PAP-806

Technical Review of Long-Throated Flume and Labyrinth Weir Hydraulics for Newtown Creek Water Pollution Control Plant Upgrade

February 1999

by

Tony L. Wahl

United States Department of the Interior

BUREAU OF RECLAMATION
RECLAMATION SERVICE CENTER
PO Box 25007
Building 67, Denver Federal Center
Denver, Colorado 80225-0007

IN REPLY REFER TO

D-8560
RES-3.50

FEB 12 1999

Mr. Manuel Gonzalez and Ms. Beth Vogt
Greeley and Hansen Engineers
100 South Wacker Drive
Chicago, Illinois 60606-4004

Subject: Review of Newtown Creek WPCP Long-Throated Flume and Labyrinth Weir Hydraulics

Dear Mr. Gonzalez and Ms. Vogt:

Please find enclosed the peer-reviewed final report on my review of the hydraulic performance of the proposed long-throated flume and labyrinth weir designs for the Newtown Creek Water Pollution Control Plant Upgrade. The enclosed report summarizes the findings related to my analysis of both the original designs and the revised designs transmitted to me in January 1999. I have appreciated the opportunity to work on this project and hope that Reclamation has an opportunity to work with you again in the future. If you have any questions regarding the report, please give me a call at 303-445-2155.

Sincerely,

Tony L. Wahl

Tony L. Wahl
Technical Service Center
Hydraulic Engineer

Enclosure

cc: D-8560 (Burgi, PAP file)

Technical Review of Long-Throated Flume and Labyrinth Weir Hydraulics for Newtown Creek Water Pollution Control Plant Upgrade

Tony L. Wahl
U.S. Bureau of Reclamation
Water Resources Research Laboratory
Denver, Colorado

The Newtown Creek Water Pollution Control Plant (WPCP) is located in the City of New York. The plant is presently being upgraded, and the design includes a long-throated flume and labyrinth weir for effluent flow measurement and water level control of the chlorine contact tanks in the plant. The design for the plant upgrade was developed by Greeley and Hansen Engineers, Chicago, Illinois. Greeley and Hansen has contracted with the Bureau of Reclamation to perform this technical review of the design.

Four primary issues were considered in the review:

1) Design and setting of long-throated flume to ensure accurate measurement over full range of flows and tailwater conditions
2) Approach distance between labyrinth weir and long-throated flume to ensure uniform flow approaching the flume
3) Water surface profiles between long-throated flume and downstream side of labyrinth weir
4) Discharge coefficient and capacity of labyrinth weir

Summary of Initial Results

Initial designs were provided to Reclamation by Greeley and Hansen in October 1998. A draft of this report was sent to Greeley and Hansen on November 6, 1998, with the following findings:

- The long-throated flume design is satisfactory, although some improvements that minimize head loss across the flume were suggested.
- The approach distance to the flume is less than that normally recommended to produce uniform approach flow, but it is expected that the flume will perform adequately when all three contact tanks are discharging. A physical hydraulic model study would be needed to further confirm this. Turbulence in the approach flow may make it necessary to use a stilling well to accurately measure the upstream sill-referenced head.
- Water surface elevations at the upstream end of the labyrinth weir exit channels will be much greater than those computed by Greeley and Hansen, causing partial submergence of the weir crests at the maximum (465 mgd) and peak (700 mgd) flow conditions. (The term *exit channels* refers to the conveyance channels, or troughs, on the downstream side of the weir crests. In spillway applications this area is often described as the *downstream apron*.)
- Discharge coefficients and total discharge capacity of the labyrinth weirs will be significantly lower than the estimates made by Greeley and Hansen, producing higher water surfaces in the portion of the plant upstream of the labyrinth weir.
- Several alternatives for modifying the design were presented, including modification or elimination of the long-throated flume, deepening of the labyrinth weir exit channels, and possible replacement of the labyrinth weir with an overshot gate.

Review of Revised Design

Following the transmittal of the initial findings described above, Greeley and Hansen made several modifications to the design. Details of these changes and a request for analysis of specific details of the revised design were provided to Reclamation on January 29, 1999, and are included in Appendix G. This report has been amended to include the additional analysis. Recommendations related to the revised design are as follows:

- The long-throated flume design was evaluated using the WinFlume software to confirm that the gaging station location 6'-9" from the upstream edge of the flume crest is satisfactory. The gage location could be moved to as close as 6'-3" from the flume crest if necessary. The downstream slope and sill height are also appropriate and will lead to reduced head loss across the flume compared to the original design. Also, the addition of a steel plate on the flume crest as proposed by Greeley and Hansen is a good means for maintaining a uniform smooth surface at the crest.
- Water surface profiles in the troughs downstream of the labyrinth weirs were recomputed using an invert elevation of 0.00 ft in the upstream ends of the troughs. The choice of a 6:1 or 8:1 slope in the transition from the troughs to the long-throated flume approach channel had only a slight effect on the profiles.
- Labyrinth weir discharge capacities were revised to reflect the fact that a sharp crest will be retained in the design for constructability and to facilitate future modifications. A water surface elevation of 10.98 ft is required upstream of the labyrinth weir to drive 233.33 mgd/cycle over the labyrinth weir, compared to 10.80 ft using a quarter-round crest shape.
- The pH, dissolved oxygen, and temperature probes mounted in 2-inch pipes and located 6'-3" upstream of the upstream edge of the flume crest should have negligible effect on the accuracy of the flume. The 18-inch diameter pump wells located 14+ ft upstream from the crest are large enough that they could have a noticeable effect on the accuracy of the flume. Unfortunately, there is no way to quantitatively estimate the effect without a physical model study. Reducing the size of the wells, or moving them upstream would reduce their effect on the flume, but within the confines of the site, the effect cannot be fully eliminated if the pump wells are located upstream of the flume.

Site Description and Operating Conditions

Flow will leave the chlorine contact tanks over a three-cycle labyrinth weir, approximately 58 ft long and 64 ft wide (20+ ft per cycle). Downstream of the labyrinth weir, the combined flows from all three cycles will pass through the long-throated flume. There are three separate chlorine contact tanks, and each of the weir cycles operates independently, serving one contact tank. Under normal operating conditions, flows over the three weir sections should be equal, although the design allows for operation of only 2 tanks during maintenance periods. The labyrinth weirs are intended to maintain sufficient depth and volume in the contact tanks during normal operations, and pass maximum flows without requiring an excessive increase in water levels upstream of the weirs. The long-throated flume is located approximately 43 ft downstream of the labyrinth weir. The flume discharges into a pool in which the flow must negotiate a 90+° right or left-hand corner to enter one of two conveyance channels that carry the flow to either the East River or Whale Creek. Tailwater levels in these conveyance channels are affected by tidal variations. The flume design is constrained by the need to maintain modular (i.e., critical depth) flow in the control section of the flume during the 25-year maximum tidal condition. Physical space at the site is limited by surrounding city streets and existing structures.

Analysis of Long-Throated Flume

A summary of the hydraulic calculations for flows of 180, 310, 465, and 700 mgd was provided by Greeley and Hansen. The procedure used was that described in Bos, Replogle, and Clemmens (1984). Page number and section references in the discussion below refer to that text. Several portions of the computation procedure are iterative in nature and require numerical solution. In general, the computations appear to have been carried out properly, with the exception of the determination of the drag coefficient, C_F. The flow on the crest was assumed to be fully turbulent and C_F was assigned a value of 0.00265. The drag coefficient for a fully turbulent flow should in fact be 0.00235 (pg. 276), and is only applicable to the flow in the approach channel, converging section, and tailwater channel, which are fully turbulent. The boundary layer on the crest is not fully turbulent (see first paragraph of section 9.4.1), and here the drag coefficient must be computed using a trial-and-error solution of equations 9.13-9.17. However, using this procedure to compute the drag coefficient and flume throat losses will likely have only a slight effect on the final outcome of the computations.

A complete evaluation of the flume design was carried out using the *WinFlume* computer program. This software is a design and hydraulic analysis tool for long-throated flumes. The software is based on the hydraulic theory and design procedures described in Bos, Replogle, and Clemmens (1984) and Clemmens, Bos, and Replogle (1993). The software is a Windows-based upgrade to the DOS-based software distributed with Clemmens, Bos, and Replogle (1993), and has been under development by the Bureau of Reclamation since June 1997. The program has undergone beta-testing and will be formally released when printed and online documentation are complete. Features and use of the software are described in Wahl and Clemmens (1998). The software and an online copy of this reference can be downloaded from the Water Resources Research Laboratory's web site at ***http://ogee.do.usbr.gov/twahl/winflume.html***.

Appendix A contains results of the analysis of the initial long-throated flume design. The design shown is for a flume with a 1:1 downstream ramp. The original design did not include a downstream ramp, but one is now being considered to help reduce foaming of the water exiting the flume. The downstream ramp has a beneficial impact on the allowable tailwater level for the flume. The flume was assumed to be constructed with a smooth concrete surface finish, and water levels upstream of the flume were assumed to be measured using a staff gage installed directly in the upstream pool (no stilling well). These assumptions affect the friction losses through the flume and the computation of the expected discharge measurement precision of the structure. Tailwater levels downstream of the flume were determined from Greeley and Hansen's Outfall Summary for the 25-year maximum tidal level and were entered for the minimum and maximum flow (180 and 700 mgd). The *WinFlume* software assumes that tailwater levels vary linearly between minimum and maximum flow. A check was made that this leads to conservative estimates of tailwater levels at flows of 310 and 465 mgd (interpolated tailwater levels were slightly higher than those provided in the Outfall Summary).

The evaluation of the flume design using *WinFlume* shows that the initial design is satisfactory when judged against the freeboard, Froude number, tailwater, and measurement precision criteria. For flows of 600 mgd and greater, there is a warning that the ratio of H_1/L is too large (ratio of upstream energy head to crest length). The recommended range for this ratio is 0.07 to 0.7 (Clemmens, Bos, and Replogle, 1993), although older publications have stated that values as high as 0.75, 0.8, or 1.0 are acceptable. Increasing the crest length to 4.5 ft would produce an H_1/L ratio less than 0.7 at maximum flow, while maintaining $H_1/L > 0.3$ at minimum flow.

Using WinFlume, the crest length was increased to 4.5 ft, and a rating table was generated for this improved design to obtain upstream water levels as a function of flow rate. The complete rating table is included in appendix B; the results are only slightly different from those obtained by Greeley and Hansen for the initial design. Table 1 summarizes the data at the key flow rates, and also shows the water levels at the upstream end of the approach channel (downstream end of labyrinth weir), which will be used later in the analysis of the flow in the exit channels of the labyrinth weir. These water levels were computed using a direct-step backwater computation performed in a spreadsheet (spreadsheets included in appendix D).

Table 1. — Water levels upstream of long-throated flume.

Flow Rate	Upstream head, h_1, at gage location, ft	Flow depth at tail end of labyrinth weir, ft
Peak Flow 700 mgd	2.790	3.805
Maximum Flow 465 mgd	2.169	3.180
Average Flow 310 mgd	1.687	2.695
Minimum Flow 180 mgd	1.202	2.207

Revised Flume Design

The revised design proposed by Greeley and Hansen was analyzed using WinFlume, and complete results are included in Appendix H. Similar backwater profiles were also computed to provide data necessary for analysis of the revised labyrinth weir exit channels. These spreadsheets are included in Appendix I.

Flume Approach Distance

To ensure accurate flow measurement by the long-throated flume, the flow approaching the flume should be uniform and have a minimum of turbulence. Generally, it is recommended that the approach channel leading to the flume be straight and clear of debris or obstructions for a distance of at least 10 times the average approach channel width. This provides the distance necessary to dissipate turbulence and allow for the development of a uniform cross-channel flow profile downstream of any bends. Ten channel widths for this case would be a distance of approximately 640 ft, which cannot be satisfied due to the physical constraints of the site. The distance between the tail end of the labyrinth weir and the gage location is only about 43 ft, and about 47 ft to the start of the converging section of the flume.

For this site, the cross-channel flow profile is likely to be relatively uniform downstream of the labyrinth weirs, when all three contact tanks are in operation. There may be some concentration of flow toward the center of the channels exiting each labyrinth weir cycle, but the available approach distance will likely allow for the development of a relatively uniform cross-channel flow profile. A more detailed study, such as a physical hydraulic model test, would be required to confirm this hypothesis. When only two contact tanks are operating, the cross-channel flow profile will be very non-uniform and the 43 ft approach distance probably will not be sufficient to produce a uniform flow at the flume. Again, a hydraulic model study could confirm this.

If one assumes that the cross-channel profile will be relatively uniform, the primary remaining issue is the need for dissipation of turbulence and the development of a typical vertical velocity profile in the approach channel. The distance required for development of the vertical velocity profile should be more closely related to the depth of flow than the width of the upstream channel, so a criteria based on depth of flow should be sought.

Although it has not typically been used in the analysis of long-throated flumes, approach distance to water measurement devices is often expressed in terms of the pipe diameter or hydraulic radius, especially for closed conduit measurements. Five to 10 pipe diameters of straight pipe is a common requirement (10 preferred). Since the hydraulic radius of a circular pipe is D/4, this requirement can also be stated as 20 to 40 times the hydraulic radius. Due to the relatively shallow flow depth, the hydraulic radius for the approach channel is nearly equal to the depth, and varies from 2.06 ft at minimum flow to 3.39 ft at maximum flow. Thus, the 43-ft approach distance to the flume is approximately 21 hydraulic radii at minimum flow, and 13 hydraulic radii at maximum flow. This is still below the 20 to 40 hydraulic radius requirement, but is at least in a range in which one might expect reasonable flume performance. A physical hydraulic model study could confirm this. If the flow was not found to be adequately uniform, the model study could investigate the use of a wave suppressor or other baffling device that would help make the flow more uniform.

A related issue is the ability to accurately measure the upstream sill-referenced head for the flume. Even if the approach flow is relatively uniform, the close proximity of the labyrinth weir may cause waves on the water surface at the gaging location, thus making it difficult to accurately read a staff gage at this location. A stilling well or wave suppressor could be used to stabilize the water surface at the gaging location.

Revised Design – Effect of Water Quality Sensors and Sampling Well Upstream of Flume

Greeley and Hansen's revised design includes pH, DO, and temperature sensors installed in 2-inch conduits located 6'-3" upstream of the upstream edge of the flume crest, and three 18-inch diameter wells for submersible sampling pumps located about 14+ ft upstream of the crest. The sensors and pump wells hang from a sampling bridge, and are terminated at the flume crest elevation, 6.25 ft, or 9 inches above the floor of the flume approach channel. The pH, DO, and temperature sensors are small enough that they should have no significant effect on the approach flow to the 64'-5" wide flume. However, the pump wells may have at least a measurable effect, since they obstruct over 5 percent of the approach flow area, and are located only 4-5 hydraulic radii upstream of the crest, depending on flow rate. The pump wells will create a wake zone downstream of the wells in which the velocity approaching the crest will be somewhat reduced. Some rough estimates of the reduction of velocity in the wake of the pump wells were made using equations contained in Schlichting (1968). At the upstream edge of the crest, the velocity will be reduced about 32 percent along the centerline of the wake, if the wells are located 14 ft upstream of the crest. The width of the wake zone will be about 2.6 ft; there is zero velocity reduction at the edges of the wake zone. Moving the pump wells upstream does not produce dramatic changes. As an example, if the pump wells were located 40 ft upstream of the crest, the velocity reduction would still be about 19 percent at the centerline of the wake, and the wake zone would be 4.4 ft wide. Unfortunately, without a physical model study there is no way to quantitatively determine the effect of the wake zone on the accuracy of the flume; there is also no way to quantitatively estimate the benefit of moving the pump wells further upstream.

The most desirable alternative would be to locate the pump wells downstream of the flume crest. If this is not possible, then reducing the diameter of the pump wells and moving them as far upstream as practicable would be beneficial.

Hydraulics of the Labyrinth Weir Exit Channels

Although labyrinth weirs have been studied in some detail by the Bureau of Reclamation and others, the focus of these studies has typically been the flow on the upstream side of the weir and its effect on the discharge capacity of the weir. Flow in the exit channel has not been a concern because these weirs have typically been used as emergency spillways, with exit channels that were steeply sloped and could easily carry the flow away from the weir without risk of submerging the weir crest. In this application, submergence of the weir crest is a possibility and must be avoided to ensure that the maximum flow can be passed over the labyrinth weir at a head that is compatible with upstream facilities in the plant.

Flow in the labyrinth weir exit channels was analyzed by Greeley and Hansen for flows of 233.33 mgd/cycle and 350 mgd/cycle in the spreadsheets labeled *Trough Hydraulic Profiles*. The computations were based on an energy balance using the Manning equation to determine friction loss in uniform flows. Using this approach, the difference in water level computed along the 58-ft length of the exit channel was 0.04 ft at a flow rate of 233.33 mgd/cycle and 0.09 ft at 350 mgd/cycle.

The flow in the labyrinth weir exit channels is a spatially varied flow (i.e., discharge varies along the length of the channel) with increasing flow in the downstream direction. Flow over the labyrinth weir crest enters the exit channel essentially perpendicular to the flow direction in the exit channel. This produces energy dissipation in the form of turbulence, rollers, and eddies as the flow entering the channel adjusts itself to the flow direction of the exit channel (see fig. 1). This energy dissipation goes far beyond that due simply to friction, and cannot be computed through any empirical or theoretical equation. Because energy is not conserved in this flow, and the energy losses cannot be computed, this flow must be analyzed using the momentum equation (momentum is always conserved). Chow (1959) describes the computation of spatially varied flow using the momentum equation and a method of numerical integration. His equation 12-38 is:

$$\Delta y' = \frac{\alpha Q_1 (V_1 + V_2)}{g(Q_1 + Q_2)}\left(\Delta V + \frac{V_2}{Q_1}\Delta Q\right) + S_f \Delta x \qquad (1)$$

in which $\Delta y'$ is the drop in water surface elevation from an upstream section 1 to a downstream section 2, a distance Δx apart. V and Q are the velocity and discharge, respectively, at each section, S_f is the friction slope, ΔV and ΔQ are the change in velocity and discharge, g is the acceleration of gravity, and α is the energy coefficient, usually assumed to be 1.0. This equation can be placed into a more convenient form for computation by recognizing that the change in depth from upstream to downstream, $\Delta y = y_2 - y_1$, is:

$$\Delta y = -\Delta y' + S_0 \Delta x \qquad (2)$$

It should be carefully noted that $\Delta y'$ is the *drop*, not the change in water elevation, so it is defined to be positive for the usual case in which the water surface elevation decreases in the downstream direction.

