	17.2	15.2	13.8	13.7
39	25.0	23.9	23.1	21.8	20.5	19.6	17.4	15.0	11.0	8.9

Table H.3 Raw experimental data collected in the physical model with modified cross-section and with bridges for a low flow. Piezometer units are cm.

Test	62A	62B	62C	62D	62E	62F	62G	62H	62I	62J
Pump Freq. (Hz)	49.0	49.0	49.0	49.0	49.0	48.7	48.5	48.5	48.5	48.5
Weir (cm)	80.02	80.13	80.18	80.29	80.59	80.44	80.35	80.45	80.55	80.46
Discharge (ft^3/s)	2.509	2.523	2.529	2.542	2.579	2.561	2.550	2.562	2.574	2.563
Water Temp (C)	22.0	22.0	22.0	21.9	21.8	21.2	21.1	21.2	21.2	21.2
Gate Height (in)	8.38	7.88	7.25	6.88	6.25	5.38	4.25	3.25	2.00	0.00
Gate Height (cm)	21.27	20.00	18.42	17.46	15.88	13.65	10.80	8.26	5.08	0.00
Piezometer										
1	25.7	25.1	24.4	23.6	22.0	20.6	19.8	19.3	19.2	19.2
2	25.8	25.0	24.2	23.4	21.8	20.2	19.2	18.6	18.5	18.4
3	25.7	25.0	24.2	23.3	21.7	20.1	19.1	18.5	18.4	18.3
4	25.7	25.0	24.2	23.3	21.6	20.1	19.1	18.5	18.4	18.3
5	25.7	25.0	24.1	23.2	21.5	19.9	18.8	18.1	17.9	17.9
6	25.6	25.0	24.1	23.2	21.5	19.9	18.8	18.1	17.9	17.9
7	25.6	25.0	24.1	23.2	21.5	19.8	18.7	18.0	17.8	17.8
8	25.6	24.9	24.1	23.2	21.5	19.8	18.6	17.9	17.6	17.6
9	25.6	24.8	24.0	23.2	21.3	19.7	18.4	17.6	17.3	17.3
10	25.5	24.8	24.0	23.1	21.4	19.6	18.3	17.5	17.3	17.3
11	25.4	24.7	23.9	23.0	21.1	19.4	18.0	17.1	16.8	16.8
12	25.4	24.7	23.9	23.0	21.2	19.4	18.1	17.2	16.9	16.8
13	25.4	24.7	23.9	23.0	21.1	19.3	18.0	17.0	16.7	16.7
14	25.5	24.7	23.9	23.0	21.1	19.3	17.9	17.0	16.7	16.6
15	25.5	24.7	23.9	23.0	21.1	19.4	17.9	17.0	16.7	16.6
16	25.4	24.6	23.8	22.8	21.0	19.1	17.7	16.7	16.3	16.3
17	25.4	24.6	23.8	22.9	21.0	19.2	17.7	16.8	16.3	16.4
18	25.3	24.6	23.7	22.8	20.9	19.0	17.5	16.4	16.0	16.0
19	25.3	24.6	23.7	22.8	20.8	19.0	17.4	16.4	15.9	15.9
20	25.3	24.6	23.7	22.8	20.8	18.9	17.4	16.3	15.8	15.8
21	25.4	24.7	23.8	22.8	20.9	18.9	17.4	16.4	15.9	15.9
22	25.4	24.6	23.8	22.8	20.9	19.0	17.3	16.3	15.8	15.8
23	25.4	24.6	23.8	22.8	20.8	18.9	17.3	16.2	15.7	15.7
24	25.4	24.6	23.8	22.8	20.8	18.8	17.2	16.0	15.5	15.5
25	25.3	24.6	23.7	22.7	20.7	18.7	17.0	15.7	15.0	15.0
26	25.3	24.6	23.7	22.8	20.8	18.8	17.2	15.9	15.3	15.3
27	25.3	24.5	23.7	22.7	20.7	18.6	16.8	15.4	14.8	14.7
28	25.3	24.5	23.7	22.7	20.7	18.6	16.9	15.5	14.8	14.8
29	25.2	24.5	23.6	22.7	20.7	18.5	16.8	15.3	14.6	14.5
30	25.2	24.5	23.6	22.6	20.5	18.4	16.5	15.0	14.1	14.1
31	25.0	24.2	23.3	22.4	20.3	18.1	16.2	14.3	13.3	13.3
32	25.0	24.2	23.4	22.5	20.4	18.2	16.3	14.6	13.6	13.5
33	25.0	24.2	23.4	22.4	20.3	18.1	16.1	14.2	13.0	13.0
34	25.0	24.2	23.4	22.4	20.3	18.1	16.1	14.2	13.0	12.9
35	25.1	24.2	23.3	22.4	20.3	18.0	16.0	14.1	12.6	12.5
36	25.2	24.4	23.4	22.5	20.3	18.2	16.2	14.2	12.8	12.7
37	25.1	24.3	23.4	22.4	20.3	18.1	15.9	13.8	12.0	11.8
38	25.2	24.4	23.5	22.6	20.4	18.2	16.2	14.2	12.4	12.3
39	25.3	24.5	23.6	22.6	20.6	18.5	16.4	14.2	10.0	7.9

Appendix H.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table H.4 Scaled/Corrected data collected in modified cross-section and with bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	60A	60B	60C	60D	60E	60F	60G	60H	60I	60J
Discharge (ft^3/s)	11880	11841	11856	11856	11875	11866	11900	11900	11910	11910
Piezometer										
1	1147.8	1147.6	1147.1	1146.8	1146.6	1146.3	1146.1	1145.7	1145.6	1145.4
2	1147.7	1147.4	1147.0	1146.7	1146.5	1146.2	1145.9	1145.6	1145.3	1145.1
3	1147.6	1147.3	1146.8	1146.6	1146.4	1146.1	1145.7	1145.4	1145.3	1145.0
4	1147.7	1147.4	1146.9	1146.7	1146.3	1146.2	1145.8	1145.6	1145.3	1145.1
5	1147.5	1147.2	1146.7	1146.5	1146.3	1145.9	1145.6	1145.3	1145.0	1144.7
6	1147.6	1147.2	1146.7	1146.5	1146.3	1145.9	1145.6	1145.3	1145.0	1144.7
7	1147.5	1147.2	1146.7	1146.4	1146.2	1145.9	1145.6	1145.3	1145.0	1144.7
8	1147.5	1147.2	1146.6	1146.4	1146.2	1145.8	1145.5	1145.2	1144.9	1144.7
9	1147.4	1147.1	1146.6	1146.3	1146.2	1145.7	1145.5	1145.1	1144.8	1144.5
10	1147.4	1147.1	1146.6	1146.3	1146.2	1145.7	1145.4	1145.1	1144.8	1144.5
11	1147.4	1147.1	1146.6	1146.3	1146.1	1145.7	1145.3	1144.9	1144.7	1144.4
12	1147.4	1147.1	1146.5	1146.3	1146.1	1145.7	1145.4	1144.9	1144.8	1144.4
13	1147.3	1147.0	1146.5	1146.2	1146.0	1145.6	1145.3	1144.8	1144.7	1144.3
14	1147.3	1147.0	1146.4	1146.2	1146.0	1145.6	1145.3	1144.8	1144.6	1144.3
15	1147.3	1147.0	1146.5	1146.2	1146.0	1145.6	1145.3	1144.9	1144.6	1144.2
16	1147.1	1146.8	1146.3	1146.1	1145.8	1145.3	1145.0	1144.6	1144.4	1144.0
17	1147.2	1146.9	1146.3	1146.1	1145.8	1145.3	1145.0	1144.6	1144.4	1144.0
18	1147.1	1146.7	1146.2	1145.9	1145.7	1145.3	1144.8	1144.4	1144.2	1143.8
19	1147.1	1146.7	1146.2	1145.9	1145.7	1145.3	1144.8	1144.4	1144.1	1143.7
20	1147.1	1146.7	1146.2	1145.9	1145.7	1145.3	1144.8	1144.4	1144.1	1143.7
21	1147.0	1146.6	1146.1	1145.7	1145.6	1145.1	1144.8	1144.4	1144.0	1143.6
22	1146.9	1146.6	1146.1	1145.7	1145.5	1145.1	1144.7	1144.3	1143.9	1143.6
23	1146.9	1146.6	1146.1	1145.7	1145.5	1145.1	1144.7	1144.3	1143.9	1143.5
24	1146.8	1146.6	1146.0	1145.7	1145.5	1145.0	1144.6	1144.2	1143.9	1143.5
25	1146.9	1146.6	1146.0	1145.7	1145.4	1144.9	1144.6	1144.1	1143.9	1143.4
26	1146.9	1146.6	1146.1	1145.7	1145.6	1145.1	1144.7	1144.3	1143.9	1143.5
27	1146.8	1146.5	1146.1	1145.7	1145.4	1144.9	1144.5	1144.0	1143.8	1143.3
28	1146.9	1146.6	1146.0	1145.7	1145.4	1144.9	1144.5	1144.1	1143.8	1143.4
29	1146.8	1146.5	1145.9	1145.6	1145.3	1144.8	1144.5	1144.0	1143.7	1143.2
30	1146.7	1146.4	1145.8	1145.5	1145.3	1144.8	1144.4	1143.9	1143.5	1143.0
31	1146.6	1146.2	1145.7	1145.3	1145.1	1144.6	1144.2	1143.7	1143.4	1142.8
32	1146.6	1146.3	1145.7	1145.5	1145.3	1144.7	1144.3	1143.9	1143.5	1143.0
33	1146.6	1146.2	1145.7	1145.4	1145.2	1144.6	1144.2	1143.7	1143.4	1142.7
34	1146.6	1146.3	1145.7	1145.4	1145.2	1144.6	1144.2	1143.8	1143.3	1142.8
35	1146.6	1146.3	1145.7	1145.3	1145.2	1144.5	1144.2	1143.7	1143.3	1142.8
36	1146.6	1146.3	1145.7	1145.4	1145.1	1144.6	1144.2	1143.7	1143.3	1142.8
37	1146.6	1146.2	1145.7	1145.3	1145.1	1144.5	1144.1	1143.6	1143.2	1142.6
38	1146.7	1146.3	1145.8	1145.5	1145.3	1144.7	1144.2	1143.8	1143.4	1142.9
39	1146.8	1146.5	1146.0	1145.7	1145.4	1144.8	1144.4	1144.0	1143.7	1143.1

Table H.4(Cont.) Scaled/Corrected data collected in modified cross-section and with bridges for a high flow. Piezometer units are ft-msl NAVD 88.

Test	60K	60L	60M	60N	60O	60P	60Q	60R	60S	60T
Discharge (ft^3/s)	11958	11924	11924	11924	11949	11895	11900	11919	11924	11910
Piezometer										
1	1145.3	1145.0	1144.8	1144.7	1144.7	1144.6	1144.5	1144.4	1144.4	1144.4
2	1144.9	1144.7	1144.4	1144.3	1144.2	1144.2	1143.9	1143.9	1143.9	1143.9
3	1144.8	1144.6	1144.4	1144.2	1144.1	1144.0	1143.9	1143.7	1143.7	1143.7
4	1144.8	1144.5	1144.4	1144.2	1144.0	1144.0	1143.9	1143.7	1143.7	1143.7
5	1144.5	1144.2	1144.0	1143.9	1143.7	1143.7	1143.5	1143.4	1143.3	1143.3
6	1144.5	1144.3	1144.0	1143.9	1143.7	1143.7	1143.5	1143.3	1143.3	1143.3
7	1144.5	1144.3	1144.0	1143.9	1143.7	1143.7	1143.5	1143.3	1143.2	1143.2
8	1144.5	1144.2	1143.9	1143.8	1143.6	1143.5	1143.4	1143.2	1143.1	1143.1
9	1144.4	1144.1	1143.8	1143.6	1143.5	1143.4	1143.1	1143.0	1142.9	1142.9
10	1144.4	1144.1	1143.8	1143.6	1143.5	1143.4	1143.1	1143.0	1142.9	1142.9
11	1144.2	1143.9	1143.5	1143.3	1143.2	1143.0	1142.8	1142.5	1142.5	1142.5
12	1144.3	1143.9	1143.6	1143.4	1143.2	1143.1	1142.9	1142.6	1142.6	1142.6
13	1144.1	1143.8	1143.5	1143.2	1143.0	1143.0	1142.7	1142.5	1142.5	1142.5
14	1144.1	1143.8	1143.5	1143.1	1143.0	1143.0	1142.6	1142.4	1142.3	1142.4
15	1144.1	1143.8	1143.4	1143.2	1143.0	1143.0	1142.6	1142.5	1142.5	1142.5
16	1143.9	1143.5	1143.0	1142.9	1142.6	1142.6	1142.3	1142.1	1142.1	1142.1
17	1143.9	1143.5	1143.1	1143.0	1142.8	1142.7	1142.4	1142.1	1142.1	1142.1
18	1143.6	1143.3	1142.8	1142.5	1142.4	1142.3	1142.0	1141.6	1141.6	1141.6
19	1143.5	1143.2	1142.7	1142.5	1142.3	1142.1	1141.8	1141.5	1141.4	1141.5
20	1143.5	1143.2	1142.7	1142.5	1142.2	1142.1	1141.8	1141.5	1141.5	1141.4
21	1143.5	1143.1	1142.5	1142.4	1142.1	1142.1	1141.6	1141.4	1141.4	1141.3
22	1143.4	1143.0	1142.5	1142.3	1142.1	1142.0	1141.6	1141.2	1141.2	1141.2
23	1143.4	1142.9	1142.4	1142.2	1142.0	1141.9	1141.5	1141.2	1141.2	1141.1
24	1143.2	1142.8	1142.3	1142.1	1141.8	1141.7	1141.2	1140.9	1140.9	1140.8
25	1143.1	1142.8	1142.2	1141.9	1141.7	1141.6	1141.1	1140.7	1140.7	1140.6
26	1143.3	1142.9	1142.3	1142.1	1141.8	1141.8	1141.3	1140.8	1140.8	1140.7
27	1143.0	1142.6	1142.1	1141.7	1141.5	1141.4	1140.8	1140.4	1140.3	1140.3
28	1143.1	1142.7	1142.1	1141.8	1141.6	1141.5	1141.0	1140.5	1140.4	1140.3
29	1143.0	1142.5	1142.0	1141.6	1141.4	1141.3	1140.7	1140.3	1140.2	1140.1
30	1142.9	1142.4	1141.8	1141.5	1141.2	1141.1	1140.4	1140.0	1139.8	1139.7
31	1142.5	1142.1	1141.4	1141.1	1140.7	1140.7	1140.0	1139.3	1139.2	1139.0
32	1142.7	1142.3	1141.6	1141.3	1140.9	1140.9	1140.3	1139.6	1139.5	1139.3
33	1142.5	1142.1	1141.4	1141.1	1140.7	1140.7	1139.8	1139.1	1139.0	1138.9
34	1142.5	1142.1	1141.3	1141.0	1140.7	1140.6	1139.8	1139.0	1138.8	1138.6
35	1142.5	1142.0	1141.3	1140.9	1140.6	1140.5	1139.7	1138.9	1138.4	1138.3
36	1142.5	1142.0	1141.2	1140.9	1140.6	1140.5	1139.6	1138.8	1138.5	1138.4
37	1142.4	1141.9	1141.2	1140.7	1140.3	1140.3	1139.3	1138.4	1137.9	1137.7
38	1142.6	1142.1	1141.4	1141.0	1140.7	1140.6	1139.7	1138.7	1138.3	1138.0
39	1142.9	1142.4	1141.6	1141.2	1140.8	1140.7	1139.7	1138.2	1136.6	1133.9

Table H.5 Scaled/Corrected data collected in modified cross-section and with bridges for a medium flow. Piezometer units are ft-msl NAVD 88.