Equations 1 and 2 can then be combined and rearranged to obtain (assuming α=1.0):

$$y_1 - y_2 = \frac{V_2^2 Q_2 - V_1^2 Q_1 + V_1 V_2 (Q_2 - Q_1)}{g(Q_1 + Q_2)} + (S_f - S_0)\Delta x \qquad (3)$$

The term $\frac{V_2^2 Q_2 - V_1^2 Q_1}{g(Q_1 + Q_2)}$ accounts for changes in velocity head, $\frac{V_1 V_2 (Q_2 - Q_1)}{g(Q_1 + Q_2)}$ accounts for changes in momentum flux, and $(S_f - S_0)\Delta x$ accounts for the depth change due to friction slope in excess of bed slope. It should be noted that for a uniform flow in which $Q_1 = Q_2$ this equation reduces to:

$$\Delta x = \frac{(y_1 + \frac{V_1^2}{2g}) - (y_2 + \frac{V_2^2}{2g})}{S_f - S_0} = \frac{E_1 - E_2}{S_f - S_0} \tag{4}$$

in which E_1 and E_2 are the specific energy at the upstream and downstream sections, respectively. This is the familiar equation for computing a direct step backwater profile in uniform flow (Chow, 1959, pg. 263). The equation used by Greeley and Hansen to compute the water surface profiles was:

$$\Delta x = \frac{y_1 - y_2}{S_f - S_0} \qquad y_1 = y_2 + (S_f - S_0)\Delta x \tag{5}$$

which neglects both the velocity head and momentum flux terms.

Equation 3 can be solved in an iterative fashion beginning from a downstream known depth in subcritical flow or from an upstream point of known depth in supercritical flow. A spreadsheet for making these computations in a circular conduit (a subsurface agricultural drain) was available, and was easily modified for application to the rectangular exit channel downstream of the labyrinth weir. The flow in the exit channel will be subcritical due to the backwater created by the long-throated flume, so the

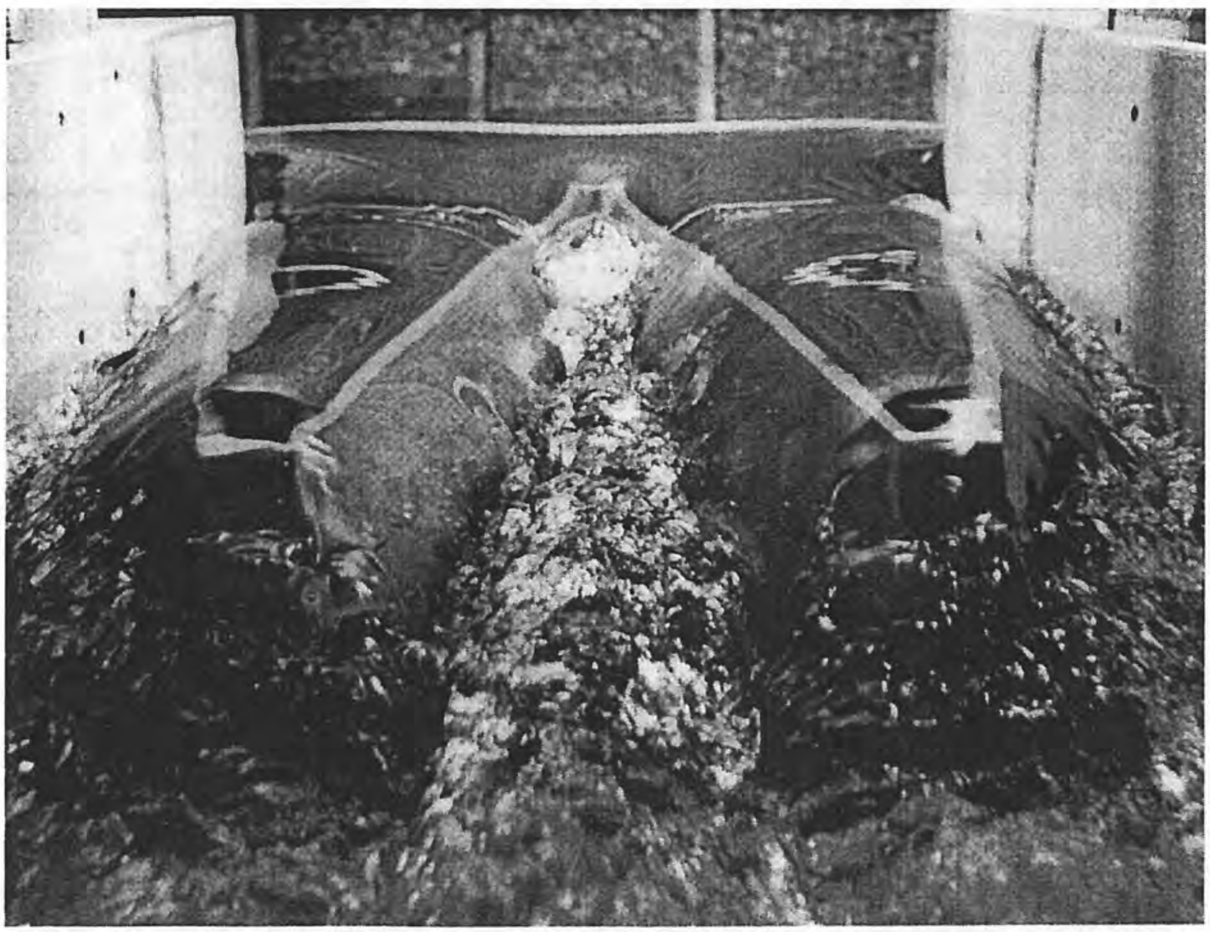


Figure 1. — Flow in the exit channel of a scale model of Hyrum Dam auxiliary spillway, tested in 1982 in Reclamation's Water Resources Research Laboratory.

Table 2. — Water levels in labyrinth weir exit channels. – ORIGINAL DESIGN

Total Discharge mgd	Q per Cycle mgd	Downstream Depth Ft	Upstream Depth ft	Upstream Water Surface Elevation Ft	Percent of Labyrinth Crest Submerged
Two Contact Tanks Operating					
180	90	2.207	2.941	8.441	0
310	155	2.695	4.013	9.513	0
465	**232.5**	**3.180**	**5.145**	**10.645**	**51**
700	**350**	**3.805**	**6.672**	**12.172**	**92**
Three Contact Tanks Operating					
180	60	2.207	2.572	8.072	0
310	103.33	2.695	3.377	8.877	0
465	**155**	**3.180**	**4.225**	**9.725**	**6**
700	**233.33**	**3.805**	**5.371**	**10.871**	**75**

calculations begin from the flow depth previously computed at the upstream end of the approach channel (i.e., downstream end of the labyrinth weir). These data are shown in the last column of table 1. The calculations proceed in the upstream direction. It was assumed that flow entered the exit channel uniformly over the 58-ft length of each labyrinth weir. Table 2 shows a summary of the results for each of the four primary flow rates (180, 310, 465, and 700 mgd) under the two-tank and three-tank operating scenarios. Figure 3 shows the computed water surface profiles under each flow condition. Appendix E contains an example of the spreadsheet used to make these calculations. Figure 3 shows that the labyrinth weir crests, which are at elevation 9.67 ft, will be partially submerged at the maximum and peak flow levels (465 mgd and 700 mgd). For these cases, the water surface profiles shown in Figure 3 are only rough approximations, since the partial submergence of the weir crest invalidates the assumption of uniform inflow to the exit channel.

There are several assumptions implicit in the analysis that may affect the computed water levels. The inflow to the exit channel is not perfectly uniform along the length of the weir, due to head losses in the labyrinth weir approach channel that reduce the discharge over the downstream sections of the weir. Also, there is some inflow to the exit channel that passes over the short sections of the weir that are perpendicular to the axis of the exit channel, rather than over the angled portion of the weir. This flow has some momentum in the direction of the exit channel flow, which is neglected in the analysis. The flow over the angled portions of the labyrinth weir also has a small component of momentum in the exit channel flow direction, due to the 7.5° angle of the weir walls. Bulking of the flow in the exit channel due to air entrainment may also affect the water surface profiles. Only a detailed physical hydraulic model study can account for all of these factors.

Revised Design

The revised design of the exit channels reduced their floor elevation to 0.00 ft in the upstream half (first 29 ft) and then provided a 6:1 or 8:1 transition into the flume approach channel. These two scenarios (6:1 vs. 8:1 transition) were analyzed in combination with the backwater profiles obtained for the revised flume design. The results are summarized in table 3. There is only a slight improvement in the water surface profiles with the 8:1 slope, and either case will perform properly at flows as high as 465 mgd. At a flow of 700 mgd, there will some submergence of the upstream portions of the labyrinth weir crest.

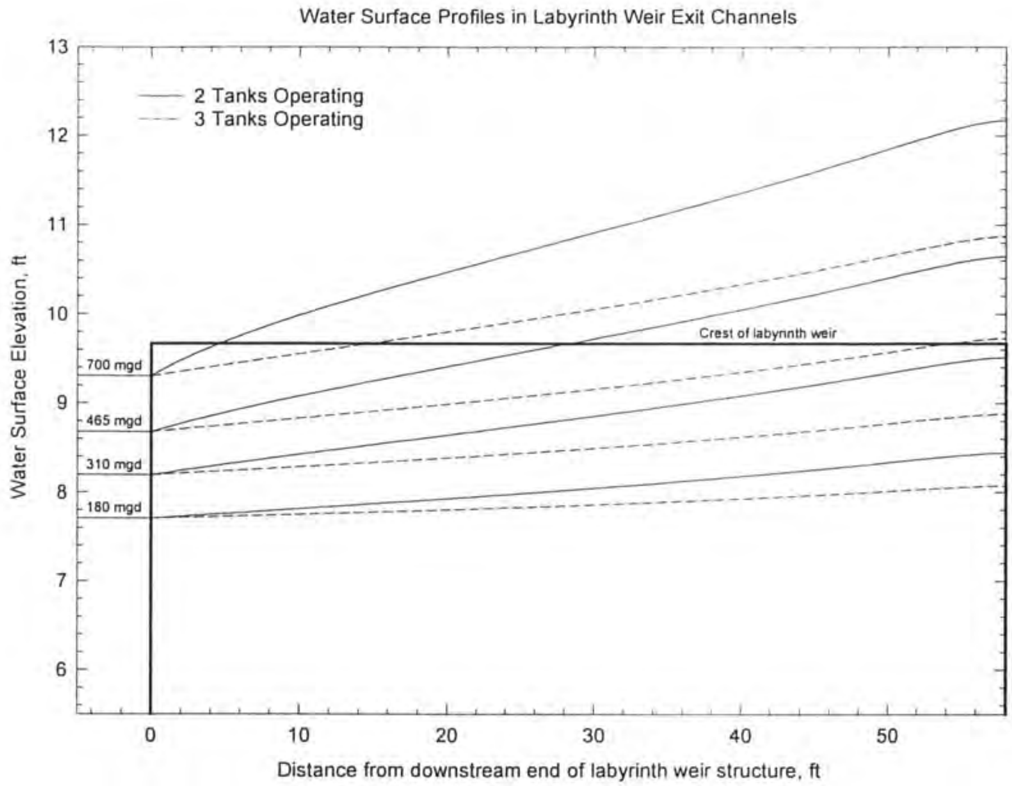


Figure 3. — Computed water surface profiles in exit channels of labyrinth weir, for original design.

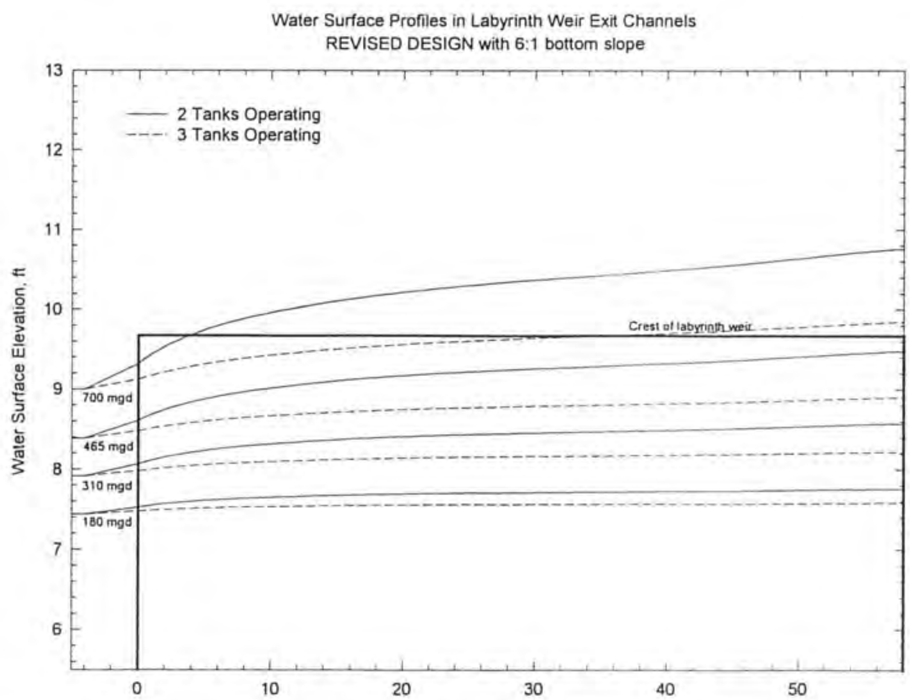


Figure 2. — Computed water surface profiles in labyrinth weir exit channels.

Table 3. — Water levels in labyrinth weir exit channels — REVISED DESIGN

Total Discharge mgd	Q per Cycle mgd	Depth at End of Transition to Flume Approach Channel, ft	Upstream Water Surface Elevation Ft	Percent of Labyrinth Crest Submerged (Tailwater Elev. > 9.67 ft)
Two Contact Tanks Operating – 6:1 transition slope				
180	90	1.939	7.759	0
310	155	2.416	8.572	0
465	232.5	2.888	9.475	0
700	**350**	**3.499**	**10.756**	**93**
Three Contact Tanks Operating – 6:1 transition slope				
180	60	1.939	7.584	0
310	103.33	2.416	8.218	0
465	155	2.888	8.897	0
700	**233.33**	**3.499**	**9.842**	**40**
Two Contact Tanks Operating – 8:1 transition slope				
180	90	1.937	7.714	0
310	155	2.413	8.489	0
465	232.5	2.885	9.350	0
700	**350**	**3.494**	**10.579**	**93**
Three Contact Tanks Operating – 8:1 transition slope				
180	60	1.937	7.562	0
310	103.33	2.413	8.176	0
465	155	2.885	8.833	0
700	**233.33**	**3.494**	**9.746**	**17**

Labyrinth Weir Discharge Coefficients

Labyrinth weirs are designed to pass large discharges with relatively little head by virtue of a greatly magnified crest length produced by wrapping the weir crest back and forth upon itself in a trapezoidal or triangular pattern across the channel. Labyrinth weirs used in emergency spillway applications usually consist of several weir cycles all supplied with water from a common upstream pool. The weir proposed for the Newtown Creek WPCP upgrade has three cycles, but each is supplied with water from a separate upstream chlorine contact tank. Despite the separation of the weirs, they can still be analyzed as a labyrinth weir, since the walls separating the upstream pools are equivalent to the streamlines of the approach flow for a multiple cycle labyrinth weir. There will be a slight reduction in discharge capacity compared to the multiple cycle labyrinth due to the fact that the wall of the upstream pool imposes a no-slip condition along this streamline (i.e., zero velocity).

A plan view of a single labyrinth cycle is shown in Figure 4. The weir crest is an 8-inch thick concrete wall up to elevation 9.42 ft, topped by an unspecified sharp crest at elevation 9.67 ft.

The data package provided by Greeley and Hansen indicates water surface elevations of 10.61 ft and 10.91 ft upstream of the labyrinth weir at flow rates of 233.33 mgd and 350 mgd per tank. These were computed using the equation $Q=CLH^{1.5}$, a discharge coefficient of $C = 3.26$ ft$^{0.5}$/sec, and an effective weir length of L=120.83 ft, assuming free-flow conditions. This is a reasonable discharge coefficient for a straight, sharp-crested weir perpendicular to the approaching flow. However, labyrinth weirs generally have lower discharge coefficients due to the approach flow being non-perpendicular to the crest, losses in the approach channels as they narrow near the downstream end of the labyrinth, and other effects such as nappe interference and unpredictable aeration of the downstream side of the weir. These effects are magnified as the head increases so that at high heads most labyrinth weirs pass only about 2 times the discharge of a typical straight weir, despite the fact that their total crest length may be 4-6 times the length of a straight weir.

For the following evaluation, discharge coefficients and total discharge capacities were estimated using data compiled by Tullis, et al. (1995) from physical model tests performed independently by several researchers. This publication is included in appendix F. They discourage the use of sharp-crested and flat-crested weirs because they have lower discharge coefficients than weirs with a quarter- or half-round top surface. In the estimates that follow, discharge coefficients for a labyrinth weir with a quarter-round crest were determined using figures in Tullis, et al., and then correction factors were used to obtain similar coefficients for a sharp-crested labyrinth weir. The correction factors were derived by comparing the Tullis et al. coefficient for a straight weir with a quarter-round crest to similar coefficients for straight sharp-crested weirs as given by the Kindsvater-Carter equation, $C=0.602+0.075h/p$ (Bos, 1989).

Discharge, Q (ft^3/sec), is computed from:

$$Q = \left(\frac{2}{3} C_d \sqrt{2g}\right) L H_t^{1.5} \qquad (6)$$

where L is the effective crest length, H_t is the total upstream head, C_d is a discharge coefficient, and g is the acceleration of gravity. The effective crest length is computed from $L=2N(A+L_2)$, where N is the number of cycles and A and L_2 are dimensions of the weir as shown in figure 2. The use of an effective crest length accounts for the fact that portions of the crest are inefficient due to flow interference in the narrow corners of the approach and exit channels. The effective crest length for one weir cycle in this design is:

$$\mathrm{L} = 2 \cdot 1 \cdot \left(2 + \frac{58 - (2 \cdot 0.67)}{\cos 7.5^\circ}\right) = 118.3 \text{ ft}$$

A figure in Tullis, et al. was used to determine C_d as a function of the weir angle α=7.5°, and the ratio of H/P. Table 4 summarizes the calculations and results. The water levels required in the contact tanks to obtain flows of 233.33 mgd/cycle and 350 mgd/cycle are 10.98 ft and 11.63 ft, respectively. These are 0.37 ft and 0.72 ft higher than the levels computed by Greeley and Hansen. If a quarter-round crest shape is used, water levels of 10.80 ft and 11.31 ft are required. It should be emphasized that these calculations assume free flow over the labyrinth weir; the discharge capacity will be further reduced when the weir crests are partially submerged, as the previous analysis of the exit channel water surface profiles indicated.

Table 4. — Discharge capacity of one cycle of labyrinth weir.

H_t, ft	H/P	Water Surface Elevation in Contact Tank, ft	C_d (1/4-round crest) (a)	C_d of straight weir with 1/4-round crest (Tullis), (b)	C_d of straight weir with sharp crest (c)	C_d of sharp-crested labyrinth weir (a*c/b)	Discharge per cycle, mgd
0.417	0.1	10.08	0.523	0.605	0.610	0.527	58.0
0.625	0.15	10.29	0.523	0.655	0.613	0.489	99.1
0.833	0.2	10.50	0.51	0.69	0.617	0.456	142.0
1.042	0.25	10.71	0.49	0.72	0.621	0.423	183.6
1.250	0.3	10.92	0.46	0.735	0.625	0.391	223.3
1.458	0.35	11.13	0.43	0.75	0.628	0.360	259.4
1.667	0.4	11.33	0.405	0.755	0.632	0.339	298.8
1.875	0.45	11.54	0.38	0.76	0.636	0.318	333.3
2.083	0.5	11.75	0.36	0.76	0.640	0.303	373.4

By linear interpolation of $H_t^{1.5}$ vs. Q, a contact tank level of 11.63 ft is required to obtain a flow of 350 mgd per cycle.

By linear interpolation of $H_t^{1.5}$ vs. Q, a contact tank level of 10.98 ft is required to obtain a flow of 233.33 mgd per cycle.

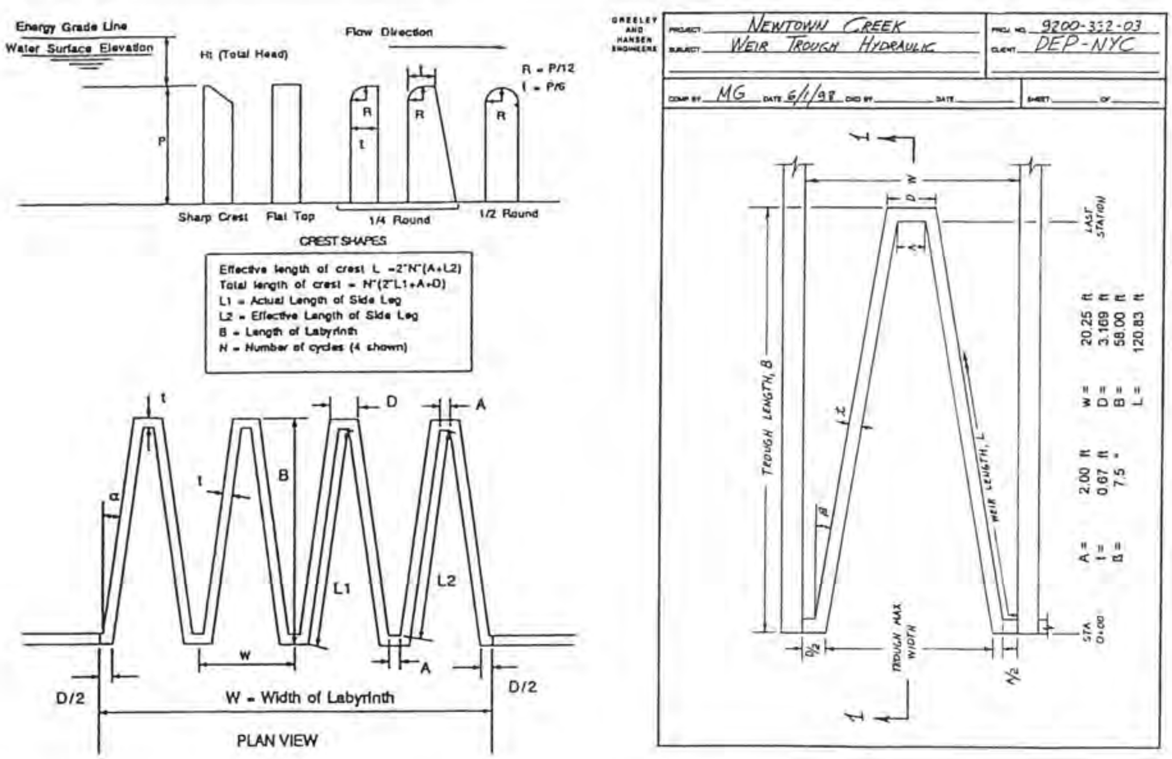


Figure 4. — Labyrinth weir nomenclature and recommended dimensions (Tullis, et al., 1995) and initial labyrinth weir layout for the Newtown Creek WPCP upgrade.

References

Bos, M.G., J.A. Replogle, and A.J. Clemmens, 1984, Flow Measuring Flumes for Open Channel Systems, John Wiley & Sons, New York, NY.

Bos, M.G., 1989, Discharge Measurement Structures, ILRI Publication 20, International Institute for Land Reclamation and Improvement, The Netherlands.

Clemmens, A.J., M.G. Bos, and J.A. Replogle, 1993, FLUME: Design and Calibration of Long-Throated Measuring Flumes, ILRI Publication 54, International Institute for Land Reclamation and Improvement, The Netherlands.

Chow, V.T., 1959, Open-Channel Hydraulics, McGraw-Hill Book Company, New York, NY.

Schlichting, H., 1968, Boundary-Layer Theory, 6th ed., McGraw-Hill Book Company, New York, NY, pg. 692.

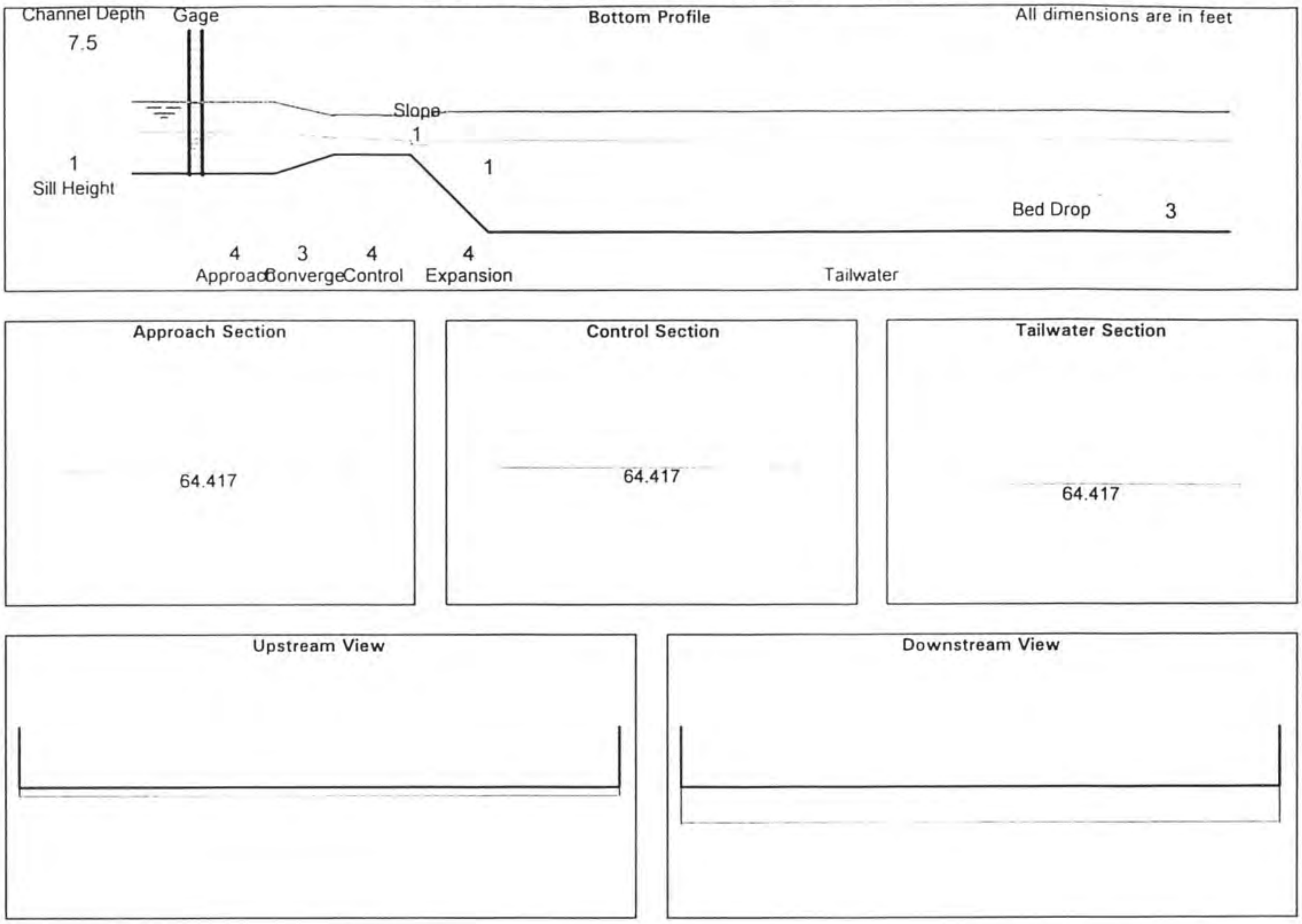
Tullis, J.P., N. Amanian, and D. Waldron, 1995, "Design of Labyrinth Spillways," *Journal of Hydraulic Engineering*, vol. 121, no. 3, March 1995.

Wahl, T.L., and A.J. Clemmens, 1998, "Improved Software for Design of Long-Throated Flumes," 14th Technical Conference on Irrigation, Drainage and Flood Control, U.S. Committee on Irrigation and Drainage, Phoenix, AZ, June 3-6, 1998.

APPENDIX A

Analysis of initial long-throated flume design

Newtown Creek flume - initial design - Revision 7



User: Tony L. Wahl WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Newton.Creek.Greeley&Hansen.Flm - Revision 7
Newtown Creek flume - initial design
Printed: 11/3/98

FLUME DATA REPORT

GENERAL DATA ON FLUME

Type of structure: Stationary Crest
Type of lining: Concrete - smooth
Roughness height of flume: 0.000492 ft

BOTTOM PROFILE DATA

```
Length per section:  Approach section = 4.000 ft
                      Converging ramp = 3.000 ft
                      Control section = 4.000 ft
                       Expansion ramp = 4.000 ft

Vertical dimensions: Upstream channel depth = 7.500 ft
                             Height of sill = 1.000 ft
                                   Bed drop = 3.000 ft
                       Expansion ramp slope = 1.000:1
```

-- APPROACH SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

-- CONTROL SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

-- TAILWATER SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

```
User: Tony L. Wahl          WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Newton.Creek.Greeley&Hansen.Flm - Revision 7
Newtown Creek flume - initial design
Printed: 11/3/98

                              EVALUATION OF FLUME DESIGN
-----------------------------------------------------------------------------------
GENERAL RESULT:  Design is acceptable.
                 One error or warning.

                EVALUATION OF FLUME DESIGN FOR EACH DESIGN REQUIREMENT

Ok.          Freeboard at Qmax = 3.711 ft          Minimum allowed = 3.580 ft

Ok.               Head at Qmax = 2.789 ft    Minimum for precision = 1.307 ft
                 Estimated discharge measurement precision at Qmax = ±2.52 %

Ok.               Head at Qmin = 1.201 ft    Minimum for precision = 0.444 ft
                 Estimated discharge measurement precision at Qmin = ±3.45 %

Ok.          Tailwater at Qmax = 6.250 ft          Maximum allowed = 6.493 ft
                                    Submergence Protection at Qmax = 0.243 ft

Ok.          Tailwater at Qmin = 4.760 ft          Maximum allowed = 4.943 ft
                                    Submergence Protection at Qmin = 0.183 ft

Ok.      Froude number at Qmax = 0.402             Maximum allowed = 0.500

                         ADVICE, WARNINGS, AND ERROR MESSAGES

ERRORS AND WARNINGS AT MAXIMUM DISCHARGE:
- Upstream energy head / control section length exceeds 0.7.

                                 RESULTING STRUCTURE
Sill Height = 1.000 ft
                              -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft

                                   DESIGN CRITERIA

Structure Type:  Stationary Crest
Freeboard design criterion:  Fixed freeboard height = 3.580 ft
Allowable discharge measurement errors for a single measurement:
  At minimum discharge: 8 %    At maximum discharge: 4 %
Head detection method: Staff gage without stilling well, Fr=0.2
   Gage readout precision = 0.023000 ft
Design discharges and associated tailwater levels:
  Minimum discharge = 180.000 mgd  Minimum tailwater depth = 4.760 ft
  Maximum discharge = 700.000 mgd  Maximum tailwater depth = 6.250 ft
  Bed drop at structure site = 3.000 ft
Values derived using:  User-specified
```

User: Tony L. Wahl   WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Newton Creek Greeley&Hansen.Flm - Revision 7
Newtown Creek flume - initial design
Flume Rating Table, Printed 11/3/98
Page 1