Test	61A	61B	61C	61D	61E	61F	61G	61H	61I	61J
Discharge (ft^3/s)	9907	9925	9934	10008	10021	10035	10074	10017	10004	10030
Piezometer										
1	1147.1	1146.3	1145.9	1145.0	1144.4	1144.1	1143.5	1143.1	1143.1	1143.1
2	1146.9	1146.2	1145.7	1144.8	1144.2	1143.8	1143.1	1142.6	1142.5	1142.5
3	1146.9	1146.2	1145.7	1144.8	1144.1	1143.7	1143.0	1142.5	1142.4	1142.4
4	1146.9	1146.2	1145.7	1144.8	1144.1	1143.7	1142.9	1142.5	1142.4	1142.4
5	1146.8	1146.1	1145.5	1144.6	1143.9	1143.5	1142.6	1142.1	1142.0	1142.0
6	1146.8	1146.1	1145.5	1144.6	1143.9	1143.5	1142.6	1142.1	1142.0	1142.0
7	1146.8	1146.1	1145.5	1144.6	1143.9	1143.5	1142.5	1142.1	1141.9	1142.0
8	1146.8	1146.1	1145.5	1144.6	1143.8	1143.4	1142.5	1142.0	1141.8	1141.8
9	1146.7	1146.0	1145.4	1144.5	1143.7	1143.3	1142.3	1141.7	1141.6	1141.6
10	1146.6	1146.0	1145.4	1144.5	1143.7	1143.3	1142.3	1141.7	1141.6	1141.6
11	1146.6	1145.9	1145.4	1144.4	1143.6	1143.0	1142.1	1141.4	1141.2	1141.2
12	1146.6	1145.9	1145.4	1144.4	1143.6	1143.0	1142.1	1141.4	1141.3	1141.2
13	1146.6	1145.9	1145.3	1144.4	1143.5	1143.0	1142.0	1141.3	1141.1	1141.1
14	1146.6	1145.8	1145.3	1144.4	1143.5	1143.0	1141.9	1141.2	1141.1	1141.1
15	1146.6	1145.8	1145.3	1144.4	1143.5	1143.0	1141.9	1141.2	1141.1	1141.1
16	1146.5	1145.7	1145.1	1144.1	1143.2	1142.7	1141.6	1140.9	1140.7	1140.7
17	1146.5	1145.7	1145.2	1144.2	1143.3	1142.8	1141.7	1140.9	1140.7	1140.7
18	1146.4	1145.7	1145.1	1144.0	1143.1	1142.5	1141.4	1140.7	1140.4	1140.4
19	1146.4	1145.7	1145.0	1144.0	1143.0	1142.5	1141.2	1140.5	1140.3	1140.2
20	1146.4	1145.7	1145.0	1144.0	1143.0	1142.5	1141.2	1140.4	1140.2	1140.2
21	1146.3	1145.6	1144.9	1143.9	1143.0	1142.4	1141.2	1140.3	1140.1	1140.1
22	1146.3	1145.5	1144.8	1143.9	1142.9	1142.3	1141.1	1140.3	1140.0	1140.0
23	1146.2	1145.5	1144.8	1143.9	1142.9	1142.3	1141.0	1140.2	1139.9	1139.9
24	1146.2	1145.5	1144.8	1143.9	1142.8	1142.2	1140.9	1140.0	1139.8	1139.8
25	1146.3	1145.5	1144.8	1143.8	1142.8	1142.2	1140.7	1139.8	1139.4	1139.3
26	1146.3	1145.6	1144.9	1143.9	1142.9	1142.3	1140.9	1139.9	1139.7	1139.6
27	1146.2	1145.4	1144.8	1143.7	1142.6	1142.1	1140.6	1139.6	1139.2	1139.2
28	1146.2	1145.5	1144.8	1143.8	1142.8	1142.1	1140.7	1139.6	1139.3	1139.2
29	1146.2	1145.4	1144.8	1143.7	1142.7	1142.1	1140.6	1139.4	1139.0	1139.0
30	1146.2	1145.3	1144.7	1143.6	1142.5	1141.9	1140.3	1139.2	1138.8	1138.7
31	1146.1	1145.2	1144.5	1143.5	1142.4	1141.6	1140.0	1138.7	1138.0	1138.0
32	1146.2	1145.3	1144.6	1143.5	1142.5	1141.7	1140.2	1138.9	1138.4	1138.3
33	1146.1	1145.3	1144.6	1143.5	1142.4	1141.6	1140.0	1138.5	1138.3	1137.9
34	1146.1	1145.3	1144.6	1143.5	1142.4	1141.6	1139.9	1138.4	1137.7	1137.6
35	1146.2	1145.3	1144.5	1143.4	1142.3	1141.6	1139.8	1138.3	1137.5	1137.4
36	1146.1	1145.3	1144.5	1143.5	1142.3	1141.6	1139.9	1138.4	1137.5	1137.4
37	1146.1	1145.2	1144.5	1143.4	1142.2	1141.5	1139.7	1138.0	1136.8	1136.7
38	1146.2	1145.3	1144.6	1143.5	1142.4	1141.6	1139.9	1138.3	1137.1	1137.1
39	1146.3	1145.4	1144.8	1143.7	1142.6	1141.9	1140.1	1138.1	1134.8	1133.1

Table H.6 Scaled/Corrected data collected in modified cross-section and with bridges for a low flow. Piezometer units are ft-msl NAVD 88.

Test	62A	62B	62C	62D	62E	62F	62G	62H	62I	62J
Discharge (ft^3/s)	7842	7884	7903	7945	8060	8002	7968	8006	8045	8010
Piezometer										
1	1147.0	1146.5	1145.9	1145.3	1143.9	1142.8	1142.1	1141.7	1141.6	1141.6
2	1147.1	1146.4	1145.7	1145.1	1143.8	1142.5	1141.6	1141.2	1141.1	1141.0
3	1147.0	1146.4	1145.7	1145.0	1143.7	1142.4	1141.6	1141.1	1141.0	1140.9
4	1147.0	1146.4	1145.7	1145.0	1143.6	1142.4	1141.6	1141.1	1141.0	1140.9
5	1147.0	1146.4	1145.7	1144.9	1143.5	1142.2	1141.3	1140.7	1140.6	1140.6
6	1146.9	1146.4	1145.7	1144.9	1143.5	1142.2	1141.3	1140.7	1140.6	1140.6
7	1146.9	1146.4	1145.7	1144.9	1143.5	1142.1	1141.2	1140.7	1140.5	1140.5
8	1146.9	1146.3	1145.7	1144.9	1143.5	1142.1	1141.2	1140.6	1140.3	1140.3
9	1146.9	1146.2	1145.6	1144.9	1143.4	1142.1	1141.0	1140.3	1140.1	1140.1
10	1146.8	1146.2	1145.6	1144.8	1143.5	1142.0	1140.9	1140.3	1140.1	1140.1
11	1146.8	1146.2	1145.6	1144.8	1143.3	1141.9	1140.7	1140.0	1139.8	1139.8
12	1146.8	1146.2	1145.6	1144.8	1143.4	1141.9	1140.8	1140.1	1139.8	1139.8
13	1146.8	1146.2	1145.6	1144.8	1143.3	1141.8	1140.7	1139.9	1139.7	1139.7
14	1146.8	1146.2	1145.5	1144.8	1143.2	1141.7	1140.6	1139.8	1139.6	1139.5
15	1146.8	1146.2	1145.5	1144.8	1143.2	1141.8	1140.6	1139.8	1139.6	1139.5
16	1146.7	1146.1	1145.4	1144.6	1143.1	1141.6	1140.4	1139.6	1139.3	1139.3
17	1146.7	1146.1	1145.4	1144.7	1143.1	1141.6	1140.4	1139.7	1139.3	1139.3
18	1146.6	1146.1	1145.3	1144.6	1143.0	1141.5	1140.3	1139.3	1139.0	1139.0
19	1146.6	1146.1	1145.3	1144.6	1143.0	1141.5	1140.2	1139.3	1138.9	1138.9
20	1146.6	1146.1	1145.3	1144.6	1143.0	1141.4	1140.2	1139.3	1138.9	1138.9
21	1146.6	1146.0	1145.3	1144.4	1142.9	1141.2	1140.0	1139.2	1138.8	1138.8
22	1146.6	1145.9	1145.3	1144.4	1142.9	1141.3	1139.9	1139.1	1138.7	1138.7
23	1146.6	1145.9	1145.3	1144.4	1142.8	1141.2	1139.9	1139.0	1138.6	1138.6
24	1146.6	1145.9	1145.3	1144.4	1142.8	1141.2	1139.8	1138.9	1138.4	1138.4
25	1146.6	1146.0	1145.3	1144.4	1142.8	1141.2	1139.8	1138.7	1138.1	1138.1
26	1146.6	1146.0	1145.3	1144.5	1142.9	1141.2	1139.9	1138.9	1138.4	1138.4
27	1146.6	1145.9	1145.3	1144.4	1142.8	1141.1	1139.6	1138.4	1138.0	1137.9
28	1146.6	1145.9	1145.3	1144.4	1142.8	1141.1	1139.7	1138.5	1138.0	1138.0
29	1146.5	1145.9	1145.2	1144.4	1142.8	1141.0	1139.6	1138.4	1137.8	1137.7
30	1146.5	1145.9	1145.2	1144.4	1142.6	1140.9	1139.3	1138.1	1137.4	1137.4
31	1146.4	1145.7	1145.0	1144.3	1142.5	1140.7	1139.2	1137.6	1136.8	1136.8
32	1146.4	1145.7	1145.1	1144.4	1142.6	1140.8	1139.3	1137.9	1137.1	1137.0
33	1146.4	1145.7	1145.1	1144.3	1142.5	1140.7	1139.1	1137.5	1136.6	1136.6
34	1146.4	1145.7	1145.1	1144.3	1142.5	1140.7	1139.1	1137.5	1136.6	1136.5
35	1146.5	1145.7	1145.0	1144.3	1142.5	1140.7	1139.0	1137.5	1136.2	1136.2
36	1146.5	1145.8	1145.0	1144.3	1142.5	1140.7	1139.1	1137.5	1136.3	1136.2
37	1146.4	1145.7	1145.0	1144.2	1142.5	1140.7	1138.9	1137.1	1135.7	1135.5
38	1146.5	1145.8	1145.1	1144.4	1142.5	1140.7	1139.1	1137.5	1136.0	1135.9
39	1146.6	1145.9	1145.2	1144.4	1142.7	1141.0	1139.3	1137.5	1134.0	1132.3

Appendix I. Modified Cross Section Roughened – Individual Bridges

Appendix I.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table I.1 Raw experimental data collected in the physical model with modified cross-section and with mainline bridge only for a high flow. Piezometer units are cm.

Test	70A	70C	70E	70G	70I	70K	70M	70O	70Q	70T
Pump Freq. (Hz)	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2
Weir (cm)	89.38	89.38	89.49	89.49	89.55	89.51	89.58	89.58	89.64	89.65
Discharge (ft^3/s)	3.806	3.806	3.824	3.824	3.833	3.827	3.838	3.838	3.847	3.849
Water Temp (C)	21.3	21.3	21.3	21.3	21.3	21.3	21.4	21.4	21.5	21.5
Gate Height (in)	7.50	7.00	6.50	6.00	5.50	5.00	4.25	3.88	3.13	0.00
Gate Height (cm)	19.05	17.78	16.51	15.24	13.97	12.70	10.80	9.84	7.94	0.00
Piezometer										
1	26.6	25.8	25.1	24.4	23.8	23.4	22.9	22.7	22.5	22.3
2	26.4	25.5	24.9	24.1	23.4	22.9	22.4	22.1	21.7	21.6
3	26.3	25.4	24.7	24.0	23.3	22.8	22.1	21.9	21.6	21.4
4	26.3	25.4	24.7	24.0	23.2	22.8	22.1	21.8	21.6	21.4
5	26.2	25.2	24.5	23.8	23.0	22.4	21.7	21.4	21.1	20.8
6	26.1	25.2	24.5	23.8	23.0	22.4	21.7	21.4	21.0	20.8
7	26.1	25.2	24.5	23.8	22.9	22.4	21.7	21.3	20.9	20.7
8	26.1	25.1	24.4	23.7	22.9	22.3	21.5	21.2	20.8	20.5
9	26.0	25.1	24.3	23.6	22.8	22.1	21.3	20.9	20.5	20.2
10	26.0	25.0	24.3	23.5	22.6	22.0	21.1	20.7	20.3	20.0
11	25.9	25.0	24.2	23.4	22.5	21.8	20.8	20.4	20.0	19.6
12	25.9	25.0	24.2	23.3	22.4	21.9	20.9	20.5	20.0	19.7
13	25.8	24.9	24.1	23.2	22.3	21.8	20.7	20.3	19.8	19.4
14	25.9	24.9	24.1	23.3	22.4	21.7	20.7	20.3	19.8	19.5
15	25.9	24.9	24.1	23.2	22.4	21.7	20.7	20.3	19.7	19.4
16	25.9	24.9	24.2	23.3	22.4	21.8	20.8	20.4	19.9	19.5
17	25.9	24.9	24.2	23.3	22.4	21.8	20.8	20.4	19.9	19.5
18	25.7	24.8	24.0	23.1	22.1	21.4	20.4	20.0	19.5	19.1
19	25.8	24.8	24.0	23.1	22.2	21.4	20.4	20.0	19.4	19.0
20	25.8	24.8	24.0	23.1	22.2	21.5	20.3	20.0	19.3	18.9
21	25.8	24.8	24.0	23.1	22.2	21.5	20.4	20.0	19.4	19.0
22	25.8	24.8	24.0	23.0	22.1	21.4	20.3	19.8	19.2	18.8
23	25.7	24.7	24.0	23.0	22.1	21.3	20.3	19.8	19.2	18.7
24	25.7	24.7	23.9	23.0	22.0	21.3	20.1	19.6	18.9	18.4
25	25.6	24.6	23.8	22.8	21.8	21.1	19.9	19.2	18.5	18.0
26	25.7	24.7	23.9	23.0	22.1	21.3	20.1	19.6	18.8	18.4
27	25.6	24.6	23.7	22.7	21.8	21.0	19.7	19.0	18.2	17.6
28	25.6	24.6	23.8	22.8	21.9	21.1	19.9	19.2	18.4	17.8
29	25.6	24.6	23.7	22.8	21.8	20.9	19.6	18.9	18.0	17.3
30	25.5	24.4	23.6	22.6	21.6	20.7	19.4	18.7	17.7	17.0
31	25.3	24.2	23.3	22.2	21.2	20.3	18.9	18.1	17.0	16.1
32	25.3	24.3	23.4	22.4	21.4	20.5	19.1	18.3	17.3	16.5
33	25.3	24.2	23.3	22.2	21.1	20.2	18.8	18.0	16.8	15.7
34	25.3	24.2	23.3	22.3	21.2	20.3	18.8	18.0	16.7	15.6
35	25.3	24.2	23.3	22.2	21.2	20.2	18.7	17.8	16.5	15.2
36	25.4	24.3	23.4	22.4	21.3	20.4	18.8	18.0	16.8	15.4
37	25.3	24.2	23.3	22.2	21.1	20.2	18.6	17.7	16.2	14.4
38	25.4	24.5	23.5	22.4	21.4	20.4	18.9	18.1	16.6	14.9
39	25.7	24.6	23.7	22.7	21.7	20.7	19.2	18.3	16.6	9.8

Table I.2 Raw experimental data collected in the physical model with modified cross-section and with spur bridge only for a high flow. Piezometer units are cm.

Test	80A	80C	80E	80G	80I	80K	80M	80O	80Q	80T
Pump Freq. (Hz)	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2
Weir (cm)	89.31	89.38	89.38	89.45	89.48	89.48	89.51	89.57	89.57	89.59
Discharge (ft^3/s)	3.795	3.806	3.806	3.817	3.822	3.822	3.827	3.836	3.836	3.839
Water Temp (C)	21.9	21.9	22.0	21.9	22.0	22.0	22.1	22.1	22.1	22.2
Gate Height (in)	7.50	7.00	6.50	6.00	5.50	5.00	4.25	3.75	3.00	0.00
Gate Height (cm)	19.05	17.78	16.51	15.24	13.97	12.70	10.80	9.53	7.62	0.00
Piezometer										
1	26.7	25.8	25.1	24.6	24.0	23.5	23.0	22.8	22.6	22.4
2	26.4	25.6	24.8	24.2	23.6	23.0	22.4	22.1	21.9	21.7
3	26.3	25.5	24.8	24.1	23.5	22.9	22.3	22.0	21.7	21.6
4	26.3	25.5	24.8	24.1	23.4	22.9	22.2	21.9	21.6	21.5
5	26.2	25.3	24.6	23.9	23.2	22.6	21.8	21.6	21.2	21.0
6	26.2	25.3	24.6	23.9	23.1	22.6	21.8	21.5	21.2	21.0
7	26.2	25.3	24.6	23.8	23.1	22.6	21.8	21.4	21.1	20.9
8	26.2	25.2	24.6	23.8	23.0	22.5	21.7	21.3	21.0	20.7
9	26.1	25.2	24.5	23.7	23.0	22.3	21.5	21.1	20.7	20.5
10	26.1	25.1	24.5	23.7	22.9	22.3	21.4	21.0	20.7	20.4
11	25.9	25.0	24.3	23.4	22.6	21.9	21.1	20.6	20.2	20.0
12	26.0	25.0	24.3	23.4	22.6	22.0	21.1	20.7	20.3	20.0
13	25.9	24.9	24.2	23.4	22.6	21.9	20.9	20.5	20.0	19.7
14	25.9	25.0	24.2	23.4	22.6	21.9	21.0	20.5	20.1	19.8
15	25.9	25.0	24.3	23.4	22.6	21.9	21.0	20.6	20.1	19.8
16	25.8	24.8	24.0	23.1	22.3	21.6	20.6	20.2	19.6	19.3
17	25.8	24.8	24.1	23.2	22.4	21.6	20.6	20.2	19.6	19.3
18	25.8	24.8	24.1	23.2	22.3	21.6	20.5	20.1	19.5	19.2
19	25.9	24.8	24.1	23.2	22.4	21.6	20.6	20.1	19.5	19.3
20	25.8	24.8	24.0	23.1	22.2	21.4	20.4	20.0	19.4	19.0
21	25.8	24.8	24.0	23.1	22.3	21.5	20.4	20.0	19.4	19.0
22	25.8	24.8	24.0	23.1	22.2	21.4	20.3	19.8	19.2	18.8
23	25.8	24.7	24.0	23.1	22.2	21.4	20.3	19.8	19.2	18.8
24	25.8	24.7	23.9	23.0	22.1	21.3	20.1	19.6	18.8	18.5
25	25.7	24.6	23.8	22.8	21.9	21.0	19.8	19.3	18.6	18.1
26	25.7	24.7	23.9	23.0	22.2	21.3	20.1	19.6	18.9	18.4
27	25.6	24.5	23.7	22.7	21.8	20.9	19.6	19.1	18.2	17.7
28	25.7	24.6	23.8	22.9	21.9	21.0	19.8	19.3	18.4	17.9
29	25.6	24.5	23.7	22.7	21.7	20.8	19.5	18.9	18.0	17.4
30	25.5	24.4	23.6	22.6	21.6	20.6	19.3	18.6	17.6	16.9
31	25.2	24.2	23.3	22.3	21.2	20.3	18.8	18.1	17.1	16.1
32	25.4	24.2	23.4	22.4	21.4	20.4	19.0	18.3	17.3	16.4
33	25.3	24.1	23.3	22.2	21.2	20.2	18.6	17.8	16.7	15.6
34	25.3	24.2	23.3	22.3	21.2	20.2	18.7	17.9	16.8	15.7
35	25.3	24.2	23.3	22.2	21.2	20.1	18.6	17.7	16.6	15.2
36	25.4	24.3	23.4	22.4	21.3	20.4	18.8	18.0	16.8	15.5
37	25.3	24.2	23.3	22.2	21.2	20.2	18.5	17.5	16.2	15.4
38	25.5	24.3	23.5	22.4	21.4	20.3	18.8	18.0	16.7	14.9
39	25.6	24.4	23.7	22.6	21.6	20.5	19.1	18.1	16.4	9.8

Appendix I.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table I.3 Scaled/Corrected data collected in modified cross-section and with only the mainline bridge for a high flow. Piezometer units are ft-msl NAVD 88.