Discharge mgd	Head at Gage, h1 ft	Froude Number	Required Head Loss ft	H1/L Ratio	Upstream Energy Head, ft	Upstream Depth ft	Upstream Velocity ft/s	Discharge Coeff	Velocity Coeff	Allowable Tailwater h2, ft	Tailwater Head, h2 ft	Tailwater Depth, y2 ft	Submerge Ratio	Modular Limit	Errors
180.0	1.201	0.234	0.108	0.316	1.263	2.201	1.965	0.988	1.079	0.943	0.760	4.760	0.612	0.756	
185.0	1.221	0.237	0.112	0.321	1.286	2.221	2.000	0.988	1.080	0.962	0.774	4.774	0.611	0.758	
190.0	1.242	0.240	0.115	0.327	1.309	2.242	2.036	0.988	1.082	0.981	0.789	4.789	0.611	0.759	
195.0	1.262	0.243	0.119	0.333	1.332	2.262	2.070	0.988	1.083	0.999	0.803	4.803	0.614	0.761	
200.0	1.282	0.246	0.122	0.339	1.354	2.282	2.105	0.989	1.085	1.017	0.817	4.817	0.615	0.762	
205.0	1.302	0.248	0.126	0.344	1.376	2.302	2.139	0.989	1.086	1.036	0.832	4.832	0.616	0.763	
210.0	1.322	0.251	0.129	0.350	1.398	2.322	2.172	0.989	1.088	1.054	0.846	4.846	0.617	0.765	
215.0	1.342	0.254	0.332	0.355	1.420	2.342	2.205	0.990	1.089	1.072	0.860	4.860	0.618	0.766	
220.0	1.361	0.257	0.336	0.361	1.442	2.361	2.238	0.990	1.091	1.090	0.875	4.875	0.619	0.767	
225.0	1.380	0.259	0.339	0.366	1.464	2.380	2.270	0.990	1.092	1.107	0.889	4.889	0.620	0.769	
230.0	1.400	0.262	0.342	0.371	1.485	2.400	2.302	0.990	1.093	1.125	0.903	4.903	0.621	0.770	
235.0	1.418	0.265	0.345	0.377	1.506	2.418	2.334	0.990	1.095	1.143	0.918	4.918	0.623	0.771	
240.0	1.437	0.267	0.348	0.382	1.528	2.437	2.365	0.991	1.096	1.160	0.932	4.932	0.624	0.772	
245.0	1.456	0.270	0.351	0.387	1.549	2.456	2.396	0.991	1.097	1.177	0.946	4.946	0.625	0.773	
250.0	1.474	0.272	0.354	0.392	1.569	2.474	2.427	0.991	1.098	1.195	0.961	4.961	0.627	0.774	
255.0	1.493	0.274	0.357	0.398	1.590	2.493	2.457	0.991	1.100	1.212	0.975	4.975	0.628	0.776	
260.0	1.511	0.277	0.360	0.403	1.611	2.511	2.487	0.991	1.101	1.229	0.989	4.989	0.629	0.777	
265.0	1.529	0.279	0.362	0.408	1.631	2.529	2.517	0.992	1.102	1.246	1.004	5.004	0.631	0.778	
270.0	1.547	0.281	0.365	0.413	1.652	2.547	2.546	0.992	1.103	1.263	1.018	5.018	0.632	0.779	
275.0	1.564	0.284	0.368	0.418	1.672	2.564	2.576	0.992	1.105	1.279	1.032	5.032	0.633	0.780	
280.0	1.582	0.286	0.370	0.423	1.692	2.582	2.605	0.992	1.106	1.296	1.047	5.047	0.635	0.781	
285.0	1.600	0.288	0.373	0.428	1.712	2.600	2.633	0.992	1.107	1.313	1.061	5.061	0.636	0.782	
290.0	1.617	0.290	0.376	0.433	1.732	2.617	2.662	0.993	1.108	1.329	1.075	5.075	0.638	0.783	
295.0	1.634	0.292	0.378	0.438	1.751	2.634	2.690	0.993	1.109	1.346	1.090	5.090	0.639	0.784	
300.0	1.652	0.294	0.381	0.443	1.771	2.652	2.718	0.993	1.110	1.362	1.104	5.104	0.641	0.785	
305.0	1.669	0.296	0.383	0.448	1.790	2.669	2.745	0.993	1.112	1.378	1.118	5.118	0.642	0.786	
310.0	1.686	0.298	0.386	0.452	1.810	2.686	2.773	0.993	1.113	1.395	1.132	5.132	0.644	0.787	
315.0	1.702	0.300	0.388	0.457	1.829	2.702	2.800	0.991	1.114	1.411	1.147	5.147	0.645	0.788	
320.0	1.719	0.302	0.390	0.462	1.848	2.719	2.827	0.991	1.115	1.427	1.161	5.161	0.647	0.789	
325.0	1.736	0.304	0.393	0.467	1.867	2.736	2.853	0.994	1.116	1.443	1.175	5.175	0.648	0.790	
330.0	1.752	0.306	0.395	0.472	1.886	2.752	2.880	0.994	1.117	1.459	1.190	5.190	0.650	0.791	
335.0	1.769	0.308	0.397	0.476	1.905	2.769	2.906	0.994	1.118	1.474	1.204	5.204	0.652	0.792	
340.0	1.785	0.310	0.399	0.481	1.924	2.785	2.932	0.994	1.119	1.490	1.218	5.218	0.651	0.792	
345.0	1.801	0.312	0.402	0.486	1.943	2.801	2.958	0.994	1.120	1.506	1.233	5.233	0.655	0.793	
350.0	1.817	0.313	0.404	0.490	1.961	2.817	2.984	0.994	1.121	1.521	1.247	5.247	0.656	0.794	
355.0	1.834	0.315	0.406	0.495	1.980	2.834	3.009	0.994	1.122	1.537	1.261	5.261	0.658	0.795	
360.0	1.849	0.317	0.408	0.500	1.998	2.849	3.035	0.995	1.123	1.553	1.276	5.276	0.659	0.796	
365.0	1.865	0.319	0.410	0.504	2.017	2.865	3.060	0.995	1.124	1.568	1.290	5.290	0.661	0.797	
370.0	1.881	0.320	0.412	0.509	2.035	2.881	3.085	0.995	1.125	1.583	1.304	5.304	0.662	0.797	
375.0	1.897	0.322	0.414	0.513	2.053	2.897	3.109	0.995	1.126	1.599	1.319	5.319	0.664	0.798	
380.0	1.913	0.324	0.416	0.518	2.071	2.913	3.134	0.995	1.127	1.614	1.333	5.333	0.666	0.799	
385.0	1.928	0.325	0.418	0.522	2.089	2.928	3.158	0.995	1.128	1.629	1.347	5.347	0.667	0.800	
390.0	1.944	0.327	0.420	0.527	2.107	2.944	3.182	0.995	1.129	1.644	1.362	5.362	0.669	0.801	
395.0	1.959	0.329	0.422	0.531	2.125	2.959	3.206	0.995	1.130	1.659	1.376	5.376	0.670	0.801	
400.0	1.974	0.330	0.424	0.536	2.143	2.974	3.230	0.996	1.131	1.674	1.390	5.390	0.672	0.802	
405.0	1.989	0.332	0.426	0.540	2.161	2.989	3.254	0.996	1.132	1.689	1.405	5.405	0.673	0.803	
410.0	2.005	0.333	0.428	0.545	2.178	3.005	3.278	0.996	1.133	1.704	1.419	5.419	0.675	0.804	
415.0	2.020	0.335	0.430	0.549	2.196	3.020	3.301	0.996	1.134	1.719	1.433	5.433	0.677	0.804	
420.0	2.035	0.336	0.432	0.553	2.213	3.035	3.324	0.996	1.135	1.734	1.448	5.448	0.678	0.805	
425.0	2.050	0.338	0.433	0.558	2.231	3.050	3.347	0.996	1.135	1.748	1.462	5.462	0.680	0.806	
430.0	2.064	0.339	0.435	0.562	2.248	3.064	3.370	0.996	1.136	1.763	1.476	5.476	0.681	0.806	
435.0	2.079	0.341	0.437	0.566	2.265	3.079	3.393	0.996	1.137	1.778	1.491	5.491	0.683	0.807	
440.0	2.094	0.342	0.439	0.571	2.283	3.094	3.416	0.996	1.138	1.792	1.505	5.505	0.684	0.808	
445.0	2.109	0.344	0.440	0.575	2.300	3.109	3.438	0.997	1.139	1.807	1.519	5.519	0.686	0.809	
450.0	2.123	0.345	0.442	0.579	2.317	3.123	3.461	0.997	1.140	1.821	1.534	5.534	0.688	0.809	
455.0	2.138	0.347	0.444	0.584	2.334	3.138	3.483	0.997	1.141	1.836	1.548	5.548	0.689	0.810	
460.0	2.152	0.348	0.445	0.588	2.351	3.152	3.505	0.997	1.142	1.850	1.562	5.562	0.691	0.811	
465.0	2.167	0.349	0.447	0.592	2.368	3.167	3.527	0.997	1.142	1.864	1.577	5.577	0.692	0.811	
470.0	2.181	0.351	0.449	0.596	2.385	3.181	3.549	0.997	1.143	1.879	1.591	5.591	0.694	0.812	
475.0	2.196	0.352	0.450	0.600	2.402	3.196	3.570	0.997	1.144	1.893	1.605	5.605	0.695	0.812	
480.0	2.210	0.353	0.452	0.605	2.418	3.210	3.592	0.997	1.145	1.907	1.620	5.620	0.697	0.813	
485.0	2.224	0.355	0.454	0.609	2.435	3.224	3.613	0.997	1.146	1.921	1.634	5.634	0.698	0.814	
490.0	2.238	0.356	0.455	0.613	2.452	3.238	3.635	0.997	1.146	1.935	1.648	5.648	0.700	0.814	
495.0	2.252	0.357	0.457	0.617	2.468	3.252	3.656	0.997	1.147	1.949	1.663	5.663	0.701	0.815	
500.0	2.266	0.359	0.458	0.621	2.485	3.266	3.677	0.997	1.148	1.963	1.677	5.677	0.703	0.816	
505.0	2.280	0.360	0.460	0.625	2.501	3.280	3.698	0.998	1.149	1.977	1.691	5.691	0.704	0.816	
510.0	2.294	0.361	0.461	0.629	2.518	3.294	3.719	0.998	1.150	1.991	1.706	5.706	0.706	0.817	
515.0	2.308	0.362	0.463	0.634	2.534	3.308	3.739	0.998	1.150	2.005	1.720	5.720	0.707	0.817	
520.0	2.322	0.364	0.464	0.638	2.550	3.322	3.760	0.998	1.151	2.019	1.734	5.734	0.709	0.818	
525.0	2.336	0.365	0.466	0.642	2.567	3.336	3.780	0.998	1.152	2.033	1.749	5.749	0.710	0.819	
530.0	2.349	0.366	0.467	0.646	2.583	3.349	3.801	0.998	1.153	2.047	1.763	5.763	0.712	0.819	
535.0	2.363	0.367	0.469	0.650	2.599	3.363	3.822	0.998	1.154	2.060	1.777	5.777	0.713	0.820	
540.0	2.376	0.369	0.470	0.654	2.615	3.376	3.842	0.998	1.155	2.074	1.792	5.792	0.715	0.820	
545.0	2.390	0.370	0.471	0.658	2.631	3.390	3.862	0.998	1.155	2.088	1.806	5.806	0.716	0.821	
550.0	2.403	0.371	0.473	0.662	2.647	3.403	3.882	0.998	1.156	2.101	1.820	5.820	0.718	0.821	
555.0	2.417	0.372	0.474	0.666	2.663	3.417	3.902	0.999	1.157	2.115	1.835	5.835	0.719	0.822	
560.0	2.430	0.373	0.476	0.670	2.679	3.430	3.921	0.999	1.157	2.128	1.849	5.849	0.721	0.822	
565.0	2.444	0.374	0.477	0.674	2.695	3.444	3.941	0.999	1.158	2.142	1.863	5.863	0.722	0.823	
570.0	2.457	0.376	0.478	0.678	2.711	3.457	3.960	0.999	1.159	2.155	1.877	5.877	0.724	0.824	
575.0	2.470	0.377	0.480	0.682	2.726	3.470	3.980	0.999	1.160	2.169	1.892	5.892	0.725	0.824	
580.0	2.483	0.378	0.481	0.686	2.742	3.483	3.999	0.999	1.160	2.182	1.906	5.906	0.727	0.825	
585.0	2.497	0.379	0.482	0.689	2.758	3.497	4.019	0.999	1.161	2.195	1.920	5.920	0.728	0.825	
590.0	2.510	0.380	0.484	0.693	2.773	3.510	4.038	0.999	1.162	2.209	1.935	5.935	0.730	0.826	
595.0	2.523	0.381	0.485	0.697	2.789	3.523	4.057	0.999	1.162	2.222	1.949	5.949	0.731	0.826	
600.0	2.536	0.382	0.486	0.701	2.805	3.536	4.076	0.999	1.163	2.235	1.963	5.963	0.732	0.827	NonFata
605.0	2.549	0.383	0.487	0.705	2.820	3.549	4.095	0.999	1.164	2.248	1.978	5.978	0.734	0.827	NonFata
610.0	2.562	0.384	0.489	0.709	2.835	3.562	4.113	0.999	1.164	2.261	1.992	5.992	0.735	0.828	NonFata
615.0	2.575	0.385	0.490	0.713	2.851	3.575	4.132	0.999	1.165	2.275	2.006	6.006	0.737	0.828	NonFata
620.0	2.588	0.386	0.491	0.717	2.866	3.588	4.151	0.999	1.166	2.288	2.021	6.021	0.738	0.829	NonFata
625.0	2.601	0.387	0.492	0.720	2.882	3.601	4.169	0.999	1.166	2.301	2.035	6.035	0.740	0.829	NonFata
630.0	2.613	0.388	0.494	0.724	2.897	3.613	4.188	1.000	1.167	2.314	2.049	6.049	0.741	0.830	NonFata
635.0	2.626	0.389	0.495	0.728	2.912	3.626	4.206	1.000	1.168	2.327	2.064	6.064	0.742	0.830	NonFata
640.0	2.639	0.390	0.496	0.732	2.927	3.639	4.224	1.000	1.168	2.340	2.078	6.078	0.744	0.831	NonFata
645.0	2.652	0.391	0.497	0.736	2.943	3.652	4.243	1.000	1.169	2.353	2.092	6.092	0.745	0.831	NonFata
650.0	2.664	0.392	0.499	0.739	2.957	3.664	4.261	1.000	1.170	2.365	2.107	6.107	0.747	0.831	NonFata
655.0	2.677	0.393	0.500	0.743	2.973	3.677	4.279	1.000	1.170	2.378	2.121	6.121	0.748	0.832	NonFata
660.0	2.689	0.394	0.501	0.747	2.988	3.689	4.297	1.000	1.171	2.391	2.135	6.135	0.749	0.832	NonFata
665.0	2.702	0.395	0.502	0.751	3.003	3.702	4.315	1.000	1.172	2.404	2.150	6.150	0.751	0.833	NonFata
670.0	2.714	0.396	0.503	0.754	3.018	3.714	4.333	1.000	1.172	2.417	2.164	6.164	0.752	0.833	NonFata
675.0	2.727	0.397	0.504	0.758	3.033	3.727	4.350	1.000	1.173	2.429	2.178	6.178	0.754	0.834	NonFata
680.0	2.739	0.398	0.505	0.762	3.048	3.739	4.368	1.000	1.173	2.442	2.193	6.193	0.755	0.834	NonFata
685.0	2.752	0.399	0.507	0.766	3.062	3.752	4.386	1.000	1.174	2.455	2.207	6.207	0.756	0.835	NonFata
690.0	2.764	0.400	0.508	0.769	3.077	3.764	4.403	1.000	1.175	2.467	2.221	6.221	0.758	0.835	NonFata
695.0	2.776	0.401	0.509	0.773	3.092	3.776	4.420	1.000	1.175	2.480	2.216	6.236	0.759	0.835	NonFata
700.0	2.789	0.402	0.510	0.777	3.107	3.789	4.438	1.000	1.176	2.493	2.250	6.250	0.760	0.836	NonFata

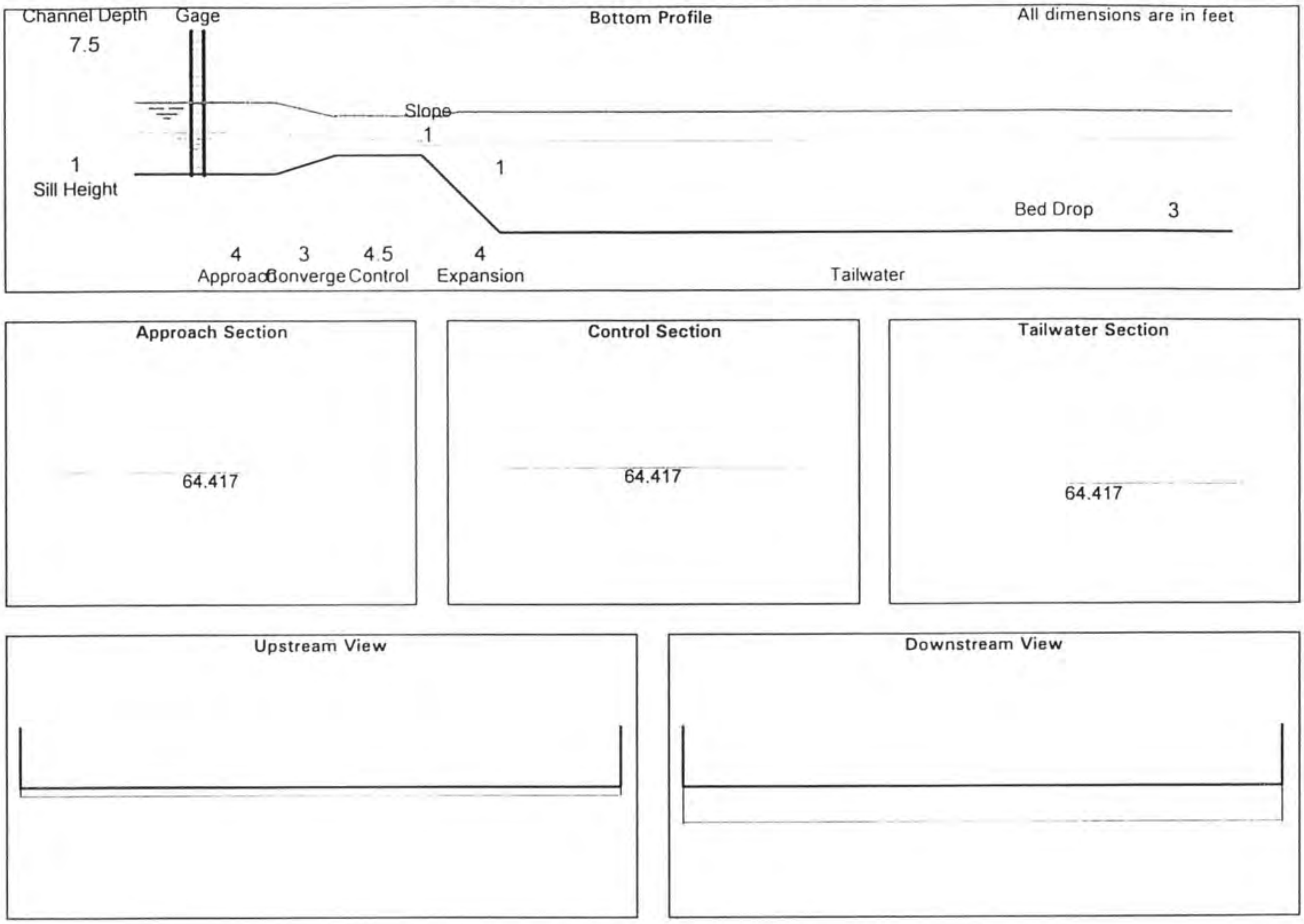
Error Summary

Upstream energy head / control section length exceeds 0.7

APPENDIX B

Long-throated flume with 4.5-ft long crest

Improved Newtown Creek flume - Revision 10



```
User: Tony L. Wahl          WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Improved.Newtown.Creek.Flm - Revision 10
Improved Newtown Creek flume
Printed: 11/3/98
                               FLUME DATA REPORT
----------------------------------------------------------------------------------
                             GENERAL DATA ON FLUME
Type of structure: Stationary Crest
Type of lining: Concrete - smooth
Roughness height of flume: 0.000492 ft

                              BOTTOM PROFILE DATA
Length per section:  Approach section = 4.000 ft
                      Converging ramp = 3.000 ft
                      Control section = 4.500 ft
                       Expansion ramp = 4.000 ft

Vertical dimensions: Upstream channel depth = 7.500 ft
                             Height of sill = 1.000 ft
                                   Bed drop = 3.000 ft
                       Expansion ramp slope = 1.000:1

                          -- APPROACH SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft

                          -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft

                          -- TAILWATER SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft
```

```
User: Tony L. Wahl          WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Improved.Newtown.Creek.Flm - Revision 10
Improved Newtown Creek flume
Printed: 11/3/98

                           EVALUATION OF FLUME DESIGN
------------------------------------------------------------------------------
GENERAL RESULT:  Design is acceptable.
                 Zero errors or warnings.


             EVALUATION OF FLUME DESIGN FOR EACH DESIGN REQUIREMENT

Ok.          Freeboard at Qmax = 3.710 ft          Minimum allowed = 3.580 ft

Ok.               Head at Qmax = 2.790 ft    Minimum for precision = 0.980 ft
                 Estimated discharge measurement precision at Qmax = ±2.27 %

Ok.               Head at Qmin = 1.202 ft    Minimum for precision = 0.444 ft
                 Estimated discharge measurement precision at Qmin = ±3.44 %

Ok.          Tailwater at Qmax = 6.250 ft          Maximum allowed = 6.493 ft
                                   Submergence Protection at Qmax = 0.243 ft

Ok.          Tailwater at Qmin = 4.760 ft          Maximum allowed = 4.944 ft
                                   Submergence Protection at Qmin = 0.184 ft

Ok.      Froude number at Qmax = 0.402             Maximum allowed = 0.500


                              RESULTING STRUCTURE
Sill Height = 1.000 ft
                          -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft


                                DESIGN CRITERIA

Structure Type:  Stationary Crest
Freeboard design criterion:  Fixed freeboard height = 3.580 ft
Allowable discharge measurement errors for a single measurement:
  At minimum discharge: 8 %    At maximum discharge: 4 %
Head detection method: Staff gage without stilling well, Fr=0.2
   Gage readout precision = 0.023000 ft
Design discharges and associated tailwater levels:
  Minimum discharge = 180.000 mgd  Minimum tailwater depth = 4.760 ft
  Maximum discharge = 700.000 mgd  Maximum tailwater depth = 6.250 ft
  Bed drop at structure site = 3.000 ft
Values derived using:  User-specified
```

User: Tony L. Wahl WinFlume32 - Version 0.57 (11/1/98)
D:\WinFlume\Source\Improved.Newtown.Creek.Flm - Revision 10
Improved Newtown Creek flume
Flume Rating Table. Printed: 11/3/98

Discharge mgd	Head at Gage, h1 ft	Froude Number	Required Head Loss ft	H1/L Ratio	Upstream Energy Head, ft	Upstream Depth ft	Upstream Velocity ft/s	Discharge Coeff.	Velocity Coeff	Allowable Tailwater h2, ft	Tailwater Head, h2 ft	Tailwater Depth, y2 ft	Submerge Ratio	Modular Limit	Errors
180.0	1.202	0.233	0.309	0.281	1.264	2.202	1.963	0.986	1.079	0.944	0.760	4.760	0.611	0.756	
185.0	1.221	0.236	0.312	0.286	1.287	2.223	1.999	0.986	1.080	0.962	0.774	4.774	0.612	0.757	
190.0	1.241	0.239	0.316	0.291	1.310	2.243	2.034	0.986	1.082	0.981	0.789	4.789	0.613	0.759	
195.0	1.264	0.242	0.320	0.296	1.333	2.264	2.069	0.987	1.083	0.999	0.803	4.803	0.614	0.760	
200.0	1.284	0.245	0.323	0.301	1.355	2.284	2.103	0.987	1.085	1.018	0.817	4.817	0.614	0.762	
205.0	1.304	0.248	0.327	0.306	1.378	2.304	2.137	0.987	1.086	1.036	0.832	4.832	0.615	0.763	
210.0	1.324	0.251	0.330	0.311	1.400	2.324	2.171	0.988	1.088	1.054	0.846	4.846	0.616	0.764	
215.0	1.343	0.254	0.333	0.316	1.422	2.343	2.204	0.988	1.089	1.072	0.860	4.860	0.617	0.766	
220.0	1.363	0.257	0.337	0.321	1.443	2.363	2.237	0.988	1.090	1.090	0.875	4.875	0.619	0.767	
225.0	1.382	0.259	0.340	0.326	1.465	2.382	2.269	0.988	1.092	1.108	0.889	4.889	0.620	0.768	
230.0	1.401	0.262	0.343	0.330	1.486	2.401	2.301	0.989	1.093	1.126	0.903	4.903	0.621	0.769	
235.0	1.420	0.264	0.346	0.335	1.508	2.420	2.333	0.989	1.094	1.143	0.918	4.918	0.622	0.771	
240.0	1.439	0.267	0.349	0.340	1.529	2.439	2.364	0.989	1.096	1.161	0.932	4.932	0.623	0.772	
245.0	1.457	0.269	0.352	0.344	1.550	2.457	2.395	0.989	1.097	1.178	0.946	4.946	0.625	0.773	
250.0	1.476	0.272	0.355	0.349	1.571	2.476	2.425	0.990	1.098	1.195	0.961	4.961	0.626	0.774	
255.0	1.494	0.274	0.358	0.354	1.591	2.494	2.456	0.990	1.099	1.212	0.975	4.975	0.627	0.775	
260.0	1.512	0.277	0.361	0.358	1.612	2.512	2.486	0.990	1.101	1.229	0.989	4.989	0.629	0.776	
265.0	1.530	0.279	0.363	0.363	1.633	2.530	2.516	0.990	1.102	1.246	1.004	5.004	0.630	0.777	
270.0	1.548	0.281	0.366	0.367	1.653	2.548	2.545	0.990	1.103	1.263	1.018	5.018	0.632	0.779	
275.0	1.566	0.283	0.369	0.372	1.673	2.566	2.574	0.991	1.104	1.280	1.032	5.032	0.633	0.780	
280.0	1.584	0.286	0.371	0.376	1.693	2.584	2.603	0.991	1.106	1.297	1.047	5.047	0.634	0.781	
285.0	1.601	0.288	0.374	0.381	1.713	2.601	2.632	0.991	1.107	1.313	1.061	5.061	0.636	0.782	
290.0	1.618	0.290	0.377	0.385	1.733	2.618	2.660	0.991	1.108	1.330	1.075	5.075	0.637	0.783	
295.0	1.636	0.292	0.379	0.389	1.753	2.636	2.688	0.991	1.109	1.346	1.090	5.090	0.639	0.784	
300.0	1.653	0.294	0.382	0.394	1.772	2.653	2.716	0.991	1.110	1.362	1.104	5.104	0.640	0.785	
305.0	1.670	0.296	0.384	0.398	1.792	2.670	2.744	0.992	1.111	1.379	1.118	5.118	0.642	0.786	
310.0	1.687	0.298	0.387	0.402	1.811	2.687	2.771	0.992	1.112	1.395	1.132	5.132	0.643	0.787	
315.0	1.704	0.300	0.389	0.407	1.830	2.704	2.798	0.992	1.113	1.411	1.147	5.147	0.645	0.788	
320.0	1.721	0.302	0.391	0.411	1.850	2.721	2.825	0.992	1.115	1.427	1.161	5.161	0.646	0.788	
325.0	1.737	0.304	0.394	0.415	1.869	2.737	2.852	0.992	1.116	1.443	1.175	5.175	0.648	0.789	
330.0	1.754	0.306	0.396	0.419	1.888	2.754	2.878	0.992	1.117	1.459	1.190	5.190	0.650	0.790	
335.0	1.770	0.308	0.398	0.424	1.907	2.770	2.905	0.993	1.118	1.475	1.204	5.204	0.651	0.791	
340.0	1.787	0.310	0.400	0.428	1.925	2.787	2.931	0.993	1.119	1.491	1.218	5.218	0.653	0.792	
345.0	1.803	0.311	0.403	0.432	1.944	2.803	2.957	0.993	1.120	1.506	1.233	5.233	0.654	0.793	
350.0	1.819	0.313	0.405	0.436	1.963	2.819	2.982	0.993	1.121	1.522	1.247	5.247	0.656	0.794	
355.0	1.835	0.315	0.407	0.440	1.981	2.835	3.008	0.993	1.122	1.537	1.261	5.261	0.657	0.795	
360.0	1.851	0.317	0.409	0.444	2.000	2.851	3.033	0.993	1.123	1.553	1.276	5.276	0.659	0.795	
365.0	1.867	0.318	0.411	0.448	2.018	2.867	3.058	0.993	1.124	1.568	1.290	5.290	0.660	0.796	
370.0	1.883	0.320	0.413	0.453	2.036	2.883	3.083	0.994	1.125	1.584	1.304	5.304	0.662	0.797	
375.0	1.898	0.322	0.415	0.457	2.055	2.898	3.108	0.994	1.126	1.599	1.319	5.319	0.664	0.798	
380.0	1.914	0.323	0.417	0.461	2.073	2.914	3.132	0.994	1.127	1.614	1.333	5.333	0.665	0.799	
385.0	1.930	0.325	0.419	0.465	2.091	2.930	3.157	0.994	1.128	1.629	1.347	5.347	0.667	0.800	
390.0	1.945	0.327	0.421	0.469	2.109	2.945	3.181	0.994	1.129	1.645	1.362	5.362	0.668	0.800	
395.0	1.960	0.328	0.423	0.473	2.127	2.960	3.205	0.994	1.130	1.660	1.376	5.376	0.670	0.801	
400.0	1.976	0.330	0.425	0.477	2.144	2.976	3.229	0.994	1.131	1.675	1.390	5.390	0.671	0.802	
405.0	1.991	0.332	0.427	0.480	2.162	2.991	3.252	0.994	1.132	1.690	1.405	5.405	0.673	0.803	
410.0	2.006	0.333	0.429	0.484	2.180	3.006	3.276	0.995	1.132	1.704	1.419	5.419	0.675	0.803	
415.0	2.021	0.335	0.431	0.488	2.197	3.021	3.299	0.995	1.133	1.719	1.433	5.433	0.676	0.804	
420.0	2.036	0.336	0.432	0.492	2.215	3.036	3.322	0.995	1.134	1.734	1.448	5.448	0.678	0.805	
425.0	2.051	0.338	0.434	0.496	2.232	3.051	3.346	0.995	1.135	1.749	1.462	5.462	0.679	0.805	
430.0	2.066	0.339	0.436	0.500	2.250	3.066	3.368	0.995	1.136	1.764	1.476	5.476	0.681	0.806	
435.0	2.081	0.341	0.438	0.504	2.267	3.081	3.391	0.995	1.137	1.778	1.491	5.491	0.682	0.807	
440.0	2.096	0.342	0.440	0.508	2.284	3.096	3.414	0.995	1.138	1.793	1.505	5.505	0.684	0.808	
445.0	2.110	0.344	0.441	0.511	2.301	3.110	3.436	0.995	1.139	1.807	1.519	5.519	0.686	0.808	
450.0	2.125	0.345	0.443	0.515	2.318	3.125	3.459	0.995	1.140	1.822	1.534	5.534	0.687	0.809	
455.0	2.140	0.346	0.445	0.519	2.336	3.140	3.481	0.996	1.140	1.836	1.548	5.548	0.689	0.810	
460.0	2.154	0.348	0.446	0.523	2.352	3.154	3.503	0.995	1.141	1.851	1.562	5.562	0.690	0.810	
465.0	2.169	0.349	0.448	0.527	2.369	3.169	3.525	0.996	1.142	1.865	1.577	5.577	0.692	0.811	
470.0	2.183	0.350	0.450	0.530	2.386	3.183	3.547	0.996	1.143	1.879	1.591	5.591	0.693	0.812	
475.0	2.197	0.352	0.451	0.534	2.403	3.197	3.569	0.996	1.144	1.893	1.605	5.605	0.695	0.812	
480.0	2.211	0.353	0.453	0.538	2.420	3.211	3.590	0.996	1.145	1.907	1.620	5.620	0.696	0.813	
485.0	2.225	0.355	0.455	0.541	2.436	3.225	3.612	0.996	1.145	1.921	1.634	5.634	0.698	0.813	
490.0	2.240	0.356	0.456	0.545	2.453	3.240	3.633	0.996	1.146	1.936	1.648	5.648	0.699	0.814	
495.0	2.254	0.357	0.458	0.549	2.470	3.254	3.654	0.996	1.147	1.950	1.663	5.663	0.701	0.815	
500.0	2.268	0.358	0.459	0.552	2.486	3.268	3.675	0.996	1.148	1.964	1.677	5.677	0.702	0.815	
505.0	2.282	0.360	0.461	0.556	2.503	3.282	3.696	0.996	1.149	1.978	1.691	5.691	0.704	0.816	
510.0	2.296	0.361	0.462	0.560	2.519	3.296	3.717	0.997	1.149	1.992	1.706	5.706	0.706	0.816	
515.0	2.309	0.362	0.464	0.563	2.535	3.309	3.738	0.997	1.150	2.005	1.720	5.720	0.707	0.817	
520.0	2.323	0.363	0.465	0.567	2.552	3.323	3.758	0.997	1.151	2.019	1.734	5.734	0.709	0.818	
525.0	2.337	0.365	0.467	0.571	2.568	3.337	3.779	0.997	1.152	2.033	1.749	5.749	0.710	0.818	
530.0	2.351	0.366	0.468	0.574	2.584	3.351	3.799	0.997	1.153	2.047	1.763	5.763	0.712	0.819	
535.0	2.364	0.367	0.470	0.578	2.600	3.364	3.819	0.997	1.153	2.061	1.777	5.777	0.713	0.819	
540.0	2.378	0.368	0.471	0.581	2.616	3.378	3.840	0.997	1.154	2.074	1.792	5.792	0.715	0.820	
545.0	2.392	0.370	0.472	0.585	2.632	3.392	3.860	0.997	1.155	2.088	1.806	5.806	0.716	0.821	
550.0	2.405	0.371	0.474	0.589	2.648	3.405	3.880	0.997	1.156	2.101	1.820	5.820	0.718	0.821	
555.0	2.419	0.372	0.475	0.592	2.664	3.419	3.900	0.997	1.156	2.115	1.835	5.835	0.719	0.822	
560.0	2.432	0.373	0.477	0.596	2.680	3.432	3.919	0.997	1.157	2.129	1.849	5.849	0.720	0.822	
565.0	2.445	0.374	0.478	0.599	2.696	3.445	3.939	0.998	1.158	2.142	1.863	5.863	0.722	0.823	
570.0	2.459	0.375	0.479	0.603	2.712	3.459	3.958	0.998	1.158	2.155	1.877	5.877	0.723	0.823	
575.0	2.472	0.376	0.481	0.606	2.728	3.472	3.978	0.998	1.159	2.169	1.892	5.892	0.725	0.824	
580.0	2.485	0.378	0.482	0.610	2.743	3.485	3.997	0.998	1.160	2.182	1.906	5.906	0.726	0.824	
585.0	2.498	0.379	0.483	0.613	2.759	3.498	4.017	0.998	1.161	2.196	1.920	5.920	0.728	0.825	
590.0	2.511	0.380	0.485	0.617	2.775	3.511	4.036	0.998	1.161	2.209	1.935	5.935	0.729	0.825	
595.0	2.524	0.381	0.486	0.620	2.790	3.524	4.055	0.998	1.162	2.222	1.949	5.949	0.731	0.826	
600.0	2.537	0.382	0.487	0.624	2.806	3.537	4.074	0.998	1.163	2.235	1.963	5.963	0.732	0.826	
605.0	2.550	0.383	0.489	0.627	2.821	3.550	4.093	0.998	1.164	2.249	1.978	5.978	0.734	0.827	
610.0	2.563	0.384	0.490	0.630	2.837	3.563	4.112	0.998	1.164	2.262	1.992	5.992	0.735	0.827	
615.0	2.576	0.385	0.491	0.634	2.852	3.576	4.131	0.999	1.165	2.275	2.006	6.006	0.736	0.828	
620.0	2.589	0.386	0.492	0.637	2.868	3.589	4.149	0.999	1.166	2.288	2.021	6.021	0.738	0.828	
625.0	2.602	0.387	0.494	0.641	2.883	3.602	4.168	0.999	1.166	2.301	2.035	6.035	0.739	0.829	
630.0	2.615	0.388	0.495	0.644	2.898	3.615	4.186	0.999	1.167	2.314	2.049	6.049	0.741	0.829	
635.0	2.627	0.389	0.496	0.647	2.913	3.627	4.205	0.999	1.168	2.327	2.064	6.064	0.742	0.830	
640.0	2.640	0.390	0.497	0.651	2.929	3.640	4.223	0.999	1.168	2.340	2.078	6.078	0.744	0.830	
645.0	2.653	0.391	0.498	0.654	2.944	3.653	4.241	0.999	1.169	2.353	2.092	6.092	0.745	0.831	
650.0	2.666	0.392	0.500	0.658	2.959	3.666	4.259	0.999	1.170	2.366	2.107	6.107	0.746	0.831	
655.0	2.678	0.393	0.501	0.661	2.974	3.678	4.277	0.999	1.170	2.379	2.121	6.121	0.748	0.832	
660.0	2.691	0.394	0.502	0.664	2.989	3.691	4.295	0.999	1.171	2.391	2.135	6.135	0.749	0.832	
665.0	2.703	0.395	0.503	0.668	3.004	3.703	4.313	0.999	1.172	2.404	2.150	6.150	0.750	0.833	
670.0	2.716	0.396	0.504	0.671	3.019	3.716	4.331	0.999	1.172	2.417	2.164	6.164	0.752	0.833	
675.0	2.728	0.397	0.505	0.674	3.034	3.728	4.349	0.999	1.173	2.430	2.178	6.178	0.753	0.833	
680.0	2.741	0.398	0.506	0.678	3.049	3.741	4.366	0.999	1.173	2.442	2.193	6.193	0.755	0.834	
685.0	2.753	0.399	0.508	0.681	3.064	3.753	4.384	0.999	1.174	2.455	2.207	6.207	0.756	0.834	
690.0	2.765	0.400	0.509	0.684	3.079	3.765	4.401	0.999	1.175	2.468	2.221	6.221	0.757	0.835	
695.0	2.778	0.401	0.510	0.687	3.093	3.778	4.419	1.000	1.175	2.480	2.236	6.236	0.759	0.835	
700.0	2.790	0.402	0.511	0.691	3.108	3.790	4.436	1.000	1.176	2.493	2.250	6.250	0.760	0.836	