Test	70A	70C	70E	70G	70I	70K	70M	70O	70Q	70T
Discharge (ft^3/s)	11895	11895	11949	11949	11978	11958	11993	11993	12022	12027
Piezometer										
1	1147.7	1147.1	1146.5	1145.9	1145.4	1145.1	1144.7	1144.5	1144.4	1144.2
2	1147.6	1146.8	1146.3	1145.7	1145.1	1144.7	1144.3	1144.0	1143.7	1143.6
3	1147.5	1146.7	1146.2	1145.6	1145.0	1144.6	1144.0	1143.9	1143.6	1143.5
4	1147.5	1146.7	1146.2	1145.6	1144.9	1144.6	1144.0	1143.8	1143.6	1143.5
5	1147.4	1146.6	1146.0	1145.4	1144.8	1144.3	1143.7	1143.5	1143.2	1143.0
6	1147.3	1146.6	1146.0	1145.4	1144.8	1144.3	1143.7	1143.5	1143.1	1143.0
7	1147.3	1146.6	1146.0	1145.4	1144.7	1144.3	1143.7	1143.4	1143.0	1142.9
8	1147.3	1146.5	1145.9	1145.3	1144.7	1144.2	1143.5	1143.3	1143.0	1142.7
9	1147.2	1146.5	1145.8	1145.3	1144.6	1144.0	1143.4	1143.0	1142.7	1142.5
10	1147.2	1146.4	1145.8	1145.2	1144.4	1143.9	1143.2	1142.9	1142.5	1142.3
11	1147.2	1146.5	1145.8	1145.2	1144.4	1143.9	1143.0	1142.7	1142.4	1142.1
12	1147.2	1146.5	1145.8	1145.1	1144.4	1143.9	1143.1	1142.8	1142.4	1142.1
13	1147.1	1146.4	1145.7	1145.0	1144.3	1143.9	1143.0	1142.6	1142.2	1141.9
14	1147.1	1146.3	1145.7	1145.0	1144.3	1143.7	1142.9	1142.5	1142.1	1141.9
15	1147.1	1146.3	1145.7	1144.9	1144.3	1143.7	1142.9	1142.5	1142.1	1141.8
16	1147.1	1146.3	1145.7	1145.0	1144.3	1143.8	1143.0	1142.6	1142.2	1141.9
17	1147.1	1146.3	1145.7	1145.0	1144.3	1143.8	1143.0	1142.6	1142.2	1141.9
18	1147.0	1146.2	1145.6	1144.8	1144.0	1143.5	1142.6	1142.3	1141.9	1141.6
19	1147.1	1146.2	1145.6	1144.8	1144.1	1143.5	1142.6	1142.3	1141.8	1141.5
20	1147.1	1146.2	1145.6	1144.8	1144.1	1143.5	1142.5	1142.3	1141.7	1141.4
21	1146.9	1146.1	1145.4	1144.7	1143.9	1143.4	1142.5	1142.1	1141.6	1141.3
22	1146.9	1146.1	1145.4	1144.6	1143.9	1143.3	1142.4	1142.0	1141.5	1141.2
23	1146.8	1146.0	1145.4	1144.6	1143.9	1143.2	1142.4	1142.0	1141.5	1141.1
24	1146.8	1146.0	1145.3	1144.6	1143.8	1143.2	1142.2	1141.8	1141.2	1140.8
25	1146.8	1146.0	1145.3	1144.5	1143.7	1143.1	1142.1	1141.6	1141.0	1140.6
26	1146.9	1146.1	1145.4	1144.7	1143.9	1143.3	1142.3	1141.9	1141.2	1140.9
27	1146.8	1146.0	1145.3	1144.4	1143.7	1143.0	1142.0	1141.4	1140.7	1140.3
28	1146.8	1146.0	1145.3	1144.5	1143.8	1143.1	1142.1	1141.6	1140.9	1140.4
29	1146.8	1146.0	1145.3	1144.5	1143.7	1143.0	1141.9	1141.3	1140.6	1140.0
30	1146.7	1145.8	1145.2	1144.4	1143.5	1142.8	1141.7	1141.2	1140.3	1139.8
31	1146.6	1145.7	1145.0	1144.1	1143.3	1142.5	1141.4	1140.7	1139.8	1139.1
32	1146.6	1145.8	1145.1	1144.3	1143.5	1142.7	1141.6	1140.9	1140.1	1139.4
33	1146.6	1145.7	1145.0	1144.1	1143.2	1142.5	1141.3	1140.7	1139.7	1138.8
34	1146.6	1145.7	1145.0	1144.2	1143.3	1142.5	1141.3	1140.7	1139.6	1138.7
35	1146.6	1145.7	1145.0	1144.1	1143.3	1142.5	1141.2	1140.5	1139.4	1138.4
36	1146.6	1145.7	1145.0	1144.2	1143.3	1142.5	1141.2	1140.6	1139.6	1138.4
37	1146.6	1145.7	1144.9	1144.0	1143.1	1142.4	1141.1	1140.3	1139.1	1137.6
38	1146.6	1145.9	1145.1	1144.2	1143.4	1142.5	1141.3	1140.7	1139.4	1138.0
39	1146.9	1146.0	1145.3	1144.4	1143.6	1142.8	1141.6	1140.8	1139.4	1133.9

Table I.4 Scaled/Corrected data collected in modified cross-section and with only the spur bridge for a high flow. Piezometer units are ft-msl NAVD 88.

Test	80A	80C	80E	80G	80I	80K	80M	80O	80Q	80T
Discharge (ft^3/s)	11861	11895	11895	11929	11944	11944	11958	11988	11988	11998
Piezometer										
1	1147.8	1147.1	1146.5	1146.1	1145.6	1145.2	1144.8	1144.6	1144.4	1144.3
2	1147.6	1146.9	1146.2	1145.7	1145.3	1144.8	1144.3	1144.0	1143.9	1143.7
3	1147.5	1146.8	1146.2	1145.7	1145.2	1144.7	1144.2	1143.9	1143.7	1143.6
4	1147.5	1146.8	1146.2	1145.7	1145.1	1144.7	1144.1	1143.9	1143.6	1143.5
5	1147.4	1146.6	1146.1	1145.5	1144.9	1144.4	1143.8	1143.6	1143.3	1143.1
6	1147.4	1146.6	1146.1	1145.5	1144.8	1144.4	1143.8	1143.5	1143.3	1143.1
7	1147.4	1146.6	1146.1	1145.4	1144.8	1144.4	1143.8	1143.5	1143.2	1143.0
8	1147.4	1146.6	1146.1	1145.4	1144.8	1144.4	1143.7	1143.4	1143.1	1142.9
9	1147.3	1146.6	1146.0	1145.3	1144.8	1144.2	1143.5	1143.2	1142.9	1142.7
10	1147.3	1146.5	1146.0	1145.3	1144.7	1144.2	1143.5	1143.1	1142.9	1142.6
11	1147.2	1146.5	1145.9	1145.2	1144.5	1143.9	1143.3	1142.9	1142.5	1142.4
12	1147.3	1146.5	1145.9	1145.2	1144.5	1144.0	1143.3	1143.0	1142.6	1142.4
13	1147.2	1146.4	1145.8	1145.2	1144.5	1143.9	1143.1	1142.8	1142.4	1142.1
14	1147.1	1146.4	1145.7	1145.1	1144.4	1143.9	1143.1	1142.7	1142.4	1142.1
15	1147.1	1146.4	1145.8	1145.1	1144.4	1143.9	1143.1	1142.8	1142.4	1142.1
16	1147.1	1146.2	1145.6	1144.8	1144.2	1143.6	1142.8	1142.5	1142.0	1141.7
17	1147.1	1146.2	1145.7	1144.9	1144.3	1143.6	1142.8	1142.5	1142.0	1141.7
18	1147.1	1146.2	1145.7	1144.9	1144.2	1143.6	1142.7	1142.4	1141.9	1141.6
19	1147.1	1146.2	1145.7	1144.9	1144.3	1143.6	1142.8	1142.4	1141.9	1141.7
20	1147.1	1146.2	1145.6	1144.8	1144.1	1143.5	1142.6	1142.3	1141.8	1141.5
21	1146.9	1146.1	1145.4	1144.7	1144.0	1143.4	1142.5	1142.1	1141.6	1141.3
22	1146.9	1146.1	1145.4	1144.7	1143.9	1143.3	1142.4	1142.0	1141.5	1141.2
23	1146.9	1146.0	1145.4	1144.7	1143.9	1143.3	1142.4	1142.0	1141.5	1141.2
24	1146.9	1146.0	1145.3	1144.6	1143.9	1143.2	1142.2	1141.8	1141.2	1140.9
25	1146.9	1146.0	1145.3	1144.5	1143.8	1143.0	1142.1	1141.6	1141.1	1140.7
26	1146.9	1146.1	1145.4	1144.7	1144.0	1143.3	1142.3	1141.9	1141.3	1140.9
27	1146.8	1145.9	1145.3	1144.4	1143.7	1143.0	1141.9	1141.5	1140.7	1140.3
28	1146.9	1146.0	1145.3	1144.6	1143.8	1143.0	1142.1	1141.6	1140.9	1140.5
29	1146.8	1145.9	1145.3	1144.4	1143.6	1142.9	1141.8	1141.3	1140.6	1140.1
30	1146.7	1145.8	1145.2	1144.4	1143.5	1142.7	1141.6	1141.1	1140.3	1139.7
31	1146.6	1145.7	1145.0	1144.2	1143.3	1142.5	1141.3	1140.7	1139.9	1139.1
32	1146.7	1145.7	1145.1	1144.3	1143.5	1142.6	1141.5	1140.9	1140.1	1139.3
33	1146.6	1145.7	1145.0	1144.1	1143.3	1142.5	1141.2	1140.5	1139.6	1138.7
34	1146.6	1145.7	1145.0	1144.2	1143.3	1142.5	1141.2	1140.6	1139.7	1138.8
35	1146.6	1145.7	1145.0	1144.1	1143.3	1142.4	1141.2	1140.4	1139.5	1138.4
36	1146.6	1145.7	1145.0	1144.2	1143.3	1142.5	1141.2	1140.6	1139.6	1138.5
37	1146.6	1145.7	1144.9	1144.0	1143.2	1142.4	1141.0	1140.2	1139.1	1138.4
38	1146.7	1145.7	1145.1	1144.2	1143.4	1142.5	1141.2	1140.6	1139.5	1138.0
39	1146.8	1145.8	1145.3	1144.4	1143.5	1142.6	1141.5	1140.7	1139.3	1133.9

Appendix J. Flume Measurements

Appendix J.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table J.1 Raw experimental data collected in the physical model for a high flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are cm.

Test	100A	100B	100C	100D	100E	100F	100G	100H	100I	100J
Date	9/15	9/15	9/15	9/15	9/15	9/15	9/15	9/20	9/20	9/20
Pump Frq. (Hz)	61.1	61.1	61.3	61.3	61.3	61.3	61.3	61.2	61.2	61.2
Weir (cm)	88.99	89.04	89.20	89.32	89.32	89.32	89.32	89.38	89.39	89.46
Discharge (ft^3/s)	3.746	3.754	3.778	3.797	3.797	3.797	3.797	3.806	3.808	3.819
Water Temp (C)	21.2	21.2	21.2	21.2	21.3	21.3	21.3	21.2	21.2	21.2
Gate Hght (in)	5.88	5.38	5.13	4.38	3.75	3.00	0.00	7.38	7.13	6.50
Gate Hght (cm)	14.92	13.65	13.02	11.11	9.53	7.62	0.00	18.73	18.10	16.51
Piezometer										
1	26.8	26.6	26.5	26.4	26.3	26.3	26.3	28.2	27.7	27.2
2	26.5	26.2	26.1	26.0	26.0	26.0	26.0	28.0	27.5	27.1
3	26.5	26.2	26.1	26.0	25.9	25.9	25.9	28.0	27.5	27.0
4	26.5	26.2	26.1	26.0	26.0	25.9	25.9	27.9	27.5	27.0
5	26.3	26.1	26.0	25.8	25.8	25.8	25.8	27.9	27.3	26.9
6	26.3	26.0	26.0	25.8	25.8	25.8	25.8	27.9	27.3	26.9
7	26.3	26.0	25.9	25.8	25.8	25.8	25.8	27.9	27.4	26.8
8	26.3	26.0	25.9	25.8	25.8	25.8	25.8	27.8	27.4	26.8
9	26.2	26.0	25.8	25.8	25.7	25.7	25.7	27.8	27.3	26.8
10	26.2	26.0	25.8	25.8	25.7	25.7	25.7	27.8	27.3	26.8
11	26.1	25.8	25.7	25.5	25.5	25.5	25.4	27.7	27.2	26.6
12	26.0	25.7	25.6	25.5	25.4	25.4	25.4	27.6	27.1	26.6
13	26.0	25.7	25.6	25.4	25.4	25.4	25.3	27.5	27.1	26.5
14	25.9	25.7	25.5	25.4	25.3	25.3	25.3	27.5	27.1	26.5
15	25.5	25.2	25.1	25.0	24.9	24.9	24.8	27.2	26.7	26.1
16	23.4	22.8	22.5	22.2	22.0	22.0	22.0	25.6	24.8	24.0
17	22.9	22.2	21.8	21.3	21.1	21.0	21.0	25.4	24.6	23.5
18	21.6	20.7	20.2	19.5	19.0	19.0	18.9	24.8	23.8	22.5
19	21.4	19.9	18.8	16.8	14.7	14.2	14.1	24.7	23.7	22.4
20	22.0	20.6	19.7	18.4	16.7	14.2	12.3	25.1	24.1	22.8
21	22.2	20.8	20.1	18.4	17.8	17.2	17.2	25.1	24.2	23.0
22	22.1	20.8	20.0	18.7	18.2	16.9	16.6	25.0	24.2	22.9
23	22.2	20.9	20.0	18.5	18.2	17.7	16.7	25.1	24.2	23.0
24	22.2	20.9	20.0	18.7	18.5	17.3	17.1	25.2	24.3	23.0
25	22.1	20.8	19.9	18.5	18.1	16.8	16.6	25.1	24.3	22.8
26	22.4	21.2	20.4	19.1	18.5	17.5	17.1	25.3	24.5	23.2
27	22.3	21.1	20.4	18.8	18.2	17.2	16.7	25.4	24.5	23.2
28	22.4	21.2	20.2	19.0	18.6	17.7	17.1	25.4	24.6	23.3
29	22.3	21.1	20.2	18.8	18.4	17.3	16.6	25.4	24.5	23.2
30	22.3	21.1	20.2	19.0	18.5	17.4	16.7	25.3	24.5	23.1
31	22.0	20.8	19.9	18.5	17.9	16.7	15.7	25.1	24.3	22.8
32	22.1	21.1	20.2	18.9	18.2	17.1	16.1	25.1	24.2	22.9
33	22.0	21.0	20.1	18.6	17.9	16.6	15.6	25.2	24.3	22.9
34	22.2	21.2	20.3	18.8	18.1	16.8	15.8	25.3	24.4	23.1
35	22.2	21.1	20.2	18.7	17.8	16.5	15.1	25.3	24.3	23.0
36	22.4	21.3	20.4	18.8	18.0	16.8	15.4	25.4	24.4	23.2
37	22.4	21.1	20.3	18.7	17.8	16.3	14.6	25.4	24.5	23.3
38	22.5	21.3	20.5	18.9	17.9	16.5	14.8	25.5	24.6	23.4
39	22.7	21.6	20.8	19.2	18.2	16.5	9.9	25.7	24.8	23.6

Table J.2 Raw experimental data collected in the physical model for a medium flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are cm.