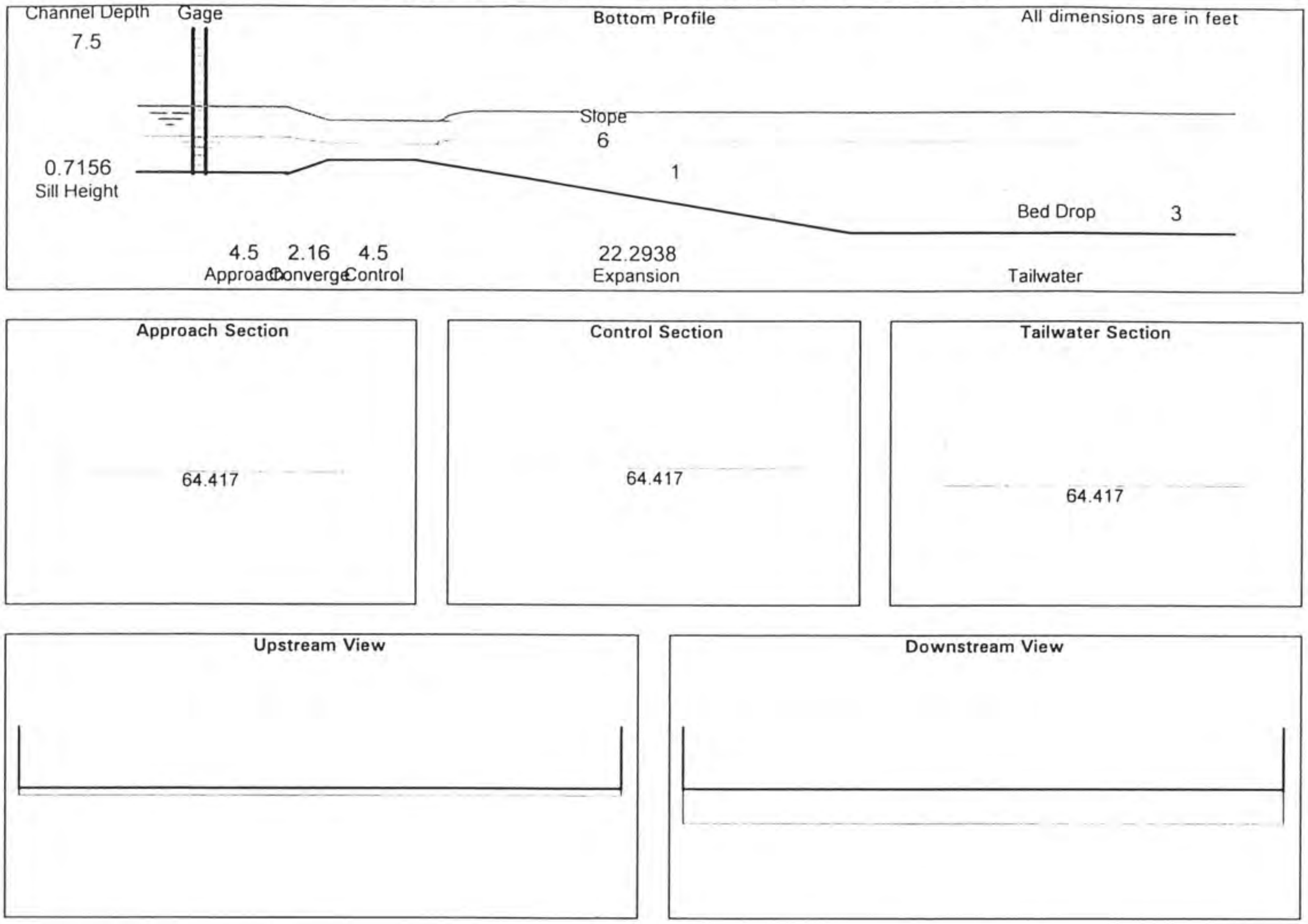
Error Summary

No errors

APPENDIX C

Long-throated flume with minimum possible head loss

Minimum headloss flume for Newtown Creek WPCP - Revision 12



User: Tony L. Wahl WinFlume32 - Version 0.58 (11/3/98)
D:\NEWTOWN\MinLoss.Newtown.Creek.Flm - Revision 12
Minimum headloss flume for Newtown Creek WPCP
Printed: 11/6/98

FLUME DATA REPORT

GENERAL DATA ON FLUME

Type of structure: Stationary Crest
Type of lining: Concrete - smooth
Roughness height of flume: 0.000492 ft

BOTTOM PROFILE DATA

Length per section: Approach section = 4.500 ft
Converging ramp = 2.160 ft
Control section = 4.500 ft
Expansion ramp = 22.294 ft

Vertical dimensions: Upstream channel depth = 7.500 ft
Height of sill = 0.716 ft
Bed drop = 3.000 ft
Expansion ramp slope = 6.000:1

-- APPROACH SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

-- CONTROL SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

-- TAILWATER SECTION DATA --

Section shape = RECTANGULAR
Bed width = 64.417 ft

```
User: Tony L. Wahl         WinFlume32 - Version 0.58 (11/3/98)
D:\NEWTOWN\MinLoss.Newtown.Creek.Flm - Revision 12
Minimum headloss flume for Newtown Creek WPCP
Printed: 11/6/98

                          EVALUATION OF FLUME DESIGN
--------------------------------------------------------------------------------
GENERAL RESULT:  Design is acceptable.
                 Zero errors or warnings.


             EVALUATION OF FLUME DESIGN FOR EACH DESIGN REQUIREMENT

Ok.          Freeboard at Qmax = 4.062 ft          Minimum allowed = 3.580 ft

Ok.               Head at Qmax = 2.722 ft    Minimum for precision = 0.980 ft
                 Estimated discharge measurement precision at Qmax = ±2.28 %

Ok.               Head at Qmin = 1.180 ft    Minimum for precision = 0.444 ft
                 Estimated discharge measurement precision at Qmin = ±3.49 %

Ok.          Tailwater at Qmax = 6.250 ft          Maximum allowed = 6.386 ft
                                    Submergence Protection at Qmax = 0.136 ft

Ok.          Tailwater at Qmin = 4.760 ft          Maximum allowed = 4.762 ft
                                    Submergence Protection at Qmin = 0.002 ft

Ok.      Froude number at Qmax = 0.465             Maximum allowed = 0.500


                             RESULTING STRUCTURE
Sill Height = 0.716 ft
                          -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft


                               DESIGN CRITERIA

Structure Type:  Stationary Crest
Freeboard design criterion:  Fixed freeboard height = 3.580 ft
Allowable discharge measurement errors for a single measurement:
  At minimum discharge: 8 %    At maximum discharge: 4 %
Head detection method: Staff gage without stilling well, Fr=0.2
   Gage readout precision = 0.023000 ft
Design discharges and associated tailwater levels:
  Minimum discharge = 180.000 mgd  Minimum tailwater depth = 4.760 ft
  Maximum discharge = 700.000 mgd  Maximum tailwater depth = 6.250 ft
  Bed drop at structure site = 3.000 ft
Values derived using:  User-specified
```

User: Tony L. Wahl WinFlume32 - Version 0.58 (11/3/98)
D:\NEWTOWN\MinLoss Newtown Creek.Flm - Revision 12
Minimum headloss flume for Newtown Creek WPCP
Flume Rating Table. Printed 11/6/98

Discharge mgd	Head at Gage, h1 ft	Froude Number	Required Head Loss ft	H1/L Ratio	Upstream Energy Head, ft	Upstream Depth ft	Upstream Velocity ft/s	Discharge Coeff.	Velocity Coeff.	Allowable Tailwater h2, ft	Tailwater Head, h2 ft	Tailwater Depth, y2 ft	Submerge Ratio	Modular Limit	Errors
180.0	1.180	0.292	0.205	0.281	1.264	1.896	2.281	0.986	1.109	1.046	1.044	4.760	0.836	0.838	
185.0	1.200	0.295	0.207	0.286	1.287	1.916	2.319	0.987	1.111	1.066	1.059	4.774	0.833	0.839	
190.0	1.220	0.299	0.210	0.291	1.310	1.936	2.357	0.987	1.112	1.086	1.073	4.789	0.830	0.840	
195.0	1.240	0.302	0.212	0.296	1.333	1.956	2.395	0.987	1.114	1.106	1.087	4.803	0.827	0.841	
200.0	1.260	0.305	0.214	0.301	1.355	1.975	2.432	0.988	1.116	1.126	1.102	4.817	0.824	0.842	
205.0	1.279	0.308	0.216	0.306	1.378	1.995	2.468	0.988	1.118	1.146	1.116	4.832	0.822	0.843	
210.0	1.298	0.311	0.218	0.311	1.400	2.014	2.505	0.988	1.119	1.165	1.130	4.846	0.820	0.844	
215.0	1.317	0.314	0.220	0.316	1.422	2.033	2.540	0.988	1.121	1.184	1.145	4.860	0.817	0.845	
220.0	1.336	0.317	0.222	0.321	1.443	2.052	2.575	0.989	1.123	1.203	1.159	4.875	0.816	0.846	
225.0	1.355	0.320	0.224	0.326	1.465	2.071	2.610	0.989	1.124	1.222	1.173	4.889	0.814	0.847	
230.0	1.373	0.323	0.226	0.330	1.487	2.089	2.644	0.989	1.126	1.241	1.188	4.903	0.812	0.848	
235.0	1.392	0.325	0.228	0.335	1.508	2.107	2.678	0.990	1.128	1.260	1.202	4.918	0.811	0.849	
240.0	1.410	0.328	0.230	0.340	1.529	2.126	2.712	0.990	1.129	1.278	1.216	4.932	0.809	0.850	
245.0	1.428	0.331	0.232	0.344	1.550	2.144	2.745	0.990	1.131	1.297	1.231	4.946	0.808	0.851	
250.0	1.446	0.333	0.234	0.349	1.571	2.162	2.778	0.990	1.132	1.315	1.245	4.961	0.807	0.851	
255.0	1.464	0.336	0.235	0.354	1.592	2.179	2.810	0.990	1.134	1.333	1.259	4.975	0.806	0.852	
260.0	1.481	0.338	0.237	0.358	1.612	2.197	2.842	0.991	1.135	1.351	1.274	4.989	0.805	0.853	
265.0	1.499	0.340	0.239	0.363	1.633	2.215	2.874	0.991	1.137	1.369	1.288	5.004	0.804	0.854	
270.0	1.516	0.343	0.240	0.367	1.653	2.232	2.906	0.991	1.138	1.387	1.302	5.018	0.804	0.855	
275.0	1.534	0.345	0.242	0.372	1.673	2.249	2.937	0.991	1.139	1.405	1.317	5.032	0.803	0.855	
280.0	1.551	0.348	0.244	0.376	1.693	2.266	2.967	0.991	1.141	1.423	1.331	5.047	0.802	0.856	
285.0	1.568	0.350	0.245	0.381	1.713	2.283	2.998	0.992	1.142	1.440	1.345	5.061	0.802	0.857	
290.0	1.585	0.352	0.247	0.385	1.733	2.300	3.028	0.992	1.144	1.458	1.360	5.075	0.801	0.858	
295.0	1.601	0.354	0.248	0.389	1.753	2.317	3.058	0.992	1.145	1.475	1.374	5.090	0.801	0.858	
300.0	1.618	0.356	0.250	0.394	1.772	2.334	3.088	0.992	1.146	1.492	1.388	5.104	0.801	0.859	
305.0	1.635	0.358	0.252	0.398	1.792	2.350	3.117	0.992	1.148	1.510	1.403	5.118	0.801	0.860	
310.0	1.651	0.361	0.253	0.402	1.811	2.367	3.146	0.993	1.149	1.527	1.417	5.132	0.800	0.860	
315.0	1.667	0.363	0.255	0.407	1.830	2.383	3.175	0.993	1.150	1.544	1.431	5.147	0.800	0.861	
320.0	1.684	0.365	0.256	0.411	1.850	2.399	3.203	0.993	1.151	1.561	1.446	5.161	0.800	0.862	
325.0	1.700	0.367	0.257	0.415	1.869	2.415	3.232	0.993	1.153	1.578	1.460	5.175	0.800	0.862	
330.0	1.716	0.369	0.259	0.420	1.888	2.432	3.260	0.993	1.154	1.594	1.474	5.190	0.800	0.863	
335.0	1.732	0.370	0.260	0.424	1.907	2.447	3.288	0.993	1.155	1.611	1.489	5.204	0.800	0.864	
340.0	1.748	0.372	0.262	0.428	1.925	2.463	3.315	0.994	1.156	1.628	1.503	5.218	0.800	0.864	
345.0	1.763	0.374	0.263	0.432	1.944	2.479	3.343	0.994	1.158	1.644	1.517	5.233	0.800	0.865	
350.0	1.779	0.376	0.264	0.436	1.963	2.495	3.370	0.994	1.159	1.660	1.531	5.247	0.801	0.865	
355.0	1.795	0.378	0.266	0.440	1.981	2.510	3.397	0.994	1.160	1.677	1.546	5.261	0.801	0.866	
360.0	1.810	0.380	0.267	0.444	2.000	2.526	3.423	0.994	1.161	1.693	1.560	5.276	0.801	0.867	
365.0	1.826	0.382	0.268	0.448	2.018	2.541	3.450	0.994	1.162	1.709	1.574	5.290	0.801	0.867	
370.0	1.841	0.383	0.270	0.453	2.036	2.557	3.476	0.995	1.163	1.725	1.589	5.304	0.802	0.868	
375.0	1.856	0.385	0.271	0.457	2.055	2.572	3.502	0.995	1.164	1.741	1.603	5.319	0.802	0.868	
380.0	1.871	0.387	0.272	0.461	2.073	2.587	3.528	0.995	1.166	1.757	1.617	5.333	0.802	0.869	
385.0	1.887	0.388	0.273	0.465	2.091	2.602	3.554	0.995	1.167	1.773	1.632	5.347	0.803	0.869	
390.0	1.902	0.390	0.274	0.469	2.109	2.617	3.579	0.995	1.168	1.789	1.646	5.362	0.803	0.870	
395.0	1.916	0.392	0.276	0.473	2.127	2.632	3.604	0.995	1.169	1.805	1.660	5.376	0.804	0.870	
400.0	1.931	0.393	0.277	0.477	2.144	2.647	3.630	0.995	1.170	1.821	1.675	5.390	0.804	0.871	
405.0	1.946	0.395	0.278	0.480	2.162	2.662	3.655	0.996	1.171	1.836	1.689	5.405	0.805	0.871	
410.0	1.961	0.397	0.279	0.484	2.180	2.677	3.679	0.996	1.172	1.852	1.703	5.419	0.805	0.872	
415.0	1.976	0.398	0.280	0.488	2.197	2.691	3.704	0.996	1.173	1.867	1.718	5.433	0.806	0.872	
420.0	1.990	0.400	0.282	0.492	2.215	2.706	3.728	0.996	1.174	1.883	1.732	5.448	0.806	0.873	
425.0	2.005	0.401	0.283	0.496	2.232	2.720	3.753	0.996	1.175	1.898	1.746	5.462	0.807	0.873	
430.0	2.019	0.403	0.284	0.500	2.250	2.735	3.777	0.996	1.176	1.914	1.761	5.476	0.807	0.874	
435.0	2.033	0.404	0.285	0.504	2.267	2.749	3.801	0.996	1.177	1.929	1.775	5.491	0.808	0.874	
440.0	2.048	0.406	0.286	0.508	2.284	2.763	3.824	0.996	1.178	1.944	1.789	5.505	0.808	0.875	
445.0	2.062	0.407	0.287	0.511	2.301	2.778	3.848	0.997	1.179	1.959	1.804	5.519	0.809	0.875	
450.0	2.076	0.408	0.288	0.515	2.319	2.792	3.871	0.997	1.180	1.974	1.818	5.534	0.810	0.876	
455.0	2.090	0.410	0.289	0.519	2.336	2.806	3.895	0.997	1.181	1.990	1.832	5.548	0.810	0.876	
460.0	2.104	0.411	0.290	0.523	2.353	2.820	3.918	0.997	1.182	2.005	1.847	5.562	0.811	0.877	
465.0	2.118	0.413	0.291	0.527	2.370	2.834	3.941	0.997	1.183	2.019	1.861	5.577	0.812	0.877	
470.0	2.132	0.414	0.292	0.530	2.386	2.848	3.964	0.997	1.184	2.034	1.875	5.591	0.812	0.878	
475.0	2.146	0.416	0.293	0.534	2.403	2.862	3.987	0.997	1.185	2.049	1.890	5.605	0.813	0.878	
480.0	2.160	0.417	0.294	0.538	2.420	2.876	4.009	0.997	1.186	2.064	1.904	5.620	0.814	0.878	
485.0	2.174	0.418	0.295	0.541	2.436	2.889	4.032	0.998	1.187	2.078	1.918	5.634	0.815	0.879	
490.0	2.187	0.420	0.296	0.545	2.453	2.903	4.054	0.998	1.188	2.093	1.933	5.648	0.815	0.879	
495.0	2.201	0.421	0.297	0.549	2.470	2.917	4.076	0.998	1.189	2.108	1.947	5.663	0.816	0.880	
500.0	2.215	0.422	0.298	0.552	2.486	2.930	4.098	0.998	1.189	2.122	1.961	5.677	0.817	0.880	
505.0	2.228	0.423	0.299	0.556	2.503	2.943	4.121	0.998	1.191	2.137	1.976	5.691	0.818	0.880	
510.0	2.241	0.425	0.300	0.560	2.519	2.957	4.143	0.998	1.192	2.151	1.990	5.706	0.818	0.881	
515.0	2.255	0.426	0.301	0.563	2.535	2.970	4.164	0.999	1.192	2.166	2.004	5.720	0.819	0.881	
520.0	2.268	0.427	0.302	0.567	2.552	2.984	4.186	0.999	1.193	2.180	2.019	5.734	0.820	0.882	
525.0	2.282	0.428	0.303	0.571	2.568	2.997	4.207	0.999	1.194	2.194	2.033	5.749	0.821	0.882	
530.0	2.295	0.430	0.304	0.574	2.584	3.011	4.228	0.999	1.195	2.209	2.047	5.763	0.822	0.882	
535.0	2.308	0.431	0.305	0.578	2.600	3.024	4.250	0.999	1.196	2.223	2.062	5.777	0.822	0.883	
540.0	2.321	0.432	0.306	0.581	2.616	3.037	4.271	0.999	1.197	2.237	2.076	5.792	0.823	0.883	
545.0	2.335	0.433	0.306	0.585	2.633	3.050	4.292	0.999	1.197	2.251	2.090	5.806	0.824	0.884	
550.0	2.348	0.434	0.307	0.589	2.649	3.063	4.312	0.999	1.198	2.265	2.105	5.820	0.825	0.884	
555.0	2.361	0.436	0.308	0.592	2.664	3.076	4.333	0.999	1.199	2.279	2.119	5.835	0.826	0.884	
560.0	2.374	0.437	0.309	0.596	2.680	3.089	4.354	0.999	1.200	2.293	2.133	5.849	0.827	0.885	
565.0	2.387	0.438	0.310	0.599	2.696	3.102	4.374	0.999	1.201	2.307	2.148	5.863	0.827	0.885	
570.0	2.400	0.439	0.311	0.603	2.712	3.115	4.395	0.999	1.201	2.321	2.162	5.877	0.828	0.885	
575.0	2.413	0.440	0.312	0.606	2.728	3.128	4.415	0.999	1.202	2.335	2.176	5.892	0.829	0.886	
580.0	2.426	0.441	0.312	0.610	2.744	3.141	4.435	0.999	1.203	2.349	2.191	5.906	0.830	0.886	
585.0	2.438	0.442	0.313	0.613	2.759	3.154	4.455	1.000	1.204	2.363	2.205	5.920	0.831	0.886	
590.0	2.451	0.443	0.314	0.617	2.775	3.167	4.475	1.000	1.205	2.377	2.219	5.935	0.832	0.887	
595.0	2.464	0.444	0.315	0.620	2.790	3.179	4.495	1.000	1.205	2.390	2.234	5.949	0.833	0.887	
600.0	2.477	0.445	0.316	0.624	2.806	3.192	4.515	1.000	1.206	2.404	2.248	5.963	0.833	0.887	
605.0	2.489	0.447	0.317	0.627	2.821	3.205	4.534	1.000	1.207	2.418	2.262	5.978	0.834	0.888	
610.0	2.502	0.448	0.317	0.630	2.837	3.217	4.554	1.000	1.208	2.431	2.276	5.992	0.835	0.888	
615.0	2.514	0.449	0.318	0.634	2.852	3.230	4.573	1.000	1.208	2.445	2.291	6.006	0.836	0.888	
620.0	2.527	0.450	0.319	0.637	2.868	3.243	4.593	1.000	1.209	2.458	2.305	6.021	0.837	0.889	
625.0	2.539	0.451	0.320	0.641	2.883	3.255	4.612	1.000	1.210	2.472	2.319	6.035	0.838	0.889	
630.0	2.552	0.452	0.320	0.644	2.898	3.267	4.631	1.000	1.210	2.485	2.334	6.049	0.839	0.889	
635.0	2.564	0.453	0.321	0.647	2.914	3.280	4.650	1.000	1.211	2.499	2.348	6.064	0.840	0.890	
640.0	2.577	0.454	0.322	0.651	2.929	3.292	4.669	1.000	1.212	2.512	2.362	6.078	0.841	0.890	
645.0	2.589	0.455	0.321	0.654	2.944	3.305	4.688	1.000	1.213	2.525	2.377	6.092	0.841	0.890	
650.0	2.601	0.456	0.323	0.658	2.959	3.317	4.707	1.000	1.213	2.539	2.391	6.107	0.842	0.891	
655.0	2.614	0.457	0.324	0.661	2.974	3.329	4.726	1.000	1.214	2.552	2.405	6.121	0.843	0.891	
660.0	2.626	0.458	0.325	0.664	2.989	3.341	4.744	1.000	1.215	2.565	2.420	6.135	0.844	0.891	
665.0	2.638	0.459	0.326	0.668	3.004	3.354	4.763	1.001	1.215	2.578	2.434	6.150	0.845	0.892	
670.0	2.650	0.459	0.326	0.671	3.019	3.366	4.781	1.001	1.216	2.592	2.448	6.164	0.846	0.892	
675.0	2.662	0.460	0.327	0.674	3.034	3.378	4.800	1.001	1.217	2.605	2.463	6.178	0.847	0.892	
680.0	2.674	0.461	0.328	0.678	3.049	3.390	4.818	1.001	1.217	2.618	2.477	6.193	0.848	0.892	
685.0	2.686	0.462	0.329	0.681	3.064	3.402	4.836	1.001	1.218	2.631	2.491	6.207	0.849	0.893	
690.0	2.698	0.463	0.329	0.684	3.079	3.414	4.854	1.001	1.219	2.644	2.506	6.221	0.850	0.893	
695.0	2.710	0.464	0.330	0.687	3.094	3.426	4.873	1.001	1.219	2.657	2.520	6.236	0.851	0.893	
700.0	2.722	0.465	0.331	0.691	3.108	3.438	4.891	1.001	1.220	2.670	2.534	6.250	0.852	0.894	