Test	101A	101B	101C	101D	101E	101F	101G	101H	101I	101J	101 K	101 L
Date	9/14	9/14	9/14	9/14	9/14	9/14	9/14	9/14	9/14	9/20	9/20	9/20
Pump Frq. (Hz)	54.8	54.8	54.8	54.8	54.8	54.8	54.8	54.8	54.8	55.1	55.1	55.1
Weir (cm)	84.89	84.90	84.95	84.98	85.04	85.07	85.14	85.14	85.19	85.19	85.29	85.30
Discharge (ft^3/s)	3.144	3.145	3.152	3.156	3.165	3.169	3.179	3.179	3.186	3.186	3.200	3.201
Water Temp (C)	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.3	21.4	21.3
Gate Hght (in)	7.13	6.75	6.38	5.63	5.00	4.00	3.00	2.00	0.00	8.13	7.75	7.25
Gate Hght (cm)	18.10	17.15	16.19	14.29	12.70	10.16	7.62	5.08	0.00	20.64	19.69	18.42
Piezometer												
1	26.1	25.6	25.0	24.6	24.4	24.1	24.1	24.1	24.1	27.6	26.9	26.2
2	25.9	25.3	24.8	24.3	24.1	23.8	23.8	23.8	23.8	27.5	26.8	26.0
3	25.8	25.3	24.7	24.2	24.0	23.7	23.7	23.7	23.7	27.4	26.7	26.0
4	25.9	25.3	24.8	24.2	24.1	23.7	23.7	23.7	23.7	27.4	26.7	26.0
5	25.8	25.2	24.6	24.1	23.9	23.6	23.6	23.6	23.6	27.3	26.7	25.9
6	25.8	25.2	24.6	24.1	23.9	23.6	23.6	23.6	23.6	27.3	26.7	25.9
7	25.8	25.2	24.6	24.1	23.9	23.6	23.6	23.6	23.6	27.3	26.6	25.9
8	25.7	25.2	24.6	24.1	23.9	23.5	23.5	23.6	23.6	27.3	26.6	25.9
9	25.7	25.1	24.5	24.0	23.8	23.5	23.4	23.5	23.5	27.3	26.6	25.8
10	25.7	25.1	24.5	24.0	23.8	23.5	23.4	23.5	23.5	27.3	26.6	25.8
11	25.5	25.0	24.3	23.8	23.6	23.3	23.3	23.3	23.3	27.2	26.5	25.7
12	25.5	24.9	24.3	23.8	23.6	23.3	23.3	23.3	23.3	27.2	26.4	25.7
13	25.5	24.9	24.3	23.7	23.5	23.2	23.2	23.2	23.2	27.1	26.4	25.6
14	25.5	24.9	24.2	23.7	23.5	23.2	23.2	23.2	23.1	27.1	26.4	25.6
15	25.3	24.6	23.9	23.4	23.2	22.7	22.7	22.7	22.7	26.9	26.2	25.3
16	23.9	23.0	22.0	21.1	20.7	19.9	19.9	19.9	19.9	25.8	24.8	23.9
17	23.7	22.8	21.6	20.5	20.0	18.8	18.7	18.7	18.7	25.7	24.8	23.8
18	23.2	22.2	20.7	19.5	18.9	17.3	16.9	16.9	16.9	25.3	24.3	23.2
19	23.2	22.2	20.6	19.0	18.0	14.9	13.3	13.2	13.2	25.3	24.3	23.2
20	23.5	22.4	21.0	19.6	18.5	16.5	13.9	12.1	12.0	25.6	24.5	23.5
21	23.6	22.5	21.2	19.7	18.8	16.7	16.0	15.7	15.7	25.6	24.6	23.6
22	23.6	22.5	21.2	19.7	18.7	16.9	16.0	15.4	15.4	25.6	24.6	23.6
23	23.6	22.6	21.2	19.8	18.8	17.1	16.2	16.0	15.9	25.6	24.6	23.6
24	23.6	22.6	21.3	20.0	18.7	17.2	16.3	15.7	15.6	25.6	24.7	23.7
25	23.6	22.5	21.3	20.0	18.7	17.2	16.0	15.3	15.2	25.6	24.6	23.6
26	23.7	22.7	21.5	20.3	19.2	17.6	16.4	15.8	15.8	25.8	24.8	23.8
27	23.7	22.7	21.4	20.0	19.0	17.3	16.1	15.4	15.3	25.7	24.8	23.7
28	23.8	22.8	21.5	20.2	19.1	17.6	16.4	15.8	15.8	25.8	24.8	23.8
29	23.7	22.6	21.4	20.1	19.0	17.4	16.1	15.6	15.5	25.8	24.7	23.7
30	23.7	22.6	21.4	20.1	19.0	17.4	16.1	15.6	15.5	25.7	24.7	23.7
31	23.4	22.3	21.2	19.8	18.7	17.0	15.4	14.8	14.6	25.5	24.5	23.4
32	23.5	22.5	21.3	20.0	19.0	17.2	15.7	15.1	15.0	25.5	24.5	23.5
33	23.5	22.4	21.2	19.9	18.9	17.0	15.2	14.3	14.3	25.6	24.6	23.5
34	23.6	22.5	21.3	20.0	19.0	17.2	15.4	14.6	14.5	25.7	24.6	23.6
35	23.5	22.5	21.3	19.9	19.0	16.9	15.0	14.0	13.9	25.6	24.6	23.6
36	23.7	22.8	21.5	20.1	19.2	17.2	15.3	14.3	14.3	25.7	24.7	23.6
37	23.6	22.7	21.5	20.1	19.1	16.9	15.0	13.6	13.5	25.7	24.8	23.7
38	23.8	22.7	21.5	20.2	19.2	17.1	15.2	13.7	13.6	25.9	24.9	23.8
39	24.0	23.0	21.8	20.5	19.4	17.3	15.1	11.2	9.2	26.0	25.0	24.0

Table J.3 Raw experimental data collected in the physical model for a low flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are cm.

Test	102A	102B	102C	102D	102E	102F	102G	102H	102I	102J	102K
Date	9/13	9/13	9/13	9/13	9/13	9/13	9/13	9/13	9/20	9/20	9/20
Pump Frq. (Hz)	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.5	49.5	49.4
Weir (cm)	79.86	79.98	80.25	80.49	80.54	80.66	80.67	80.67	80.35	80.41	80.48
Discharge (ft^3/s)	2.490	2.505	2.537	2.567	2.573	2.588	2.589	2.589	2.550	2.557	2.566
Water Temp (C)	21.1	21.0	20.9	20.9	20.9	20.9	20.9	20.9	21.4	21.4	21.3
Gate Hght (in)	7.75	7.13	6.00	5.00	4.00	3.00	1.25	0.00	9.13	8.50	7.63
Gate Hght (cm)	19.69	18.10	15.24	12.70	10.16	7.62	3.18	0.00	23.18	21.59	19.37
Piezometer											
1	25.0	24.4	23.1	22.1	21.7	21.8	21.8	21.9	27.4	26.5	25.2
2	24.8	24.2	22.8	21.8	21.5	21.4	21.4	21.5	27.3	26.4	25.1
3	24.8	24.1	22.7	21.7	21.4	21.4	21.4	21.4	27.3	26.3	25.1
4	24.8	24.2	22.7	21.8	21.5	21.4	21.4	21.4	27.3	26.4	25.1
5	24.7	24.0	22.6	21.6	21.2	21.2	21.2	21.2	27.2	26.3	25.0
6	24.7	24.0	22.7	21.6	21.2	21.2	21.2	21.2	27.2	26.3	25.0
7	24.7	24.0	22.6	21.6	21.2	21.2	21.2	21.2	27.2	26.3	25.0
8	24.7	24.0	22.6	21.6	21.2	21.1	21.1	21.1	27.2	26.3	25.0
9	24.7	23.9	22.5	21.5	21.0	21.0	21.0	21.0	27.2	26.2	24.9
10	24.6	23.9	22.6	21.4	21.0	21.0	21.0	21.0	27.2	26.2	24.9
11	24.5	23.8	22.4	21.2	20.8	20.8	20.8	20.8	27.1	26.2	24.8
12	24.5	23.8	22.4	21.2	20.9	20.8	20.8	20.8	27.1	26.1	24.8
13	24.5	23.7	22.3	21.2	20.8	20.8	20.8	20.8	27.1	26.1	24.7
14	24.5	23.8	22.3	21.2	20.7	20.7	20.7	20.7	27.1	26.1	24.8
15	24.4	23.6	22.1	20.8	20.5	20.4	20.4	20.4	26.9	26.0	24.6
16	23.4	22.5	20.5	18.6	17.8	17.7	17.7	17.7	26.3	25.3	23.7
17	23.4	22.5	20.3	18.0	17.0	16.7	16.7	16.7	26.3	25.2	23.6
18	23.1	22.1	19.8	17.5	15.9	14.8	14.7	14.7	26.1	25.0	23.3
19	23.1	22.2	19.7	17.2	14.3	12.1	11.8	11.7	26.1	25.0	23.4
20	23.3	22.3	20.0	17.6	15.6	13.5	12.3	11.9	26.2	25.1	23.5
21	23.3	22.4	20.2	17.8	16.0	14.5	13.2	13.3	26.3	25.2	23.6
22	23.4	22.4	20.1	17.7	15.7	14.5	13.5	13.6	26.2	25.1	23.6
23	23.4	22.4	20.2	17.8	16.1	15.0	14.3	14.1	26.2	25.1	23.6
24	23.4	22.4	20.3	18.0	16.1	15.1	14.6	14.5	26.2	25.1	23.6
25	23.3	22.4	20.2	18.0	16.3	15.1	14.5	14.5	26.3	25.1	23.6
26	23.5	22.5	20.4	18.2	16.5	15.4	14.8	14.8	26.4	25.2	23.7
27	23.4	22.5	20.2	18.1	16.2	15.1	14.5	14.5	26.4	25.3	23.7
28	23.5	22.6	20.3	18.3	16.4	15.2	14.7	14.7	26.4	25.2	23.7
29	23.4	22.5	20.3	18.1	16.3	15.0	14.3	14.3	26.3	25.2	23.7
30	23.4	22.5	20.3	18.2	16.3	14.9	14.2	14.3	26.3	25.2	23.6
31	23.2	22.2	20.1	17.7	15.9	14.2	13.3	13.3	26.2	24.9	23.4
32	23.3	22.3	20.2	18.0	16.2	14.5	13.7	13.7	26.1	25.0	23.4
33	23.2	22.3	20.1	17.9	16.0	14.1	13.1	13.1	26.2	25.0	23.4
34	23.3	22.4	20.2	18.0	16.1	14.3	13.2	13.2	26.3	25.1	23.5
35	23.3	22.3	20.2	18.1	16.0	14.0	12.7	12.7	26.2	25.1	23.5
36	23.4	22.5	20.3	18.2	16.2	14.2	12.9	12.9	26.3	25.2	23.6
37	23.3	22.4	20.2	18.0	16.0	13.9	12.2	12.2	26.3	25.2	23.6
38	23.5	22.5	20.3	18.1	16.1	14.0	12.3	12.3	26.4	25.3	23.7
39	23.7	22.7	20.5	18.3	16.3	14.1	9.1	8.2	26.5	25.4	23.8

Appendix J.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table J.4 Scaled/Corrected data collected for a high flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are ft-msl NAVD 88.

Test	100A	100B	100C	100D	100E	100F	100G	100H	100I	100J
Q (ft^3/s)	11706	11730	11807	11866	11866	11866	11866	11895	11900	11934
Piezometer										
1	1147.9	1147.7	1147.6	1147.6	1147.5	1147.5	1147.5	1149.0	1148.6	1148.2
2	1147.6	1147.4	1147.3	1147.2	1147.2	1147.2	1147.2	1148.9	1148.5	1148.1
3	1147.6	1147.4	1147.3	1147.2	1147.1	1147.1	1147.1	1148.9	1148.5	1148.0
4	1147.6	1147.4	1147.3	1147.2	1147.2	1147.1	1147.1	1148.8	1148.5	1148.0
5	1147.5	1147.3	1147.2	1147.1	1147.1	1147.1	1147.1	1148.8	1148.3	1148.0
6	1147.5	1147.2	1147.2	1147.1	1147.1	1147.1	1147.1	1148.8	1148.3	1148.0
7	1147.5	1147.2	1147.1	1147.1	1147.1	1147.1	1147.1	1148.8	1148.4	1147.9
8	1147.5	1147.2	1147.1	1147.1	1147.1	1147.1	1147.1	1148.7	1148.4	1147.9
9	1147.4	1147.2	1147.1	1147.1	1147.0	1147.0	1147.0	1148.7	1148.3	1147.9
10	1147.4	1147.2	1147.1	1147.1	1147.0	1147.0	1147.0	1148.7	1148.3	1147.9
11	1147.4	1147.1	1147.1	1146.9	1146.9	1146.9	1146.8	1148.7	1148.3	1147.8
12	1147.3	1147.1	1147.0	1146.9	1146.8	1146.8	1146.8	1148.6	1148.2	1147.8
13	1147.3	1147.1	1147.0	1146.8	1146.8	1146.8	1146.7	1148.5	1148.2	1147.7
14	1147.1	1147.0	1146.8	1146.7	1146.6	1146.6	1146.6	1148.5	1148.1	1147.6
15	1146.8	1146.6	1146.5	1146.4	1146.3	1146.3	1146.2	1148.2	1147.8	1147.3
16	1145.1	1144.6	1144.4	1144.1	1143.9	1143.9	1143.9	1146.9	1146.2	1145.6
17	1144.7	1144.1	1143.8	1143.4	1143.2	1143.1	1143.1	1146.7	1146.1	1145.2
18	1143.6	1142.9	1142.5	1141.9	1141.5	1141.5	1141.4	1146.2	1145.4	1144.4
19	1143.5	1142.2	1141.3	1139.7	1138.0	1137.5	1137.5	1146.2	1145.3	1144.3
20	1143.9	1142.8	1142.1	1141.0	1139.6	1137.5	1136.0	1146.5	1145.7	1144.6
21	1143.9	1142.8	1142.2	1140.8	1140.3	1139.8	1139.8	1146.3	1145.6	1144.6
22	1143.9	1142.8	1142.1	1141.1	1140.7	1139.6	1139.3	1146.2	1145.6	1144.5
23	1143.9	1142.9	1142.1	1140.9	1140.7	1140.3	1139.4	1146.3	1145.6	1144.6
24	1143.9	1142.9	1142.1	1141.1	1140.9	1139.9	1139.8	1146.4	1145.7	1144.6
25	1143.9	1142.9	1142.1	1141.0	1140.7	1139.6	1139.4	1146.4	1145.7	1144.5
26	1144.2	1143.2	1142.5	1141.5	1141.0	1140.2	1139.8	1146.6	1145.9	1144.8
27	1144.1	1143.1	1142.5	1141.2	1140.7	1139.9	1139.5	1146.6	1145.9	1144.8
28	1144.2	1143.2	1142.4	1141.4	1141.1	1140.3	1139.8	1146.6	1146.0	1144.9
29	1144.1	1143.1	1142.4	1141.2	1140.9	1140.0	1139.4	1146.6	1145.9	1144.8
30	1144.1	1143.1	1142.4	1141.4	1141.0	1140.1	1139.5	1146.6	1145.9	1144.8
31	1143.9	1143.0	1142.2	1141.1	1140.6	1139.6	1138.8	1146.5	1145.8	1144.6
32	1144.0	1143.2	1142.5	1141.4	1140.8	1139.9	1139.1	1146.5	1145.7	1144.7
33	1143.9	1143.1	1142.4	1141.2	1140.6	1139.5	1138.7	1146.6	1145.8	1144.7
34	1144.1	1143.3	1142.5	1141.3	1140.7	1139.7	1138.9	1146.6	1145.9	1144.8
35	1144.1	1143.2	1142.5	1141.2	1140.5	1139.4	1138.3	1146.6	1145.8	1144.8
36	1144.2	1143.3	1142.5	1141.2	1140.6	1139.6	1138.4	1146.6	1145.8	1144.8
37	1144.2	1143.1	1142.5	1141.2	1140.4	1139.2	1137.8	1146.6	1145.9	1144.9
38	1144.3	1143.3	1142.6	1141.3	1140.5	1139.3	1138.0	1146.7	1146.0	1145.0
39	1144.4	1143.5	1142.9	1141.6	1140.7	1139.3	1133.9	1146.9	1146.2	1145.2

Table J.5 Scaled/Corrected data collected for a medium flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are ft-msl NAVD 88.