Error Summary

No errors

APPENDIX D

Spreadsheets for computation of backwater curves in long-throated flume approach channel

D:\NEWTOWN\DSTEP180.WK4 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	180
Q, cfs =	278.5205
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	0.83423
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4 ft upstream of start of ramp) to a distance 43 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
2.202	141.8462	2.06	2.62	1.964	0.0599	2.2619		0.000112				0.0
2.203	141.9107	2.06	2.62	1.963	0.0598	2.2628	-0.0009	0.000112	0.000112	-0.00011	8.41	8.4
2.204	141.9751	2.06	2.63	1.962	0.0598	2.2638	-0.0009	0.000112	0.000112	-0.00011	8.43	16.8
2.205	142.0395	2.06	2.63	1.961	0.0597	2.2647	-0.0009	0.000112	0.000112	-0.00011	8.44	25.3
2.206	142.1039	2.06	2.63	1.960	0.0597	2.2657	-0.0009	0.000112	0.000112	-0.00011	8.45	33.7
2.207	142.1683	2.07	2.63	1.959	0.0596	2.2666	-0.0009	0.000112	0.000112	-0.00011	8.46	42.2

D:\NEWTOWN\DSTEP310.WK4 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	310
Q, cfs =	479.6742
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	1.198612
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4 ft upstream of start of ramp) to a distance 43 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
2.687	173.0885	2.48	3.36	2.771	0.1193	2.8063		0.000175				0.0
2.688	173.1529	2.48	3.36	2.770	0.1192	2.8072	-0.0009	0.000175	0.000175	-0.00017	5.21	5.2
2.689	173.2173	2.48	3.36	2.769	0.1191	2.8081	-0.0009	0.000175	0.000175	-0.00017	5.21	10.4
2.69	173.2817	2.48	3.36	2.768	0.1190	2.8090	-0.0009	0.000174	0.000175	-0.00017	5.22	15.6
2.691	173.3461	2.48	3.36	2.767	0.1189	2.8099	-0.0009	0.000174	0.000174	-0.00017	5.23	20.9
2.692	173.4106	2.48	3.36	2.766	0.1188	2.8108	-0.0009	0.000174	0.000174	-0.00017	5.24	26.1
2.693	173.475	2.49	3.37	2.765	0.1187	2.8117	-0.0009	0.000174	0.000174	-0.00017	5.24	31.4
2.694	173.5394	2.49	3.37	2.764	0.1186	2.8126	-0.0009	0.000174	0.000174	-0.00017	5.25	36.6
2.695	173.6038	2.49	3.37	2.763	0.1185	2.8135	-0.0009	0.000173	0.000174	-0.00017	5.26	41.9

D:\NEWTOWN\DSTEP465.WK4 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	465
Q, cfs =	719.5113
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	1.570626
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4 ft upstream of start of ramp) to a distance 43 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
3.169	204.1375	2.89	4.11	3.525	0.1929	3.3619		0.000231				0.0
3.17	204.2019	2.89	4.11	3.524	0.1928	3.3628	-0.0009	0.000231	0.000231	-0.00023	3.80	3.8
3.171	204.2663	2.89	4.11	3.522	0.1927	3.3637	-0.0009	0.000231	0.000231	-0.00023	3.80	7.6
3.172	204.3307	2.89	4.11	3.521	0.1925	3.3645	-0.0009	0.000231	0.000231	-0.00023	3.80	11.4
3.173	204.3951	2.89	4.11	3.520	0.1924	3.3654	-0.0009	0.000231	0.000231	-0.00023	3.81	15.2
3.174	204.4596	2.89	4.12	3.519	0.1923	3.3663	-0.0009	0.00023	0.00023	-0.00023	3.81	19.0
3.175	204.524	2.89	4.12	3.518	0.1922	3.3672	-0.0009	0.00023	0.00023	-0.00023	3.82	22.8
3.176	204.5884	2.89	4.12	3.517	0.1921	3.3681	-0.0009	0.00023	0.00023	-0.00023	3.82	26.7
3.177	204.6528	2.89	4.12	3.516	0.1919	3.3689	-0.0009	0.00023	0.00023	-0.00023	3.83	30.5
3.178	204.7172	2.89	4.12	3.515	0.1918	3.3698	-0.0009	0.000229	0.00023	-0.00023	3.83	34.3
3.179	204.7816	2.89	4.12	3.514	0.1917	3.3707	-0.0009	0.000229	0.000229	-0.00023	3.84	38.2
3.18	204.8461	2.89	4.12	3.512	0.1916	3.3716	-0.0009	0.000229	0.000229	-0.00023	3.84	42.0

D:\NEWTOWN\DSTEP700.WK4 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	700
Q, cfs =	1083.135
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	2.063017
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4 ft upstream of start of ramp) to a distance 43 ft upstream (approx. tail of labyrinth weir).

REFERENCE. Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
3.79	244.1404	3.39	5.09	4.437	0.3056	4.0956		0.000296				0.0
3.791	244.2048	3.39	5.10	4.435	0.3055	4.0965	-0.0008	0.000295	0.000296	-0.0003	2.84	2.8
3.792	244.2693	3.39	5.10	4.434	0.3053	4.0973	-0.0008	0.000295	0.000295	-0.0003	2.84	5.7
3.793	244.3337	3.39	5.10	4.433	0.3051	4.0981	-0.0008	0.000295	0.000295	-0.0003	2.84	8.5
3.794	244.3981	3.39	5.10	4.432	0.3050	4.0990	-0.0008	0.000295	0.000295	-0.00029	2.85	11.4
3.795	244.4625	3.39	5.10	4.431	0.3048	4.0998	-0.0008	0.000294	0.000295	-0.00029	2.85	14.2
3.796	244.5269	3.40	5.10	4.430	0.3047	4.1007	-0.0008	0.000294	0.000294	-0.00029	2.85	17.1
3.797	244.5913	3.40	5.11	4.428	0.3045	4.1015	-0.0008	0.000294	0.000294	-0.00029	2.85	19.9
3.798	244.6558	3.40	5.11	4.427	0.3043	4.1023	-0.0008	0.000294	0.000294	-0.00029	2.86	22.8
3.799	244.7202	3.40	5.11	4.426	0.3042	4.1032	-0.0008	0.000293	0.000294	-0.00029	2.86	25.6
3.8	244.7846	3.40	5.11	4.425	0.3040	4.1040	-0.0008	0.000293	0.000293	-0.00029	2.86	28.5
3.801	244.849	3.40	5.11	4.424	0.3039	4.1049	-0.0008	0.000293	0.000293	-0.00029	2.87	31.4
3.802	244.9134	3.40	5.11	4.423	0.3037	4.1057	-0.0008	0.000293	0.000293	-0.00029	2.87	34.2
3.803	244.9779	3.40	5.12	4.421	0.3035	4.1065	-0.0008	0.000292	0.000293	-0.00029	2.87	37.1
3.804	245.0423	3.40	5.12	4.420	0.3034	4.1074	-0.0008	0.000292	0.000292	-0.00029	2.87	40.0
3.805	245.1067	3.40	5.12	4.419	0.3032	4.1082	-0.0008	0.000292	0.000292	-0.00029	2.88	42.9

APPENDIX E

Example spreadsheet for calculation of water surface profiles in labyrinth weir exit channels

D:\NEWTOWN\EXAMPLE.WK4

Gradually varied flow in a rectangular exit channel of varying width

Bed slope, So	0	ft/ft		
Manning's n	0.013			
Gravity	32.2	ft/s^2		
Q	541.57	cfs	350	mgd
Length	58	ft		
Inflow per unit length	9.337	cfs/ft		

Analysis of spatially varied flow in conveyance channel downstream of labyrinth weir.

Starting WSE	9.305		
Exit Channel Floor Elevation	5.5		
Upstream Depth	6.672	Max. Convergence Error	0
Upstream WSE	12.172		

x	Q	WSE	Assumed Depth, y	Width	Area, A	WP	TW	Hyd. Depth	Velocity, V	Froude	Sf	Velocity Head Term, ft	Momentum Flux Term, ft	Friction & Bed Slope Term, ft	Computed Depth, y	Err
0	541.6	9.305	3.805	17.081	64.993	24.691	17.081	3.805	8.333	0.753	0.001462					
0.58	536.2	9.360	3.860	16.930	65.356	24.651	16.930	3.860	8.204	0.736	0.001404	0.044	0.011	0.001	3.860	0.00E+00
1.16	530.7	9.412	3.912	16.779	65.638	24.603	16.779	3.912	8.086	0.720	0.001352	0.040	0.010	0.001	3.912	0.00E+00
1.74	525.3	9.460	3.960	16.629	65.853	24.549	16.629	3.960	7.977	0.706	0.001307	0.037	0.010	0.001	3.960	0.00E+00
2.32	519.9	9.506	4.006	16.478	66.012	24.490	16.478	4.006	7.876	0.693	0.001266	0.035	0.010	0.001	4.006	0.00E+00
...																
...	EXAMPLE CALCULATION...INTERMEDIATE ROWS NOT SHOWN															
55.7	21.7	12.119	6.619	2.603	17.231	15.841	2.603	6.619	1.257	0.086	0.000108	0.017	0.006	0.000	6.619	0.00E+00
56.3	16.2	12.139	6.639	2.452	16.283	15.731	2.452	6.639	0.998	0.068	0.000073	0.015	0.006	0.000	6.639	0.00E+00
56.8	10.8	12.156	6.656	2.302	15.320	15.614	2.302	6.656	0.707	0.048	0.000039	0.012	0.004	0.000	6.656	0.00E+00
57.4	5.4	12.168	6.668	2.151	14.341	15.486	2.151	6.668	0.378	0.026	0.000012	0.009	0.003	0.000	6.668	0.00E+00
58	0.0	12.172	6.672	2.000	13.344	15.344	2.000	6.672	0.000	0.000	0	0.004	0.000	0.000	6.672	0.00E+00

APPENDIX F

"Design of Labyrinth Spillways" by Tullis, et al. (1995)

Design of Labyrinth Spillways

By J. Paul Tullis,[1] Member, ASCE, Nosratollah Amanian,[2] and David Waldron[3]

Abstract: The capacity of a labyrinth spillway is a function of the total head, the effective crest length, and the crest coefficient. The crest coefficient depends on the total head, weir height, thickness, crest shape, apex configuration, and the angle of the side legs. Data and a procedure are presented for designing labyrinth weirs for angles between 6° and 35°, and for a range of heads. The design procedure allows the angle of the side legs and the number of cycles to be varied until the desired layout and capacity are achieved. The solution is presented in a spreadsheet format that automatically calculates the dimensions for the labyrinth. Even though the design procedure is quite accurate, it is recommended that the capacity and performance be verified with a model study. The model can evaluate factors not included in the design procedure, like aeration effects at low heads, unusual flow conditions in the approach channel, and flow conditions in the discharge channel.

INTRODUCTION

A labyrinth spillway is an overflow weir folded in plan view to provide a longer total effective length for a given overall spillway width. Fig. 1 shows a typical layout. A labyrinth spillway has advantages compared to the straight overflow weir and the standard ogee crest. The total length of the labyrinth weir is typically three to five times the spillway width. Its capacity varies with head and is typically about twice that of a standard weir or overflow crest of the same width. Labyrinth weirs can be used to increase outlet capacity for a given spillway crest elevation and length or to increase storage by raising the crest while maintaining spillway capacity. The variables that need to be considered in designing a labyrinth include the length and width of the labyrinth, the crest height, the labyrinth angle, the number of cycles, and several other less important variables such as wall thickness, crest shape, and apex configuration.

An extensive investigation dealing with the behavior of labyrinth weirs was performed by Taylor (1968). He presented his results in terms of a magnification ratio of the labyrinth flow to the flow for a sharp-crested linear weir having the same channel width. As a follow-up to that work, Hay and Taylor (1970) published a design procedure for labyrinth weirs, including criteria for estimating the discharge over triangular or trapezoidal labyrinth weirs.

A number of hydraulic models have also been tested in order to learn about the design of labyrinth spillways. Darvas (1971) for example used the experimental results of the model studies of Woronora and Avon weirs in Australia and developed a family of curves for designing labyrinth weirs. Mayer (1980) used a 1:20 scale model to study the effect on discharge of a proposed labyrinth weir spillway to be added to the Bartlett's Ferry project. The conceptual design of the structure was based on the approach of Hay and Taylor (1970) and was found to be inadequate as the structure would not pass the required flow. Lux (1984) assessed the hydraulic performance of labyrinth weirs using data obtained from flume studies and site-specific models. He developed an equation for discharge over labyrinth weirs.

The U.S. Bureau of Reclamation tested models for the labyrinth spillways of the Ute Dam and Hyrum Dam (Houston 1982, 1983; Hinchliff and Houston 1984). Testing of the originally designed 10-cycle model of the Ute Dam labyrinth spillway, which was based on Hay and Taylor (1970) design curves, showed that the design discharge could not be passed by the spillway at the maximum reservoir elevation. They found that the discrepancy between their results and those of Hay and Taylor was partly due to the difference in head definition. Houston (1982, 1983) and Lux (1984) used the total head instead of the piezometric head. Use of piezometric head does not allow for differences in the approach velocity and can introduce significant errors in the predictions.

More recently the Bureau of Reclamation completed a model of the Ritschard Dam labyrinth spillway (Vermeyen 1991). The model results of that study were used to design a labyrinth for Standley Lake (Tullis 1993).

Researchers have been involved in developing data and a procedure to improve and simplify the design of labyrinth weirs. Several experimental programs were completed at the Utah Water

[1]Prof. of Civ. and Envir. Engrg., Utah State Univ., Logan, UT 84322-8200.

[2]Asst. Prof., Univ. of Yazd, Yazd, Iran.

[3]Grad. Res. Asst., Utah Water Res. Lab., Logan, UT.

Note. Discussion open until August 1, 1995. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on December 30, 1993. This paper is part of the *Journal of Hydraulic Engineering*, Vol. 121, No. 3, March, 1995. ©ASCE, ISSN 0733-9429/95/0003-0247–0255/$2.00 + $.25 per page. Paper No. 7549.