Test	101A	101B	101C	101D	101E	101F	101G	101H	101I	101J	101K	101L
Q (ft^3/s)	9825	9829	9851	9864	9890	9903	9934	9934	9956	9956	9999	10004
Piezometer												
1	1147.3	1146.9	1146.4	1146.1	1145.9	1145.7	1145.7	1145.7	1145.7	1148.5	1148.0	1147.4
2	1147.1	1146.6	1146.2	1145.8	1145.7	1145.4	1145.4	1145.4	1145.4	1148.5	1147.9	1147.2
3	1147.1	1146.6	1146.2	1145.7	1145.6	1145.3	1145.3	1145.3	1145.3	1148.4	1147.8	1147.2
4	1147.1	1146.6	1146.2	1145.7	1145.7	1145.3	1145.3	1145.3	1145.3	1148.4	1147.8	1147.2
5	1147.1	1146.6	1146.1	1145.7	1145.5	1145.3	1145.3	1145.3	1145.3	1148.3	1147.8	1147.1
6	1147.1	1146.6	1146.1	1145.7	1145.5	1145.3	1145.3	1145.3	1145.3	1148.3	1147.8	1147.1
7	1147.1	1146.6	1146.1	1145.7	1145.5	1145.3	1145.3	1145.3	1145.3	1148.3	1147.7	1147.1
8	1147.0	1146.6	1146.1	1145.7	1145.5	1145.2	1145.2	1145.3	1145.3	1148.3	1147.7	1147.1
9	1147.0	1146.5	1146.0	1145.6	1145.4	1145.2	1145.1	1145.2	1145.2	1148.3	1147.7	1147.1
10	1147.0	1146.5	1146.0	1145.6	1145.4	1145.2	1145.1	1145.2	1145.2	1148.3	1147.7	1147.1
11	1146.9	1146.5	1145.9	1145.5	1145.3	1145.1	1145.1	1145.1	1145.1	1148.3	1147.7	1147.1
12	1146.9	1146.4	1145.9	1145.5	1145.3	1145.1	1145.1	1145.1	1145.1	1148.3	1147.6	1147.1
13	1146.9	1146.4	1145.9	1145.4	1145.3	1145.0	1145.0	1145.0	1145.0	1148.2	1147.6	1147.0
14	1146.8	1146.3	1145.7	1145.3	1145.2	1144.9	1144.9	1144.9	1144.8	1148.1	1147.6	1146.9
15	1146.6	1146.1	1145.5	1145.1	1144.9	1144.5	1144.5	1144.5	1144.5	1148.0	1147.4	1146.6
16	1145.5	1144.8	1143.9	1143.2	1142.9	1142.2	1142.2	1142.2	1142.2	1147.1	1146.2	1145.5
17	1145.3	1144.6	1143.6	1142.7	1142.3	1141.3	1141.2	1141.2	1141.2	1147.0	1146.2	1145.4
18	1144.9	1144.1	1142.9	1141.9	1141.4	1140.1	1139.8	1139.8	1139.8	1146.6	1145.8	1144.9
19	1144.9	1144.1	1142.8	1141.5	1140.7	1138.1	1136.8	1136.7	1136.7	1146.6	1145.8	1144.9
20	1145.2	1144.3	1143.1	1142.0	1141.1	1139.4	1137.3	1135.8	1135.7	1146.9	1146.0	1145.2
21	1145.1	1144.2	1143.1	1141.9	1141.2	1139.4	1138.9	1138.6	1138.6	1146.7	1145.9	1145.1
22	1145.1	1144.2	1143.1	1141.9	1141.1	1139.6	1138.9	1138.4	1138.4	1146.7	1145.9	1145.1
23	1145.1	1144.3	1143.1	1142.0	1141.2	1139.8	1139.0	1138.9	1138.8	1146.7	1145.9	1145.1
24	1145.1	1144.3	1143.2	1142.1	1141.1	1139.8	1139.1	1138.6	1138.5	1146.7	1146.0	1145.2
25	1145.2	1144.3	1143.3	1142.2	1141.2	1139.9	1138.9	1138.4	1138.3	1146.8	1146.0	1145.2
26	1145.3	1144.4	1143.5	1142.5	1141.6	1140.3	1139.3	1138.8	1138.8	1147.0	1146.2	1145.3
27	1145.3	1144.4	1143.4	1142.2	1141.4	1140.0	1139.0	1138.4	1138.4	1146.9	1146.2	1145.3
28	1145.3	1144.5	1143.5	1142.4	1141.5	1140.3	1139.3	1138.8	1138.8	1147.0	1146.2	1145.3
29	1145.3	1144.4	1143.4	1142.3	1141.4	1140.1	1139.0	1138.6	1138.5	1147.0	1146.1	1145.3
30	1145.3	1144.4	1143.4	1142.3	1141.4	1140.1	1139.0	1138.6	1138.5	1146.9	1146.1	1145.3
31	1145.1	1144.2	1143.3	1142.1	1141.2	1139.8	1138.5	1138.0	1137.9	1146.8	1146.0	1145.1
32	1145.2	1144.4	1143.4	1142.3	1141.5	1140.0	1138.8	1138.3	1138.2	1146.8	1146.0	1145.2
33	1145.2	1144.3	1143.3	1142.2	1141.4	1139.8	1138.4	1137.6	1137.6	1146.9	1146.1	1145.2
34	1145.3	1144.4	1143.4	1142.3	1141.5	1140.0	1138.5	1137.9	1137.8	1147.0	1146.1	1145.3
35	1145.2	1144.4	1143.4	1142.2	1141.5	1139.8	1138.2	1137.4	1137.3	1146.9	1146.1	1145.3
36	1145.3	1144.5	1143.5	1142.3	1141.6	1139.9	1138.4	1137.5	1137.5	1146.9	1146.1	1145.2
37	1145.2	1144.4	1143.5	1142.3	1141.5	1139.7	1138.1	1137.0	1136.9	1146.9	1146.2	1145.3
38	1145.3	1144.4	1143.5	1142.4	1141.6	1139.8	1138.3	1137.1	1137.0	1147.1	1146.2	1145.3
39	1145.5	1144.7	1143.7	1142.6	1141.7	1140.0	1138.2	1135.0	1133.4	1147.1	1146.3	1145.5

Table J.6 Scaled/Corrected data collected for a low flow with flume and model bridges in place. 2:1 Entrance and Exit. Piezometer units are ft-msl NAVD 88.

Test	102A	102B	102C	102D	102E	102F	102G	102H	102I	102J	102K
Q (ft^3/s)	7781	7827	7929	8022	8041	8087	8091	8091	7968	7991	8018
Piezometer											
1	1146.4	1145.9	1144.8	1144.0	1143.7	1143.8	1143.8	1143.9	1148.4	1147.6	1146.6
2	1146.2	1145.7	1144.6	1143.8	1143.5	1143.5	1143.5	1143.5	1148.3	1147.6	1146.5
3	1146.2	1145.7	1144.5	1143.7	1143.5	1143.5	1143.5	1143.5	1148.3	1147.5	1146.5
4	1146.2	1145.7	1144.5	1143.8	1143.5	1143.5	1143.5	1143.5	1148.3	1147.6	1146.5
5	1146.2	1145.6	1144.4	1143.6	1143.3	1143.3	1143.3	1143.3	1148.2	1147.5	1146.4
6	1146.2	1145.6	1144.5	1143.6	1143.3	1143.3	1143.3	1143.3	1148.2	1147.5	1146.4
7	1146.2	1145.6	1144.4	1143.6	1143.3	1143.3	1143.3	1143.3	1148.2	1147.5	1146.4
8	1146.2	1145.6	1144.4	1143.6	1143.3	1143.2	1143.2	1143.2	1148.2	1147.5	1146.4
9	1146.2	1145.5	1144.4	1143.5	1143.1	1143.1	1143.1	1143.1	1148.2	1147.4	1146.3
10	1146.1	1145.5	1144.4	1143.5	1143.1	1143.1	1143.1	1143.1	1148.2	1147.4	1146.3
11	1146.1	1145.5	1144.4	1143.4	1143.0	1143.0	1143.0	1143.0	1148.2	1147.5	1146.3
12	1146.1	1145.5	1144.4	1143.4	1143.1	1143.0	1143.0	1143.0	1148.2	1147.4	1146.3
13	1146.1	1145.4	1144.3	1143.4	1143.0	1143.0	1143.0	1143.0	1148.2	1147.4	1146.2
14	1146.0	1145.4	1144.2	1143.3	1142.9	1142.9	1142.9	1142.9	1148.1	1147.3	1146.2
15	1145.9	1145.3	1144.0	1143.0	1142.7	1142.6	1142.6	1142.6	1148.0	1147.2	1146.1
16	1145.1	1144.4	1142.7	1141.2	1140.5	1140.4	1140.4	1140.4	1147.5	1146.6	1145.3
17	1145.1	1144.4	1142.5	1140.7	1139.8	1139.6	1139.6	1139.6	1147.5	1146.6	1145.3
18	1144.8	1144.0	1142.1	1140.3	1138.9	1138.0	1138.0	1138.0	1147.3	1146.4	1145.0
19	1144.8	1144.1	1142.1	1140.0	1137.6	1135.8	1135.6	1135.5	1147.3	1146.4	1145.1
20	1145.0	1144.2	1142.3	1140.3	1138.7	1137.0	1136.0	1135.7	1147.4	1146.5	1145.2
21	1144.8	1144.1	1142.3	1140.3	1138.9	1137.6	1136.6	1136.6	1147.3	1146.4	1145.1
22	1144.9	1144.1	1142.2	1140.3	1138.6	1137.6	1136.8	1136.9	1147.2	1146.3	1145.1
23	1144.9	1144.1	1142.3	1140.3	1138.9	1138.0	1137.5	1137.3	1147.2	1146.3	1145.1
24	1144.9	1144.1	1142.4	1140.5	1138.9	1138.1	1137.7	1137.6	1147.2	1146.3	1145.1
25	1144.9	1144.2	1142.4	1140.6	1139.2	1138.2	1137.7	1137.7	1147.4	1146.4	1145.2
26	1145.1	1144.3	1142.5	1140.7	1139.3	1138.4	1138.0	1138.0	1147.5	1146.5	1145.3
27	1145.0	1144.3	1142.4	1140.7	1139.1	1138.2	1137.7	1137.7	1147.5	1146.6	1145.3
28	1145.1	1144.4	1142.5	1140.8	1139.3	1138.3	1137.9	1137.9	1147.5	1146.5	1145.3
29	1145.0	1144.3	1142.5	1140.7	1139.2	1138.1	1137.5	1137.5	1147.4	1146.5	1145.3
30	1145.0	1144.3	1142.5	1140.7	1139.2	1138.0	1137.5	1137.5	1147.4	1146.5	1145.2
31	1144.9	1144.1	1142.4	1140.4	1138.9	1137.5	1136.8	1136.8	1147.4	1146.3	1145.1
32	1145.0	1144.2	1142.5	1140.7	1139.2	1137.8	1137.1	1137.1	1147.3	1146.4	1145.1
33	1144.9	1144.2	1142.4	1140.6	1139.0	1137.5	1136.6	1136.6	1147.4	1146.4	1145.1
34	1145.0	1144.3	1142.5	1140.7	1139.1	1137.6	1136.7	1136.7	1147.5	1146.5	1145.2
35	1145.0	1144.2	1142.5	1140.7	1139.0	1137.4	1136.3	1136.3	1147.4	1146.5	1145.2
36	1145.0	1144.3	1142.5	1140.7	1139.1	1137.5	1136.4	1136.4	1147.4	1146.5	1145.2
37	1144.9	1144.2	1142.4	1140.6	1138.9	1137.2	1135.8	1135.8	1147.4	1146.5	1145.2
38	1145.1	1144.3	1142.5	1140.7	1139.0	1137.3	1135.9	1135.9	1147.5	1146.6	1145.3
39	1145.3	1144.4	1142.6	1140.8	1139.2	1137.4	1133.3	1132.5	1147.6	1146.6	1145.3

Appendix K. Flume Measurements with Pier Extensions

Appendix K.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table K.1 Raw experimental data collected in the physical model for a high flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are cm.

Test	120A	120B	120C	120D	120E	120F	120G	120H
Date	9/24	9/24	9/24	9/24	9/24	9/24	9/24	9/24
Pump Frq. (Hz)	61.2	61.2	61.2	61.2	61.2	61.2	61.2	61.2
Weir (cm)	89.36	89.29	89.45	89.49	89.45	89.39	89.39	89.43
Discharge (ft^3/s)	3.803	3.792	3.817	3.824	3.817	3.808	3.808	3.814
Water Temp (C)	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7
Gate Hght (in)	7.63	7.13	6.50	6.25	5.50	5.38	4.38	4.00
Gate Hght (cm)	19.37	18.10	16.51	15.88	13.97	13.65	11.11	10.16
Piezometer								
1	28.1	27.8	27.3	27.0	26.8	26.6	26.5	26.4
2	27.9	27.5	27.1	26.8	26.5	26.4	26.2	26.2
3	27.9	27.5	27.0	26.7	26.4	26.3	26.1	26.1
4	27.9	27.5	27.0	26.7	26.4	26.3	26.1	26.1
5	27.8	27.4	26.9	26.6	26.3	26.2	26.0	26.0
6	27.8	27.4	26.9	26.6	26.3	26.2	26.0	26.0
7	27.8	27.4	26.9	26.6	26.3	26.1	26.0	26.0
8	27.8	27.4	26.8	26.5	26.3	26.1	25.9	25.9
9	27.7	27.3	26.8	26.5	26.2	26.0	25.9	25.8
10	27.7	27.3	26.8	26.5	26.2	26.0	25.9	25.8
11	27.6	27.2	26.6	26.3	26.0	25.9	25.7	25.7
12	27.5	27.2	26.5	26.3	26.0	25.8	25.7	25.7
13	27.5	27.1	26.5	26.2	25.9	25.8	25.6	25.5
14	27.4	27.0	26.5	26.2	25.8	25.7	25.6	25.5
15	27.1	26.7	26.1	25.7	25.4	25.3	25.2	25.1
16	25.5	24.9	23.9	23.5	22.8	22.5	22.3	22.1
17	25.4	24.7	23.5	23.0	22.2	21.8	21.4	21.1
18	24.7	23.9	22.4	21.6	20.6	20.2	19.7	19.2
19	24.7	23.9	22.2	21.3	19.8	18.9	16.9	14.8
20	25.0	24.3	22.7	22.0	20.6	19.8	18.4	16.9
21	25.0	24.3	22.9	22.2	20.8	20.2	18.7	18.1
22	25.0	24.3	22.9	22.1	20.7	20.0	18.8	18.3
23	25.1	24.3	23.0	22.2	20.8	20.2	18.6	18.4
24	25.1	24.4	23.0	22.3	20.8	20.1	18.8	18.5
25	25.1	24.4	22.8	22.2	20.6	19.9	18.6	18.2
26	25.3	24.6	23.2	22.5	21.1	20.5	19.2	18.5
27	25.3	24.6	23.1	22.4	21.0	20.3	18.8	18.2
28	25.4	24.7	23.2	22.5	21.1	20.5	19.0	18.6
29	25.3	24.6	23.1	22.4	21.0	20.3	18.8	18.5
30	25.3	24.6	23.1	22.4	21.0	20.3	18.9	18.6
31	25.0	24.2	22.7	22.1	20.6	20.0	18.5	18.1
32	25.2	24.4	22.9	22.2	20.8	20.2	18.8	18.3
33	25.2	24.4	22.8	22.1	20.8	20.1	18.6	18.0
34	25.2	24.5	23.0	22.2	21.0	20.3	18.9	18.2
35	25.3	24.4	22.9	22.2	21.0	20.3	18.7	18.0
36	25.4	24.5	23.2	22.4	21.1	20.4	18.8	18.0
37	25.4	24.7	23.1	22.5	21.1	20.4	18.8	18.1
38	25.5	24.8	23.2	22.7	21.2	20.5	19.0	18.1
39	25.7	25.0	23.5	23.0	21.5	20.9	19.3	18.4

Table K.2 Raw experimental data collected in the physical model for a medium flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are cm.

Test	121A	121B	121C	121D	121E	121F	121G	121H	121I
Date	9/27	9/27	9/27	9/27	9/27	9/27	9/27	9/27	9/27
Pump Frq. (Hz)	55.2	55.2	55.2	55.2	55.2	55.0	54.8	54.8	54.8
Weir (cm)	85.18	85.21	85.36	85.37	85.39	85.37	85.23	85.30	85.24
Discharge (ft^3/s)	3.184	3.189	3.210	3.211	3.214	3.211	3.191	3.201	3.193
Water Temp (C)	20.6	20.6	20.6	20.6	20.6	20.5	20.5	20.5	20.5
Gate Hght (in)	8.13	7.50	7.13	6.75	6.38	5.50	5.13	4.00	3.13
Gate Hght (cm)	20.64	19.05	18.10	17.15	16.19	13.97	13.02	10.16	7.94
Piezometer									
1	27.5	26.9	26.3	25.9	25.5	24.8	24.6	24.4	24.0
2	27.3	26.7	26.1	25.6	25.2	24.5	24.3	24.0	23.9
3	27.3	26.7	26.1	25.6	25.2	24.5	24.2	24.0	23.9
4	27.3	26.7	26.1	25.6	25.2	24.5	24.2	24.0	23.8
5	27.2	26.6	26.0	25.5	25.1	24.4	24.1	23.9	23.7
6	27.2	26.6	26.0	25.5	25.1	24.4	24.1	23.9	23.7
7	27.2	26.6	26.0	25.5	25.1	24.4	24.1	23.9	23.7
8	27.2	26.6	26.0	25.5	25.1	24.4	24.1	23.8	23.7
9	27.1	26.5	25.9	25.4	25.0	24.3	24.0	23.8	23.6
10	27.1	26.5	25.9	25.4	25.0	24.3	24.0	23.8	23.6
11	27.0	26.4	25.8	25.3	24.8	24.1	23.8	23.5	23.4
12	27.0	26.3	25.7	25.2	24.7	24.0	23.7	23.5	23.4
13	26.9	26.3	25.7	25.2	24.7	23.9	23.6	23.4	23.3
14	27.0	26.3	25.7	25.2	24.7	23.9	23.6	23.3	23.3
15	26.7	26.0	25.4	24.8	24.4	23.6	23.3	23.0	22.8
16	25.7	24.7	23.9	23.2	22.4	21.2	20.7	20.1	19.8
17	25.6	24.7	23.7	23.0	22.2	20.7	20.1	19.2	18.6
18	25.3	24.3	23.2	22.4	21.3	19.5	18.8	18.0	17.2
19	25.2	24.2	23.2	22.4	21.2	19.1	18.0	15.6	13.2
20	25.5	24.4	23.5	22.6	21.6	19.6	18.7	16.7	14.2
21	25.5	24.5	23.6	22.8	21.7	19.9	18.8	17.1	16.1
22	25.4	24.5	23.6	22.7	21.7	19.7	18.9	17.1	16.1
23	25.5	24.6	23.6	22.8	21.7	20.0	18.8	16.9	16.2
24	25.6	24.6	23.6	22.8	21.8	20.1	18.8	17.0	16.4
25	25.5	24.6	23.6	22.7	21.7	20.0	18.8	16.8	16.0
26	25.6	24.7	23.7	22.9	22.1	20.4	19.4	17.4	16.5
27	25.6	24.7	23.7	22.9	22.0	20.2	19.1	17.0	16.1
28	25.7	24.8	23.8	23.0	22.1	20.3	19.2	17.3	16.4
29	25.7	24.7	23.7	22.9	21.9	20.2	19.1	17.2	16.2
30	25.6	24.7	23.7	22.9	21.9	20.2	19.2	17.2	16.2
31	25.4	24.4	23.4	22.6	21.6	19.9	18.8	16.8	15.6
32	25.4	24.5	23.5	22.7	21.7	20.0	18.9	17.1	15.7
33	25.5	24.5	23.5	22.6	21.7	19.9	19.0	17.0	15.3
34	25.5	24.6	23.6	22.8	21.8	20.1	19.1	17.1	15.5
35	25.4	24.5	23.6	22.8	21.7	20.0	19.0	17.0	15.2
36	25.7	24.7	23.7	22.8	21.9	20.1	19.2	17.2	15.3
37	25.6	24.8	23.7	22.9	22.0	20.2	19.2	17.1	15.3
38	25.8	24.9	23.8	23.1	22.1	20.3	19.3	17.2	15.3
39	25.9	25.0	24.1	23.3	22.3	20.5	19.6	17.5	15.4

Table K.3 Raw experimental data collected in the physical model for a low flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are cm.

Test	122A	122B	122C	122D	122E	122F	122G	122H	122I
Date	9/28	9/28	9/28	9/28	9/28	9/28	9/28	9/28	9/28
Pump Frq. (Hz)	49.8	49.8	49.8	49.8	49.8	49.2	49.2	49.2	49.2
Weir (cm)	80.13	80.26	80.46	80.54	80.79	80.29	80.52	80.50	80.66
Discharge (ft^3/s)	2.523	2.539	2.563	2.573	2.604	2.542	2.571	2.568	2.588
Water Temp (C)	20.8	20.8	20.8	20.8	20.7	20.7	20.7	20.7	20.7
Gate Hght (in)	9.25	8.63	7.50	7.13	6.00	5.13	4.25	3.25	0.00
Gate Hght (cm)	23.50	21.91	19.05	18.10	15.24	13.02	10.80	8.26	0.00
Piezometer									
1	27.4	26.7	25.3	24.5	23.3	22.2	21.9	21.8	21.8
2	27.3	26.5	25.1	24.3	23.1	21.9	21.6	21.5	21.5
3	27.3	26.4	25.1	24.3	23.0	21.8	21.5	21.4	21.4
4	27.3	26.4	25.1	24.3	23.0	21.8	21.5	21.4	21.4
5	27.2	26.4	25.0	24.2	22.9	21.7	21.3	21.2	21.2
6	27.2	26.3	25.0	24.2	22.9	21.7	21.3	21.2	21.2
7	27.2	26.3	25.0	24.2	22.9	21.7	21.3	21.2	21.2
8	27.2	26.3	25.0	24.2	22.8	21.7	21.3	21.1	21.2
9	27.2	26.3	24.9	24.1	22.8	21.6	21.2	21.0	21.1
10	27.2	26.3	24.9	24.1	22.8	21.6	21.1	21.0	21.0
11	27.1	26.2	24.8	23.9	22.6	21.3	20.9	20.7	20.8
12	27.1	26.2	24.8	23.9	22.6	21.3	20.9	20.7	20.8
13	27.1	26.1	24.8	23.9	22.5	21.3	20.9	20.7	20.8
14	27.1	26.1	24.8	23.9	22.5	21.2	20.8	20.6	20.7
15	27.0	26.0	24.6	23.7	22.2	20.9	20.5	20.3	20.4
16	26.4	25.3	23.7	22.5	20.5	18.6	17.6	17.4	17.3
17	26.3	25.3	23.6	22.4	20.3	18.3	17.0	16.5	16.4
18	26.1	25.1	23.3	22.1	19.8	17.6	16.4	15.1	15.0
19	26.1	25.1	23.4	22.1	19.7	17.2	15.1	11.9	11.5
20	26.2	25.2	23.5	22.3	20.0	17.6	15.6	13.4	9.9
21	26.3	25.3	23.6	22.3	20.2	17.8	16.0	13.8	13.4
22	26.3	25.3	23.5	22.4	20.1	17.8	15.8	14.1	12.9
23	26.3	25.3	23.5	22.4	20.2	17.9	16.0	14.4	13.8
24	26.3	25.3	23.6	22.4	20.3	18.1	15.8	15.0	14.0
25	26.3	25.3	23.5	22.4	20.2	18.0	16.0	14.9	14.0
26	26.3	25.3	23.7	22.5	20.4	18.4	16.4	15.4	14.7
27	26.3	25.4	23.7	22.5	20.3	18.2	16.1	15.1	14.4
28	26.3	25.4	23.7	22.5	20.4	18.3	16.3	15.3	14.5
29	26.3	25.4	23.6	22.4	20.4	18.2	16.1	15.1	14.2
30	26.3	25.3	23.6	22.4	20.4	18.2	16.2	15.0	14.2
31	26.1	25.1	23.4	22.2	20.1	18.0	15.8	14.4	13.3
32	26.2	25.2	23.4	22.3	20.2	18.1	16.0	14.5	13.3
33	26.2	25.2	23.5	22.3	20.1	17.9	15.9	14.1	12.8
34	26.2	25.2	23.5	22.3	20.2	18.1	16.1	14.3	13.1
35	26.2	25.2	23.5	22.3	20.2	18.1	16.0	14.1	12.7
36	26.3	25.2	23.6	22.4	20.3	18.2	16.2	14.2	12.8
37	26.3	25.2	23.7	22.5	20.3	18.2	16.2	14.2	12.6
38	26.4	25.3	23.7	22.6	20.4	18.2	16.2	14.2	12.3
39	26.5	25.5	23.8	22.7	20.6	18.4	16.4	14.2	8.1

Appendix K.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table K.4 Scaled/Corrected data collected for a high flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are ft-msl NAVD 88.

Test	120A	120B	120C	120D	120E	120F	120G	120H
Q (ft^3/s)	11885	11851	11929	11949	11929	11900	11900	11919
Piezometer								
1	1148.9	1148.7	1148.3	1148.0	1147.9	1147.7	1147.6	1147.6
2	1148.8	1148.5	1148.1	1147.9	1147.6	1147.6	1147.4	1147.4
3	1148.8	1148.5	1148.0	1147.8	1147.6	1147.5	1147.3	1147.3
4	1148.8	1148.5	1148.0	1147.8	1147.6	1147.5	1147.3	1147.3
5	1148.7	1148.4	1148.0	1147.7	1147.5	1147.4	1147.2	1147.2
6	1148.7	1148.4	1148.0	1147.7	1147.5	1147.4	1147.2	1147.2
7	1148.7	1148.4	1148.0	1147.7	1147.5	1147.3	1147.2	1147.2
8	1148.7	1148.4	1147.9	1147.6	1147.5	1147.3	1147.1	1147.1
9	1148.6	1148.3	1147.9	1147.6	1147.4	1147.2	1147.1	1147.1
10	1148.6	1148.3	1147.9	1147.6	1147.4	1147.2	1147.1	1147.1
11	1148.6	1148.3	1147.8	1147.6	1147.3	1147.2	1147.1	1147.1
12	1148.5	1148.3	1147.7	1147.6	1147.3	1147.1	1147.1	1147.1
13	1148.5	1148.2	1147.7	1147.5	1147.2	1147.1	1147.0	1146.9
14	1148.4	1148.0	1147.6	1147.4	1147.1	1147.0	1146.9	1146.8
15	1148.1	1147.8	1147.3	1147.0	1146.7	1146.6	1146.6	1146.5
16	1146.8	1146.3	1145.5	1145.2	1144.6	1144.4	1144.2	1144.0
17	1146.7	1146.2	1145.2	1144.8	1144.1	1143.8	1143.5	1143.2
18	1146.2	1145.5	1144.3	1143.6	1142.8	1142.5	1142.1	1141.6
19	1146.2	1145.5	1144.1	1143.4	1142.1	1141.4	1139.8	1138.0
20	1146.4	1145.8	1144.5	1143.9	1142.8	1142.1	1141.0	1139.8
21	1146.2	1145.7	1144.5	1143.9	1142.8	1142.3	1141.1	1140.6
22	1146.2	1145.7	1144.5	1143.9	1142.7	1142.1	1141.2	1140.7
23	1146.3	1145.7	1144.6	1143.9	1142.8	1142.3	1141.0	1140.8
24	1146.3	1145.7	1144.6	1144.0	1142.8	1142.2	1141.2	1140.9
25	1146.4	1145.8	1144.5	1144.0	1142.7	1142.1	1141.1	1140.7
26	1146.6	1146.0	1144.8	1144.3	1143.1	1142.6	1141.6	1141.0
27	1146.6	1146.0	1144.8	1144.2	1143.0	1142.5	1141.2	1140.7
28	1146.6	1146.1	1144.8	1144.3	1143.1	1142.6	1141.4	1141.1
29	1146.6	1146.0	1144.8	1144.2	1143.0	1142.5	1141.2	1141.0
30	1146.6	1146.0	1144.8	1144.2	1143.0	1142.5	1141.3	1141.1
31	1146.4	1145.7	1144.5	1144.0	1142.8	1142.3	1141.1	1140.7
32	1146.6	1145.9	1144.7	1144.1	1143.0	1142.5	1141.3	1140.9
33	1146.6	1145.9	1144.6	1144.0	1143.0	1142.4	1141.2	1140.7
34	1146.6	1146.0	1144.8	1144.1	1143.1	1142.5	1141.4	1140.8
35	1146.6	1145.9	1144.7	1144.1	1143.1	1142.5	1141.2	1140.7
36	1146.6	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.6
37	1146.6	1146.1	1144.8	1144.3	1143.1	1142.5	1141.2	1140.7
38	1146.7	1146.2	1144.8	1144.4	1143.2	1142.6	1141.4	1140.7
39	1146.9	1146.3	1145.1	1144.7	1143.5	1143.0	1141.6	1140.9

Table K.5 Scaled/Corrected data collected for a medium flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are ft-msl NAVD 88.

Test	121A	121B	121C	121D	121E	121F	121G	121H	121I
Q (ft^3/s)	9951	9964	10030	10035	10043	10035	9973	10004	9977
Piezometer									
1	1148.5	1148.0	1147.5	1147.1	1146.8	1146.2	1146.1	1145.9	1145.6
2	1148.3	1147.8	1147.3	1146.9	1146.6	1146.0	1145.8	1145.6	1145.5
3	1148.3	1147.8	1147.3	1146.9	1146.6	1146.0	1145.7	1145.6	1145.5
4	1148.3	1147.8	1147.3	1146.9	1146.6	1146.0	1145.7	1145.6	1145.4
5	1148.2	1147.7	1147.2	1146.8	1146.5	1145.9	1145.7	1145.5	1145.3
6	1148.2	1147.7	1147.2	1146.8	1146.5	1145.9	1145.7	1145.5	1145.3
7	1148.2	1147.7	1147.2	1146.8	1146.5	1145.9	1145.7	1145.5	1145.3
8	1148.2	1147.7	1147.2	1146.8	1146.5	1145.9	1145.7	1145.4	1145.3
9	1148.1	1147.6	1147.1	1146.7	1146.4	1145.8	1145.6	1145.4	1145.3
10	1148.1	1147.6	1147.1	1146.7	1146.4	1145.8	1145.6	1145.4	1145.3
11	1148.1	1147.6	1147.1	1146.7	1146.3	1145.7	1145.5	1145.3	1145.2
12	1148.1	1147.6	1147.1	1146.6	1146.2	1145.7	1145.4	1145.3	1145.2
13	1148.0	1147.6	1147.1	1146.6	1146.2	1145.6	1145.3	1145.2	1145.1
14	1148.0	1147.5	1147.0	1146.6	1146.2	1145.5	1145.3	1145.0	1145.0
15	1147.8	1147.2	1146.7	1146.2	1145.9	1145.3	1145.0	1144.8	1144.6
16	1147.0	1146.2	1145.5	1144.9	1144.3	1143.3	1142.9	1142.4	1142.1
17	1146.9	1146.2	1145.3	1144.8	1144.1	1142.9	1142.4	1141.6	1141.2
18	1146.6	1145.8	1144.9	1144.3	1143.4	1141.9	1141.3	1140.7	1140.0
19	1146.6	1145.7	1144.9	1144.3	1143.3	1141.6	1140.7	1138.7	1136.7
20	1146.8	1145.9	1145.2	1144.4	1143.6	1142.0	1141.2	1139.6	1137.5
21	1146.6	1145.8	1145.1	1144.4	1143.5	1142.1	1141.2	1139.8	1138.9
22	1146.6	1145.8	1145.1	1144.4	1143.5	1141.9	1141.2	1139.8	1138.9
23	1146.6	1145.9	1145.1	1144.4	1143.5	1142.1	1141.2	1139.6	1139.0
24	1146.7	1145.9	1145.1	1144.4	1143.6	1142.2	1141.2	1139.7	1139.2
25	1146.7	1146.0	1145.2	1144.4	1143.6	1142.2	1141.2	1139.6	1138.9
26	1146.8	1146.1	1145.3	1144.6	1143.9	1142.5	1141.7	1140.1	1139.3
27	1146.8	1146.1	1145.3	1144.6	1143.9	1142.4	1141.5	1139.8	1139.0
28	1146.9	1146.2	1145.3	1144.7	1143.9	1142.5	1141.6	1140.0	1139.3
29	1146.9	1146.1	1145.3	1144.6	1143.8	1142.4	1141.5	1139.9	1139.1
30	1146.8	1146.1	1145.3	1144.6	1143.8	1142.4	1141.6	1139.9	1139.1
31	1146.7	1145.9	1145.1	1144.4	1143.6	1142.2	1141.3	1139.7	1138.7
32	1146.7	1146.0	1145.2	1144.5	1143.7	1142.3	1141.4	1139.9	1138.8
33	1146.8	1146.0	1145.2	1144.4	1143.7	1142.2	1141.5	1139.8	1138.4
34	1146.8	1146.1	1145.3	1144.6	1143.8	1142.4	1141.6	1139.9	1138.6
35	1146.7	1146.0	1145.3	1144.6	1143.7	1142.3	1141.5	1139.8	1138.4
36	1146.9	1146.1	1145.3	1144.5	1143.8	1142.3	1141.6	1139.9	1138.4
37	1146.8	1146.2	1145.3	1144.6	1143.9	1142.4	1141.6	1139.8	1138.4
38	1147.0	1146.2	1145.3	1144.8	1143.9	1142.5	1141.6	1139.9	1138.4
39	1147.1	1146.3	1145.6	1144.9	1144.1	1142.6	1141.9	1140.2	1138.4

Table K.6 Scaled/Corrected data collected for a low flow with flume and model bridges in place. 2:1 Entrance and Exit. Pier extensions on the spur bridge central columns. Piezometer units are ft-msl NAVD 88.

Test	122A	122B	122C	122D	122E	122F	122G	122H	122I
Q (ft^3/s)	7884	7933	8010	8041	8138	7945	8033	8025	8087
Piezometer									
1	1148.4	1147.8	1146.6	1146.0	1145.0	1144.1	1143.9	1143.8	1143.8
2	1148.3	1147.6	1146.5	1145.8	1144.8	1143.9	1143.6	1143.5	1143.5
3	1148.3	1147.6	1146.5	1145.8	1144.8	1143.8	1143.5	1143.5	1143.5
4	1148.3	1147.6	1146.5	1145.8	1144.8	1143.8	1143.5	1143.5	1143.5
5	1148.2	1147.6	1146.4	1145.7	1144.7	1143.7	1143.4	1143.3	1143.3
6	1148.2	1147.5	1146.4	1145.7	1144.7	1143.7	1143.4	1143.3	1143.3
7	1148.2	1147.5	1146.4	1145.7	1144.7	1143.7	1143.4	1143.3	1143.3
8	1148.2	1147.5	1146.4	1145.7	1144.6	1143.7	1143.4	1143.2	1143.3
9	1148.2	1147.5	1146.3	1145.7	1144.6	1143.6	1143.3	1143.1	1143.2
10	1148.2	1147.5	1146.3	1145.7	1144.6	1143.6	1143.2	1143.1	1143.1
11	1148.2	1147.5	1146.3	1145.6	1144.5	1143.5	1143.1	1143.0	1143.0
12	1148.2	1147.5	1146.3	1145.6	1144.5	1143.5	1143.1	1143.0	1143.0
13	1148.2	1147.4	1146.3	1145.6	1144.4	1143.5	1143.1	1143.0	1143.0
14	1148.1	1147.3	1146.2	1145.5	1144.4	1143.3	1143.0	1142.8	1142.9
15	1148.0	1147.2	1146.1	1145.3	1144.1	1143.0	1142.7	1142.5	1142.6
16	1147.6	1146.6	1145.3	1144.4	1142.7	1141.2	1140.3	1140.2	1140.1
17	1147.5	1146.6	1145.3	1144.3	1142.5	1140.9	1139.8	1139.4	1139.3
18	1147.3	1146.5	1145.0	1144.0	1142.1	1140.3	1139.3	1138.3	1138.2
19	1147.3	1146.5	1145.1	1144.0	1142.1	1140.0	1138.3	1135.7	1135.3
20	1147.4	1146.6	1145.2	1144.2	1142.3	1140.3	1138.7	1136.9	1134.0
21	1147.3	1146.5	1145.1	1144.0	1142.3	1140.3	1138.9	1137.1	1136.7
22	1147.3	1146.5	1145.0	1144.1	1142.2	1140.3	1138.7	1137.3	1136.3
23	1147.3	1146.5	1145.0	1144.1	1142.3	1140.4	1138.9	1137.5	1137.1
24	1147.3	1146.5	1145.1	1144.1	1142.4	1140.6	1138.7	1138.0	1137.2
25	1147.4	1146.6	1145.1	1144.2	1142.4	1140.6	1138.9	1138.0	1137.3
26	1147.4	1146.6	1145.3	1144.3	1142.5	1140.9	1139.3	1138.4	1137.9
27	1147.4	1146.6	1145.3	1144.3	1142.5	1140.7	1139.0	1138.2	1137.6
28	1147.4	1146.6	1145.3	1144.3	1142.5	1140.8	1139.2	1138.4	1137.7
29	1147.4	1146.6	1145.2	1144.2	1142.5	1140.7	1139.0	1138.2	1137.5
30	1147.4	1146.6	1145.2	1144.2	1142.5	1140.7	1139.1	1138.1	1137.5
31	1147.3	1146.5	1145.1	1144.1	1142.4	1140.7	1138.9	1137.7	1136.8
32	1147.4	1146.6	1145.1	1144.2	1142.5	1140.7	1139.0	1137.8	1136.8
33	1147.4	1146.6	1145.2	1144.2	1142.4	1140.6	1138.9	1137.5	1136.4
34	1147.4	1146.6	1145.2	1144.2	1142.5	1140.7	1139.1	1137.6	1136.6
35	1147.4	1146.6	1145.2	1144.2	1142.5	1140.7	1139.0	1137.5	1136.3
36	1147.4	1146.5	1145.2	1144.2	1142.5	1140.7	1139.1	1137.5	1136.3
37	1147.4	1146.5	1145.3	1144.3	1142.5	1140.7	1139.1	1137.5	1136.2
38	1147.5	1146.6	1145.3	1144.4	1142.5	1140.7	1139.1	1137.5	1135.9
39	1147.6	1146.7	1145.3	1144.4	1142.7	1140.9	1139.3	1137.5	1132.5

Appendix L. Flume Measurements without Spur Bridge

Appendix L.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table L.1 Raw experimental data collected in the physical model for a high flow through the flume and with the spur bridge removed. 2:1 Entrance and Exit. Piezometer units are cm.

Test	130A	130B	130C	130D	130E	130F	130G	130H
Date	11/2	11/2	11/2	11/2	11/2	11/2	11/2	11/2
Pump Frq. (Hz)	61.4	61.4	61.4	61.4	61.4	61.4	61.4	61.4
Weir (cm)	89.45	89.46	89.57	89.57	89.66	89.63	89.67	89.68
Discharge (ft^3/s)	3.817	3.819	3.836	3.836	3.850	3.846	3.852	3.853
Water Temp (C)	18.2	18.1	18.2	18.4	18.4	18.4	18.5	18.5
Gate Hght (in)	7.50	7.13	6.50	6.13	5.50	5.25	4.13	3.88
Gate Hght (cm)	19.05	18.10	16.51	15.56	13.97	13.34	10.48	9.84
Piezometer								
1	27.7	27.2	26.6	26.3	26.0	25.9	25.8	25.7
2	27.4	27.0	26.3	26.0	25.7	25.5	25.4	25.3
3	27.4	26.9	26.2	25.9	25.6	25.5	25.3	25.2
4	27.4	26.9	26.2	25.9	25.6	25.4	25.3	25.2
5	27.3	26.8	26.1	25.8	25.4	25.3	25.2	25.1
6	27.3	26.8	26.1	25.8	25.4	25.3	25.2	25.1
7	27.3	26.7	26.1	25.8	25.4	25.3	25.2	25.1
8	27.3	26.7	26.1	25.8	25.4	25.3	25.1	25.0
9	27.2	26.7	26.0	25.7	25.3	25.2	25.0	24.9
10	27.2	26.7	26.0	25.7	25.3	25.2	25.0	24.9
11	27.1	26.5	25.8	25.5	25.1	25.0	24.8	24.7
12	27.1	26.4	25.8	25.4	25.0	24.9	24.8	24.7
13	27.0	26.3	25.7	25.3	24.9	24.8	24.7	24.6
14	27.0	26.4	25.7	25.3	24.9	24.8	24.6	24.5
15	26.6	26.0	25.2	24.9	24.4	24.3	24.1	24.0
16	25.8	25.0	24.0	23.5	22.9	22.7	22.4	22.3
17	25.4	24.7	23.5	23.0	22.2	22.0	21.7	21.4
18	24.8	23.8	22.4	21.6	20.8	20.5	19.9	19.5
19	24.8	23.8	22.3	21.2	19.5	18.7	16.6	14.6
20	25.1	24.2	22.7	21.8	20.3	19.8	18.3	16.3
21	25.1	24.1	22.8	21.9	20.6	20.1	18.1	17.7
22	25.0	24.1	22.7	22.0	20.5	20.1	18.6	18.1
23	25.0	24.1	22.8	21.9	20.5	20.0	18.4	18.4
24	25.0	24.2	22.8	21.9	20.4	20.0	18.5	18.4
25	25.0	24.2	22.7	21.9	20.5	20.0	18.3	18.0
26	25.4	24.2	23.2	22.3	21.0	20.3	18.4	18.4
27	25.4	24.6	23.1	22.3	20.9	20.3	18.6	18.1
28	25.4	24.6	23.2	22.3	21.0	20.5	19.0	18.6
29	25.3	24.4	23.1	22.2	20.8	20.3	18.8	18.4
30	25.3	24.5	23.2	22.3	21.0	20.5	18.9	18.5
31	25.0	24.2	22.8	21.9	20.7	20.1	18.4	17.8
32	25.1	24.3	23.0	22.2	20.9	20.4	18.8	18.2
33	25.1	24.3	22.9	22.2	20.8	20.3	18.6	17.9
34	25.2	24.4	23.1	22.3	21.0	20.4	18.7	18.1
35	25.3	24.4	23.0	22.2	21.0	20.4	18.6	17.8
36	25.4	24.5	23.2	22.4	21.1	20.4	18.8	18.0
37	25.5	24.5	23.2	22.4	21.1	20.4	18.7	17.8
38	25.6	24.7	23.3	22.5	21.2	20.5	18.8	17.9
39	25.8	24.9	23.5	22.8	21.4	20.8	19.0	18.1

Table L.2 Raw experimental data collected in the physical model for a high flow through the flume and with the spur bridge removed. 2:1 Entrance and Exit. Piezometer units are cm. Rerun of tests 130D – 130H to improve discharge similarities between tests with and without spur bridge.

Test	140D	140E	140F	140G	140H
Date	11/5	11/5	11/5	11/5	11/5
Pump Frq. (Hz)	60.5	60.5	60.5	60.7	60.7
Weir (cm)	89.13	89.13	89.19	89.34	89.36
Discharge (ft^3/s)	3.767	3.767	3.777	3.800	3.803
Water Temp (C)	18.2	18.2	18.3	18.3	18.3
Gate Hght (in)	5.88	5.50	5.13	4.38	4.00
Gate Hght (cm)	14.92	13.97	13.02	11.11	10.16
Piezometer					
1	26.1	25.8	25.7	25.6	25.5
2	25.8	25.5	25.3	25.2	25.1
3	25.7	25.4	25.2	25.1	25.1
4	25.7	25.4	25.2	25.1	25.1
5	25.6	25.2	25.1	25.0	24.9
6	25.6	25.2	25.1	25.0	24.9
7	25.6	25.2	25.1	25.0	24.9
8	25.5	25.2	25.1	24.9	24.9
9	25.4	25.1	25.0	24.8	24.8
10	25.4	25.1	25.0	24.8	24.8
11	25.3	24.9	24.7	24.6	24.5
12	25.3	24.8	24.7	24.6	24.5
13	25.2	24.8	24.6	24.5	24.4
14	25.1	24.7	24.6	24.4	24.3
15	24.6	24.3	24.1	23.9	23.8
16	23.4	22.8	22.6	22.3	22.1
17	22.9	22.1	21.9	21.5	21.2
18	21.7	20.7	20.3	19.7	19.4
19	21.4	19.7	18.6	16.7	14.6
20	21.8	20.3	19.7	18.3	16.5
21	22.0	20.7	19.9	18.3	17.8
22	22.0	20.6	19.9	18.6	18.2
23	22.0	20.6	19.8	18.4	18.3
24	22.0	20.6	19.8	18.6	18.6
25	22.0	20.7	19.8	18.5	18.1
26	22.4	21.2	20.4	19.2	18.5
27	22.3	21.0	20.2	18.8	18.2
28	22.3	21.1	20.4	19.1	18.5
29	22.2	21.0	20.2	18.9	18.4
30	22.3	21.1	20.4	19.0	18.5
31	22.1	20.8	20.0	18.5	17.9
32	22.2	21.0	20.2	18.9	18.2
33	22.2	20.9	20.1	18.7	17.9
34	22.3	21.0	20.2	18.8	18.0
35	22.3	21.0	20.2	18.6	17.8
36	22.4	21.1	20.4	18.8	18.0
37	22.4	21.1	20.3	18.7	17.8
38	22.5	21.2	20.4	18.9	18.0
39	22.8	21.4	20.7	19.1	18.3

Appendix L.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table L.3 Scaled/Corrected data collected for a high flow through the flume and with the spur bridge removed. 2:1 Entrance and Exit. Piezometer units are ft-msl NAVD 88.

Test	130A	130B	130C	130D	130E	130F	130G	130H
Q (ft^3/s)	11929	11934	11988	11988	12032	12017	12037	12042
Piezometer								
1	1148.6	1148.2	1147.7	1147.5	1147.2	1147.1	1147.1	1147.0
2	1148.4	1148.0	1147.5	1147.2	1147.0	1146.8	1146.7	1146.6
3	1148.4	1148.0	1147.4	1147.1	1146.9	1146.8	1146.6	1146.6
4	1148.4	1148.0	1147.4	1147.1	1146.9	1146.7	1146.6	1146.6
5	1148.3	1147.9	1147.3	1147.1	1146.7	1146.6	1146.6	1146.5
6	1148.3	1147.9	1147.3	1147.1	1146.7	1146.6	1146.6	1146.5
7	1148.3	1147.8	1147.3	1147.1	1146.7	1146.6	1146.6	1146.5
8	1148.3	1147.8	1147.3	1147.1	1146.7	1146.6	1146.5	1146.4
9	1148.2	1147.8	1147.2	1147.0	1146.6	1146.6	1146.4	1146.3
10	1148.2	1147.8	1147.2	1147.0	1146.6	1146.6	1146.4	1146.3
11	1148.2	1147.7	1147.1	1146.9	1146.6	1146.5	1146.3	1146.2
12	1148.2	1147.6	1147.1	1146.8	1146.5	1146.4	1146.3	1146.2
13	1148.1	1147.6	1147.1	1146.7	1146.4	1146.3	1146.2	1146.2
14	1148.0	1147.6	1147.0	1146.6	1146.3	1146.2	1146.1	1146.0
15	1147.7	1147.2	1146.6	1146.3	1145.9	1145.8	1145.7	1145.6
16	1147.1	1146.4	1145.6	1145.2	1144.7	1144.5	1144.3	1144.2
17	1146.7	1146.2	1145.2	1144.8	1144.1	1143.9	1143.7	1143.5
18	1146.2	1145.4	1144.3	1143.6	1143.0	1142.7	1142.2	1141.9
19	1146.2	1145.4	1144.2	1143.3	1141.9	1141.2	1139.5	1137.9
20	1146.5	1145.7	1144.5	1143.8	1142.5	1142.1	1140.9	1139.3
21	1146.3	1145.5	1144.4	1143.7	1142.6	1142.2	1140.6	1140.3
22	1146.2	1145.5	1144.4	1143.8	1142.5	1142.2	1141.0	1140.6
23	1146.2	1145.5	1144.4	1143.7	1142.5	1142.1	1140.8	1140.8
24	1146.2	1145.6	1144.4	1143.7	1142.5	1142.1	1140.9	1140.8
25	1146.3	1145.7	1144.4	1143.8	1142.6	1142.2	1140.8	1140.6
26	1146.6	1145.7	1144.8	1144.1	1143.0	1142.5	1140.9	1140.9
27	1146.6	1146.0	1144.8	1144.1	1143.0	1142.5	1141.1	1140.7
28	1146.6	1146.0	1144.8	1144.1	1143.0	1142.6	1141.4	1141.1
29	1146.6	1145.8	1144.8	1144.0	1142.9	1142.5	1141.2	1140.9
30	1146.6	1145.9	1144.8	1144.1	1143.0	1142.6	1141.3	1141.0
31	1146.4	1145.7	1144.6	1143.9	1142.9	1142.4	1141.0	1140.5
32	1146.5	1145.8	1144.8	1144.1	1143.0	1142.6	1141.3	1140.8
33	1146.5	1145.8	1144.7	1144.1	1143.0	1142.5	1141.2	1140.6
34	1146.6	1145.9	1144.8	1144.2	1143.1	1142.6	1141.2	1140.7
35	1146.6	1145.9	1144.8	1144.1	1143.1	1142.6	1141.2	1140.5
36	1146.6	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.6
37	1146.7	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.4
38	1146.8	1146.1	1144.9	1144.3	1143.2	1142.6	1141.2	1140.5
39	1147.0	1146.2	1145.1	1144.5	1143.4	1142.9	1141.4	1140.7

Table L.4 Scaled/Corrected data collected for a high flow through the flume and with the spur bridge removed. 2:1 Entrance and Exit. Piezometer units are ft-msl NAVD 88.

Test	130A	130B	130C	140D	140E	140F	140G	140H
Q (ft^3/s)	11929	11934	11988	11773	11773	11803	11875	11885
Piezometer								
1	1148.6	1148.2	1147.7	1147.3	1147.1	1147.0	1146.9	1146.8
2	1148.4	1148.0	1147.5	1147.1	1146.8	1146.6	1146.6	1146.5
3	1148.4	1148.0	1147.4	1147.0	1146.7	1146.6	1146.5	1146.5
4	1148.4	1148.0	1147.4	1147.0	1146.7	1146.6	1146.5	1146.5
5	1148.3	1147.9	1147.3	1146.9	1146.6	1146.5	1146.4	1146.3
6	1148.3	1147.9	1147.3	1146.9	1146.6	1146.5	1146.4	1146.3
7	1148.3	1147.8	1147.3	1146.9	1146.6	1146.5	1146.4	1146.3
8	1148.3	1147.8	1147.3	1146.8	1146.6	1146.5	1146.3	1146.3
9	1148.2	1147.8	1147.2	1146.7	1146.5	1146.4	1146.2	1146.2
10	1148.2	1147.8	1147.2	1146.7	1146.5	1146.4	1146.2	1146.2
11	1148.2	1147.7	1147.1	1146.7	1146.4	1146.2	1146.2	1146.1
12	1148.2	1147.6	1147.1	1146.7	1146.3	1146.2	1146.2	1146.1
13	1148.1	1147.6	1147.1	1146.6	1146.3	1146.2	1146.1	1146.0
14	1148.0	1147.6	1147.0	1146.5	1146.2	1146.1	1145.9	1145.8
15	1147.7	1147.2	1146.6	1146.1	1145.8	1145.7	1145.5	1145.4
16	1147.1	1146.4	1145.6	1145.1	1144.6	1144.4	1144.2	1144.0
17	1146.7	1146.2	1145.2	1144.7	1144.0	1143.9	1143.5	1143.3
18	1146.2	1145.4	1144.3	1143.7	1142.9	1142.5	1142.1	1141.8
19	1146.2	1145.4	1144.2	1143.5	1142.1	1141.2	1139.6	1137.9
20	1146.5	1145.7	1144.5	1143.8	1142.5	1142.1	1140.9	1139.4
21	1146.3	1145.5	1144.4	1143.8	1142.7	1142.1	1140.7	1140.3
22	1146.2	1145.5	1144.4	1143.8	1142.6	1142.1	1141.0	1140.7
23	1146.2	1145.5	1144.4	1143.8	1142.6	1142.0	1140.8	1140.7
24	1146.2	1145.6	1144.4	1143.8	1142.6	1142.0	1141.0	1141.0
25	1146.3	1145.7	1144.4	1143.9	1142.8	1142.1	1141.0	1140.7
26	1146.6	1145.7	1144.8	1144.2	1143.2	1142.5	1141.6	1141.0
27	1146.6	1146.0	1144.8	1144.1	1143.0	1142.4	1141.2	1140.7
28	1146.6	1146.0	1144.8	1144.1	1143.1	1142.5	1141.5	1141.0
29	1146.6	1145.8	1144.8	1144.0	1143.0	1142.4	1141.3	1140.9
30	1146.6	1145.9	1144.8	1144.1	1143.1	1142.5	1141.4	1141.0
31	1146.4	1145.7	1144.6	1144.0	1143.0	1142.3	1141.1	1140.6
32	1146.5	1145.8	1144.8	1144.1	1143.1	1142.5	1141.4	1140.8
33	1146.5	1145.8	1144.7	1144.1	1143.0	1142.4	1141.2	1140.6
34	1146.6	1145.9	1144.8	1144.2	1143.1	1142.5	1141.3	1140.7
35	1146.6	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.5
36	1146.6	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.6
37	1146.7	1145.9	1144.8	1144.2	1143.1	1142.5	1141.2	1140.4
38	1146.8	1146.1	1144.9	1144.3	1143.2	1142.5	1141.3	1140.6
39	1147.0	1146.2	1145.1	1144.5	1143.4	1142.8	1141.5	1140.8

Appendix M. Flume Measurements with Elliptical Entrances

Appendix M.1. Raw Model Piezometer Data

Uncorrected Piezometer Data

Table M.1 Raw experimental data collected in the physical model for a high flow through the flume. Elliptical entrance and 2:1 Exit. Piezometer units are cm.

Test	150A	150B	150C	150D	150E	150F	150G	150H
Date	11/22	11/22	11/22	11/22	11/22	11/22	11/22	11/22
Pump Frq. (Hz)	61.3	61.3	61.5	60.7	60.7	60.8	61.0	61.0
Weir (cm)	89.27	89.23	89.33	89.03	89.05	89.12	89.24	89.24
Discharge (ft^3/s)	3.789	3.783	3.799	3.752	3.755	3.766	3.785	3.785
Water Temp (C)	16.8	16.9	16.9	17.0	17.0	17.0	17.0	17.1
Gate Hght (in)	7.75	7.13	6.75	6.25	5.63	5.38	4.50	4.13
Gate Hght (cm)	19.69	18.10	17.15	15.88	14.29	13.65	11.43	10.48
Piezometer								
1	28.2	27.8	27.3	26.9	26.8	26.6	26.5	26.5
2	28.0	27.5	27.1	26.7	26.5	26.4	26.3	26.2
3	28.0	27.5	27.0	26.6	26.4	26.3	26.2	26.1
4	28.0	27.5	27.0	26.6	26.4	26.3	26.2	26.1
5	27.9	27.4	26.9	26.5	26.3	26.2	26.1	26.0
6	27.9	27.4	26.9	26.5	26.3	26.2	26.1	26.0
7	27.9	27.4	26.9	26.5	26.3	26.1	26.1	26.0
8	27.9	27.3	26.9	26.4	26.3	26.1	26.0	26.0
9	27.8	27.3	26.8	26.4	26.2	26.0	25.9	25.9
10	27.8	27.3	26.8	26.4	26.2	26.0	25.9	25.9
11	27.6	27.1	26.6	26.2	26.0	25.8	25.7	25.7
12	27.6	27.1	26.6	26.2	25.9	25.8	25.7	25.6
13	27.5	27.0	26.5	26.1	25.8	25.7	25.6	25.5
14	27.4	27.0	26.4	26.0	25.8	25.6	25.0	25.4
15	27.0	26.5	25.9	25.5	25.2	25.0	24.9	24.8
16	25.5	24.8	23.9	23.3	22.8	22.5	22.2	22.0
17	25.4	24.5	23.5	22.7	22.2	21.7	21.2	21.0
18	24.7	23.7	22.4	21.6	20.8	20.2	19.5	19.0
19	24.7	23.7	22.3	21.4	20.0	18.8	16.7	14.6
20	25.1	24.1	22.8	22.0	20.6	19.7	18.3	16.2
21	25.0	24.1	22.9	22.1	20.8	20.1	18.2	17.7
22	25.0	24.2	22.9	22.0	20.8	20.0	18.6	18.1
23	25.1	24.3	22.9	22.2	20.8	20.0	18.4	18.2
24	25.2	24.3	23.0	22.2	20.9	19.9	18.6	18.5
25	25.2	24.2	22.8	22.2	20.8	19.8	18.5	18.1
26	25.3	24.4	23.2	22.4	21.3	20.4	19.1	18.5
27	25.3	24.5	23.1	22.3	21.1	20.2	18.6	18.2
28	25.4	24.5	23.2	22.4	21.2	20.4	18.9	18.5
29	25.3	24.5	23.1	22.3	21.0	20.3	18.8	18.3
30	25.3	24.4	23.1	22.3	21.1	20.2	18.9	18.4
31	25.1	24.2	22.8	22.0	20.8	19.9	18.4	17.8
32	25.2	24.3	23.0	22.2	21.2	20.2	18.8	18.1
33	25.2	24.2	22.9	22.2	21.1	20.2	18.6	17.8
34	25.3	24.3	23.0	22.2	21.2	20.3	18.8	17.9
35	25.2	24.3	23.0	22.2	21.1	20.3	18.6	17.8
36	25.4	24.4	23.2	22.4	21.3	20.4	18.8	18.0
37	25.4	24.5	23.2	22.4	21.3	20.4	18.7	17.9
38	25.5	24.6	23.4	22.6	21.5	20.5	18.9	18.0
39	25.7	24.8	23.7	23.0	21.7	20.8	19.2	18.2

Table M.2 Raw experimental data collected in the physical model for a medium flow through the flume. Elliptical entrance and 2:1 Exit. Piezometer units are cm.

Test	151A	151B	151C	151D	151E	151F	151G	151H	151I
Date	11/23	11/23	11/23	11/23	11/23	11/23	11/23	11/23	11/23
Pump Frq. (Hz)	55.4	55.4	55.4	54.9	54.9	54.9	54.9	54.9	54.9
Weir (cm)	85.20	85.25	85.20	84.94	85.03	85.05	85.09	85.14	85.15
Discharge (ft^3/s)	3.187	3.194	3.187	3.151	3.163	3.166	3.172	3.179	3.180
Water Temp (C)	17.3	17.3	17.3	17.4	17.4	17.4	17.4	17.3	17.4
Gate Hght (in)	8.00	7.50	7.13	6.75	6.25	5.50	5.25	4.13	3.00
Gate Hght (cm)	20.32	19.05	18.10	17.15	15.88	13.97	13.34	10.48	7.62
Piezometer									
1	27.6	26.9	26.3	25.8	25.2	24.8	24.6	24.3	24.3
2	27.4	26.7	26.1	25.6	25.0	24.5	24.3	24.0	24.0
3	27.4	26.6	26.1	25.5	24.9	24.4	24.2	23.9	23.9
4	27.4	26.6	26.1	25.5	24.9	24.4	24.2	24.0	23.9
5	27.3	26.5	26.0	25.4	24.8	24.3	24.1	23.8	23.8
6	27.3	26.5	26.0	25.4	24.8	24.3	24.1	23.8	23.8
7	27.3	26.5	26.0	25.4	24.8	24.3	24.0	23.8	23.7
8	27.3	26.5	26.0	25.4	24.8	24.2	24.0	23.8	23.7
9	27.2	26.4	25.9	25.3	24.7	24.2	23.9	23.7	23.6
10	27.2	26.4	25.9	25.3	24.7	24.2	23.9	23.7	23.6
11	27.1	26.4	25.7	25.2	24.5	24.0	23.8	23.5	23.4
12	27.1	26.3	25.7	25.1	24.5	23.9	23.8	23.5	23.4
13	27.1	26.3	25.6	25.1	24.4	23.8	23.7	23.4	23.3
14	27.0	26.2	25.6	25.0	24.3	23.8	23.6	23.3	23.2
15	26.6	25.8	25.2	24.6	23.8	23.2	23.0	22.7	22.6
16	25.7	24.7	23.9	23.1	22.0	21.0	20.6	20.0	19.9
17	25.6	24.6	23.7	22.9	21.7	20.5	20.0	19.0	18.8
18	25.2	24.2	23.2	22.3	20.8	19.4	18.9	17.6	17.1
19	25.3	24.2	23.2	22.3	20.6	18.8	18.0	15.4	13.4
20	25.5	24.4	23.4	22.6	21.1	19.4	18.5	16.8	13.3
21	25.6	24.5	23.5	22.7	21.2	19.6	18.8	16.8	15.9
22	25.5	24.5	23.5	22.7	21.2	19.6	18.8	17.2	15.9
23	25.5	24.5	23.6	22.8	21.2	19.8	18.8	16.8	16.1
24	25.5	24.5	23.6	22.7	21.2	20.0	18.8	17.0	16.3
25	25.5	24.5	23.5	22.6	21.2	20.0	18.8	17.0	16.1
26	25.6	24.7	23.7	22.9	21.6	20.3	19.3	17.4	16.4
27	25.6	24.7	23.7	22.8	21.4	20.1	19.0	17.0	16.1
28	25.7	24.7	23.8	22.9	21.5	20.2	19.2	17.4	16.4
29	25.6	24.6	23.7	22.8	21.4	20.0	19.1	17.2	16.1
30	25.6	24.6	23.7	22.8	21.4	20.1	19.2	17.3	16.2
31	25.4	24.3	23.4	22.5	21.2	19.8	18.8	17.0	15.4
32	25.5	24.4	23.5	22.7	21.4	20.0	19.1	17.3	15.8
33	25.5	24.5	23.5	22.7	21.3	19.9	19.0	17.0	15.3
34	25.5	24.5	23.5	22.7	21.4	20.0	19.1	17.1	15.4
35	25.5	24.6	23.5	22.6	21.3	20.0	19.1	17.0	15.1
36	25.7	24.7	23.6	22.8	21.5	20.1	19.2	17.2	15.3
37	25.7	24.7	23.7	22.8	21.5	20.1	19.2	17.1	15.1
38	25.8	24.8	23.8	23.0	21.6	20.2	19.3	17.2	15.2
39	26.0	24.9	24.0	23.2	21.8	20.4	19.5	17.5	15.2

Appendix M.2. Prototype Piezometer Data

Corrected and Scaled Piezometer Data

Table M.3 Scaled/Corrected data collected for a high flow through the flume. Elliptical Entrance and 2:1 Exit. Piezometer units are ft-msl NAVD 88.

Test	150A	150B	150C	150D	150E	150F	150G	150H
Q (ft^3/s)	11841	11822	11871	11725	11735	11769	11827	11827
Piezometer								
1	1149.0	1148.7	1148.3	1148.0	1147.9	1147.7	1147.6	1147.6
2	1148.9	1148.5	1148.1	1147.8	1147.6	1147.6	1147.5	1147.4
3	1148.9	1148.5	1148.0	1147.7	1147.6	1147.5	1147.4	1147.3
4	1148.9	1148.5	1148.0	1147.7	1147.6	1147.5	1147.4	1147.3
5	1148.8	1148.4	1148.0	1147.6	1147.5	1147.4	1147.3	1147.2
6	1148.8	1148.4	1148.0	1147.6	1147.5	1147.4	1147.3	1147.2
7	1148.8	1148.4	1148.0	1147.6	1147.5	1147.3	1147.3	1147.2
8	1148.8	1148.3	1148.0	1147.6	1147.5	1147.3	1147.2	1147.2
9	1148.7	1148.3	1147.9	1147.6	1147.4	1147.2	1147.1	1147.1
10	1148.7	1148.3	1147.9	1147.6	1147.4	1147.2	1147.1	1147.1
11	1148.6	1148.2	1147.8	1147.5	1147.3	1147.1	1147.1	1147.1
12	1148.6	1148.2	1147.8	1147.5	1147.2	1147.1	1147.1	1147.0
13	1148.5	1148.1	1147.7	1147.4	1147.1	1147.1	1147.0	1146.9
14	1148.4	1148.0	1147.6	1147.2	1147.1	1146.9	1146.4	1146.7
15	1148.0	1147.6	1147.1	1146.8	1146.6	1146.4	1146.3	1146.2
16	1146.8	1146.2	1145.5	1145.0	1144.6	1144.4	1144.1	1143.9
17	1146.7	1146.0	1145.2	1144.5	1144.1	1143.7	1143.3	1143.1
18	1146.2	1145.3	1144.3	1143.6	1143.0	1142.5	1141.9	1141.5
19	1146.2	1145.3	1144.2	1143.5	1142.3	1141.3	1139.6	1137.9
20	1146.5	1145.7	1144.6	1143.9	1142.8	1142.1	1140.9	1139.2
21	1146.2	1145.5	1144.5	1143.9	1142.8	1142.2	1140.7	1140.3
22	1146.2	1145.6	1144.5	1143.8	1142.8	1142.1	1141.0	1140.6
23	1146.3	1145.7	1144.5	1143.9	1142.8	1142.1	1140.8	1140.7
24	1146.4	1145.7	1144.6	1143.9	1142.9	1142.1	1141.0	1140.9
25	1146.5	1145.7	1144.5	1144.0	1142.9	1142.1	1141.0	1140.7
26	1146.6	1145.8	1144.8	1144.2	1143.3	1142.5	1141.5	1141.0
27	1146.6	1145.9	1144.8	1144.1	1143.1	1142.4	1141.1	1140.7
28	1146.6	1145.9	1144.8	1144.2	1143.2	1142.5	1141.3	1141.0
29	1146.6	1145.9	1144.8	1144.1	1143.0	1142.5	1141.2	1140.8
30	1146.6	1145.8	1144.8	1144.1	1143.1	1142.4	1141.3	1140.9
31	1146.5	1145.7	1144.6	1143.9	1143.0	1142.2	1141.0	1140.5
32	1146.6	1145.8	1144.8	1144.1	1143.3	1142.5	1141.3	1140.7
33	1146.6	1145.7	1144.7	1144.1	1143.2	1142.5	1141.2	1140.5
34	1146.6	1145.8	1144.8	1144.1	1143.3	1142.5	1141.3	1140.6
35	1146.6	1145.8	1144.8	1144.1	1143.2	1142.5	1141.2	1140.5
36	1146.6	1145.8	1144.8	1144.2	1143.3	1142.5	1141.2	1140.6
37	1146.6	1145.9	1144.8	1144.2	1143.3	1142.5	1141.2	1140.5
38	1146.7	1146.0	1145.0	1144.4	1143.5	1142.6	1141.3	1140.6
39	1146.9	1146.2	1145.3	1144.7	1143.6	1142.9	1141.6	1140.7

Table M.4 Scaled/Corrected data collected for a medium flow through the flume. Elliptical Entrance and 2:1 Exit. Piezometer units are ft-msl NAVD 88.

Test	151A	151B	151C	151D	151E	151F	151G	151H	151I
Q (ft^3/s)	9960	9982	9960	9846	9886	9894	9912	9934	9938
Piezometer									
1	1148.5	1148.0	1147.5	1147.1	1146.6	1146.2	1146.1	1145.8	1145.8
2	1148.4	1147.8	1147.3	1146.9	1146.4	1146.0	1145.8	1145.6	1145.6
3	1148.4	1147.7	1147.3	1146.8	1146.3	1145.9	1145.7	1145.5	1145.5
4	1148.4	1147.7	1147.3	1146.8	1146.3	1145.9	1145.7	1145.6	1145.5
5	1148.3	1147.6	1147.2	1146.7	1146.2	1145.8	1145.7	1145.4	1145.4
6	1148.3	1147.6	1147.2	1146.7	1146.2	1145.8	1145.7	1145.4	1145.4
7	1148.3	1147.6	1147.2	1146.7	1146.2	1145.8	1145.6	1145.4	1145.3
8	1148.3	1147.6	1147.2	1146.7	1146.2	1145.7	1145.6	1145.4	1145.3
9	1148.2	1147.6	1147.1	1146.6	1146.2	1145.7	1145.5	1145.3	1145.3
10	1148.2	1147.6	1147.1	1146.6	1146.2	1145.7	1145.5	1145.3	1145.3
11	1148.2	1147.6	1147.1	1146.6	1146.1	1145.7	1145.5	1145.3	1145.2
12	1148.2	1147.6	1147.1	1146.6	1146.1	1145.6	1145.5	1145.3	1145.2
13	1148.2	1147.6	1147.0	1146.6	1146.0	1145.5	1145.4	1145.2	1145.1
14	1148.0	1147.4	1146.9	1146.4	1145.8	1145.4	1145.3	1145.0	1144.9
15	1147.7	1147.1	1146.6	1146.1	1145.4	1144.9	1144.8	1144.5	1144.4
16	1147.0	1146.2	1145.5	1144.8	1143.9	1143.1	1142.8	1142.3	1142.2
17	1146.9	1146.1	1145.3	1144.7	1143.7	1142.7	1142.3	1141.5	1141.3
18	1146.6	1145.7	1144.9	1144.2	1143.0	1141.8	1141.4	1140.3	1139.9
19	1146.6	1145.7	1144.9	1144.2	1142.8	1141.3	1140.7	1138.5	1136.9
20	1146.8	1145.9	1145.1	1144.4	1143.2	1141.8	1141.1	1139.7	1136.8
21	1146.7	1145.8	1145.0	1144.4	1143.1	1141.8	1141.2	1139.5	1138.8
22	1146.6	1145.8	1145.0	1144.4	1143.1	1141.8	1141.2	1139.8	1138.8
23	1146.6	1145.8	1145.1	1144.4	1143.1	1142.0	1141.2	1139.5	1138.9
24	1146.6	1145.8	1145.1	1144.4	1143.1	1142.1	1141.2	1139.7	1139.1
25	1146.7	1145.9	1145.1	1144.4	1143.2	1142.2	1141.2	1139.8	1139.0
26	1146.8	1146.1	1145.3	1144.6	1143.5	1142.5	1141.6	1140.1	1139.3
27	1146.8	1146.1	1145.3	1144.5	1143.4	1142.3	1141.4	1139.8	1139.0
28	1146.9	1146.1	1145.3	1144.6	1143.5	1142.4	1141.6	1140.1	1139.3
29	1146.8	1146.0	1145.3	1144.5	1143.4	1142.2	1141.5	1139.9	1139.0
30	1146.8	1146.0	1145.3	1144.5	1143.4	1142.3	1141.6	1140.0	1139.1
31	1146.7	1145.8	1145.1	1144.4	1143.3	1142.1	1141.3	1139.8	1138.5
32	1146.8	1145.9	1145.2	1144.5	1143.5	1142.3	1141.6	1140.1	1138.9
33	1146.8	1146.0	1145.2	1144.5	1143.4	1142.2	1141.5	1139.8	1138.4
34	1146.8	1146.0	1145.2	1144.5	1143.5	1142.3	1141.6	1139.9	1138.5
35	1146.8	1146.1	1145.2	1144.4	1143.4	1142.3	1141.6	1139.8	1138.3
36	1146.9	1146.1	1145.2	1144.5	1143.5	1142.3	1141.6	1139.9	1138.4
37	1146.9	1146.1	1145.3	1144.5	1143.5	1142.3	1141.6	1139.8	1138.2
38	1147.0	1146.2	1145.3	1144.7	1143.5	1142.4	1141.6	1139.9	1138.3
39	1147.1	1146.2	1145.5	1144.8	1143.7	1142.5	1141.8	1140.2	1138.3