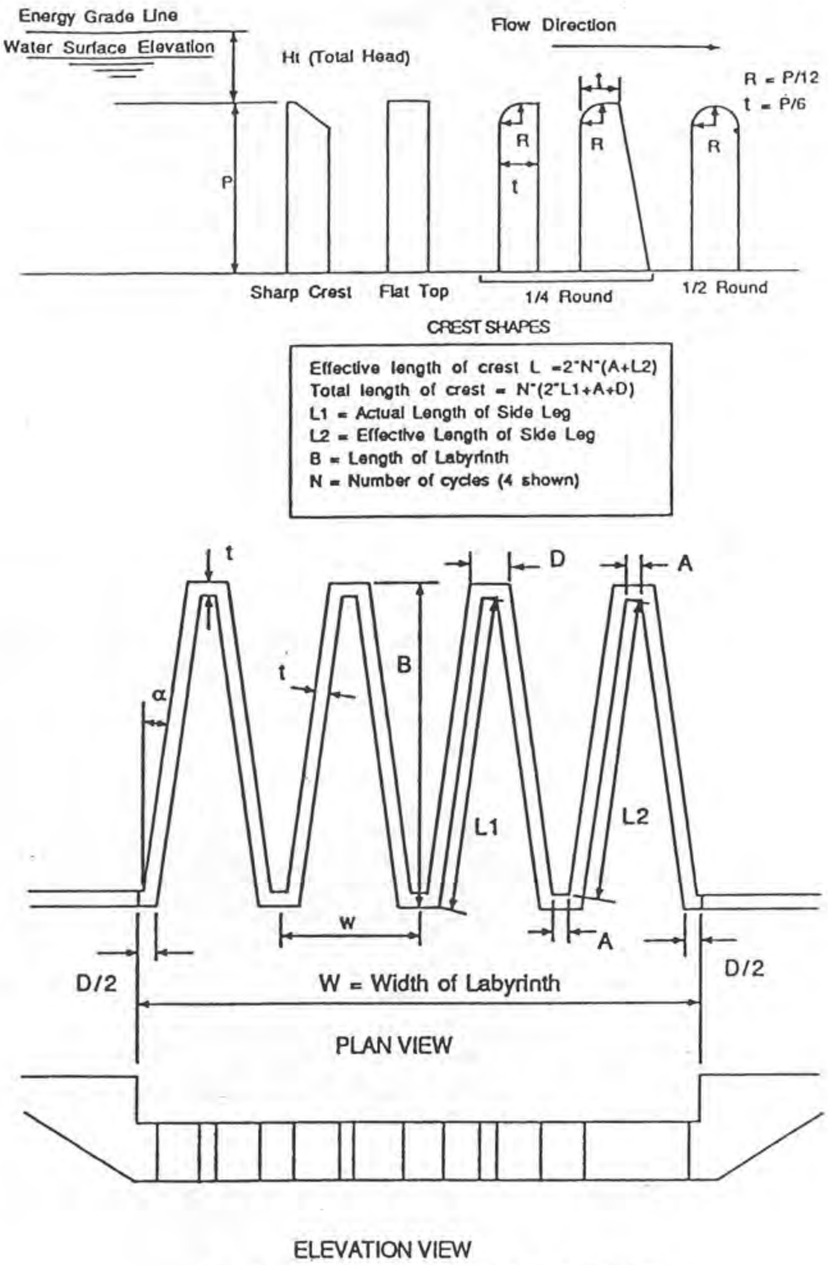


FIG. 1. Layout and Details of Labyrinth Weir

Research Laboratory (UWRL) to evaluate the crest coefficient for labyrinth weirs (Aman 1987; Baasiri et al., unpublished report, 1992; and Waldron 1994). Each researcher used same (3-ft) 1.0-m-wide flume. Linear weirs with flat, quarter-round and half-round crest sha were tested over a range of H_t/P from about 0.05 to about 1.0. The model weirs were 152- a 229-mm high. Labyrinth weirs were tested at angles from 6° and 35°. Most of the weirs w 152-mm high and 25.4-mm thick with quarter-round and half-round crest shapes. The weirs w carefully aligned, leveled, sealed, and measured to determine the net length (defined in F 1). A point gauge, readable to 0.3 mm, located 1 m upstream from the weir was used to meas water depth. The point gauge was accurately referenced to the crest elevation and check periodically during the testing. Flow was measured by weigh tanks and volumetric tanks to accuracy of 0.25%. Details of the experimental studies are contained in the original works the three researchers (Amanian 1987; Baasiri et al., unpublished report, 1992; Waldron 19

The end results of these experimental studies was the development of a database and des procedure. It is based on a specific crest geometry. The input-system data required for the procedure is the design flow and head. The procedure allows complete flexibility in select the number of cycles and the angle of the side legs. Limitations are placed on some of the des variables, such as the height of the weir and the width to length ratio of the labyrinth. With input data selected, the spreadsheet automatically solves for the corresponding labyrinth mensions. Each of the input variables can be varied to determine its influence on the design. There will be many layouts that provide the design flow at design head. The final choice should be based on which design fits best into the overall layout of the project, is cost-effective, and produces an acceptable outflow hydrograph.

WEIR EQUATION

The proposed method for designing a labyrinth weir using the basic equation developed for linear weirs is

$$Q = \frac{2}{3} C_d L \sqrt{2g} H_t^{1.5} \tag{1}$$

where C_d = a dimensionless crest coefficient; g = acceleration of gravity; L = effective length of the weir; and H_t = total head on the crest. The total head is normally determined a short distance upstream from the weir and is equal to the measured depth of water above the crest plus the velocity head of the approach flow at the point of measurement. For a weir with a short approach where inlet losses are negligible, H_t is the elevation difference between the reservoir water level and the elevation of the weir crest.

For a linear weir without side contractions and with normal approach flow, the effective length L is the actual measured length of the weir. The crest coefficient is dependent on H_t/P, the wall thickness t, crest configuration, and nappe aeration. Fig. 2 shows the variation of the crest coefficient with H_t/P for an aerated linear weir with t/P = 1/6 and the crest rounded on the upstream corner at a radius of $P/12$. Three sets of data obtained by three different researchers at the UWRL (Amanian 1987; Baasiri et al., unpublished report, 1992; and Waldron 1994) are plotted in Fig. 2 for the linear weir with an aerated nappe. Establishing reliable data for the linear weir is important in the analysis of the crest coefficients for labyrinth weirs because it represents the upper boundary of the C_d values.

For a labyrinth, the effective length to be used in (1) is defined in Fig. 1. The crest coefficient is dependent on the same variables influencing a linear weir plus the configuration of the labyrinth at its apex, and the angle of the labyrinth.

VARIABLES AFFECTING CREST COEFFICIENT

The height, thickness, and shape of the crest have a significant influence on the crest coefficient (Amanian 1987). There are four basic options for the shape of the crest (shown in Fig. 1): sharp-crested, flat, quarter-round on the upstream side and half-round.

Wall thickness is determined from structural analysis and is dependent on height of the crest, hydraulic forces, ice loading, and specific site conditions. For economy and strength, it may be preferable to have the downstream side of the wall tapered. This will not influence the crest coefficient. To make the coefficients in the present paper applicable, it is necessary to make the radius of curvature R = $P/12$, as shown in Fig. 1.

Sharp-crest and flat-crest weirs are generally not preferred because their crest coefficients are measurably less than those for rounded crested weirs. The most efficient and practical shape

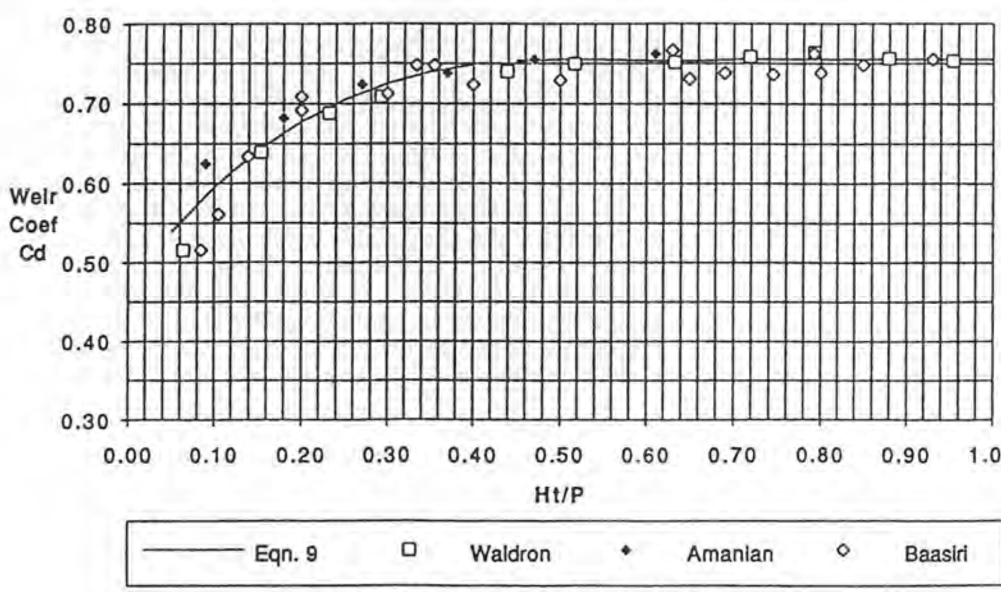


FIG. 2. Crest Coefficient for Linear Weir

appears to be the quarter round (Amanian 1987). Even though the quarter-round crest has smaller C_d at low heads ($H/P < 0.5$) compared to a full half-round crest, it has a large C_d high heads and is easier to construct. Therefore, the proposed design procedure assumes quarter-round crest with the top wall thickness $t = P/6$ or a tapered wall with $R = P/12$. If th wall is made thicker for structural reasons, it has little effect on the crest coefficient. Howeve a significant decrease in the wall thickness and the corresponding reduction in the radius curvature causes separation and reduces the crest coefficient.

The weir height P is the difference between the crest elevation and the elevation of th upstream apron. The weir height influences losses in the approach channel and spillway capacit For a linear weir, C_d reaches a maximum and becomes constant at large values of H_t/P (se Fig. 2). For a labyrinth weir, as the head increases, C_d continues to decrease and the spillwa capacity eventually approaches that of a linear weir having a length equal to the apron widt It is therefore necessary to limit the H_t/P to maintain the effectiveness of the labyrinth. Th writers recommend that a maximum flow H_t/P be less than about 0.9. The labyrinth still functio at higher heads but the advantage of the labyrinth design continues to diminish as the he continues to increase. The final decision will probably be based on economics.

The width A of the apex (defined in Fig. 1) influences spillway capacity. It reduces the n length of the labyrinth weir and decreases spillway capacity. Consequently, A should be as sm as possible. Typically, the inside apex is one or two times the wall thickness.

The design is based on a labyrinth sitting on a horizontal apron with the upstream an downstream portion at the same elevation. The flow downstream from the labyrinth should super critical to avoid submergence effects. To use the design data herein, the downstrea channel must have a supercritical slope or at least a short section at a steep slope to preve submergence of the crest.

Depending on the configuration of the inlet channel and the placement of the spillway, t angle of the approach flow β may not be perpendicular to the axis of the labyrinth. Data a available for $\beta = 15°, 30°$, and $45°$ that identify the influence of the approach angle β on capac (Amanian 1987). The percent reduction of flow for these three approach angles is only 1 4%, and 6%, respectively. Since it would be highly unlikely that approach conditions wou result in an angle over 15°, the effect of β is generally negligible. If the approach conditions a very unusual, a physical-model study would be recommended. All data included in the prese paper are for $\beta = 0\%$.

Past research on linear weirs has documented that nappe aeration influences the crest co ficient and, therefore, the spillway capacity. When the weir is aerated, the cavity beneath t nappe is near atmospheric pressure and the crest coefficient has a minimum value. A line weir is easy to aerate at heads below about $H_t/P \approx 0.7$. The primary purpose for venting line weirs is to reduce vibrations caused by pressure variations under the nappe. The data for t linear weir in Fig. 2 are for a fully aerated nappe. It is recommended that these values be us for design unless it is certain that the nappe is not aerated. When the nappe is not aerated, t weir passes more flow than predicted by the C_d values shown in Fig. 2 (Amanian 1987; Waldr 1994). The crest coefficient values for nonaerated flows can be slightly above $C_d = 0.75$ small H_t/P values.

Assuming a constant crest shape and similar aerated nappe conditions, the C_d values fo labyrinth cannot be higher than those for a linear weir as shown in Fig. 2. Several sets published crest coefficient values show C_d values at low heads exceeding 0.75. These values l above the curve for the linear weir in Fig. 2. Such values can be obtained when the crest operating nonaerated with a negative pressure below the nappe. A labyrinth tends to oper with a slight negative pressure at H_t/P between about 0.1 and 0.2. Experimental data poi that exceeded those for the linear weir were ignored. The reason was to provide conservativ low C_d values for designing the labyrinth. When it is important to accurately know the rat curve at low reservoir elevations, a physical-model study should be conducted.

The most important part of the research at the UWRL was to determine the value of t crest coefficient C_d for the full range of variables studied. The crest coefficients for a labyri weir are shown in Fig. 3 for labyrinth angles between 6° and 35° (Amanian 1987; Baasiri et a unpublished report, 1992; Tullis 1993; Waldron 1994). To facilitate using a spreadsheet to des a labyrinth, regression equations [(2)–(9)] were determined for variation of C_d with H_t/P. The equations are valid for apex width $t \leq A \leq 2t$; $H_t/P < 0.9$; $t = P/6$; crest shape is a quar round (on upstream side); and the radius of crest curvature $R = P/12$

$$C_d = 0.49 - 0.24(H_t/P) - 1.20(H_t/P)^2 + 2.17(H_t/P)^3 - 1.03(H_t/P)^4; \quad \text{for } \alpha = 6°$$

$$C_d = 0.49 + 1.08(H_t/P) - 5.27(H_t/P)^2 + 6.79(H_t/P)^3 - 2.83(H_t/P)^4; \quad \text{for } \alpha = 8°$$

$$C_d = 0.49 + 1.06(H_t/P) - 4.43(H_t/P)^2 + 5.18(H_t/P)^3 - 1.97(H_t/P)^4; \quad \text{for } \alpha = 12°$$

$$C_d = 0.49 + 1.00(H_t/P) - 3.57(H_t/P)^2 + 3.82(H_t/P)^3 - 1.38(H_t/P)^4; \quad \text{for } \alpha = 15°$$

$$C_d = 0.49 + 1.32(H_t/P) - 4.13(H_t/P)^2 + 4.24(H_t/P)^3 - 1.50(H_t/P)^4; \quad \text{for } \alpha = 18°$$

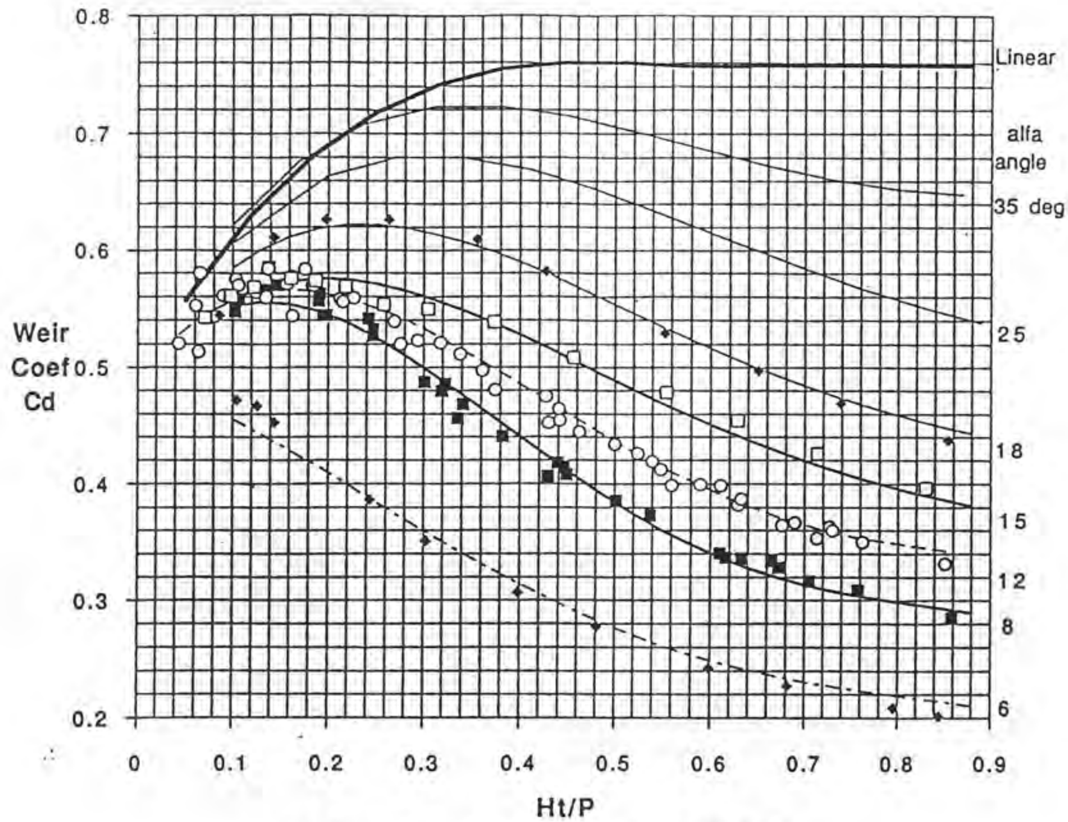


FIG. 3. Crest Coefficient for Labyrinth Spillways

$$C_d = 0.49 + 1.51(H_t/P) - 3.83(H_t/P)^2 + 3.40(H_t/P)^3 - 1.05(H_t/P)^4; \quad \text{for } \alpha = 25° \tag{7}$$

$$C_d = 0.49 + 1.69(H_t/P) - 4.05(H_t/P)^2 + 3.62(H_t/P)^3 - 1.10(H_t/P)^4; \quad \text{for } \alpha = 35° \tag{8}$$

$$C_d = 0.49 + 1.46(H_t/P) - 2.56(H_t/P)^2 + 1.44(H_t/P)^3; \quad \text{for } H_t/P < 0.7 \text{ and } \alpha = 90° \tag{9}$$

Eqs. (2)–(9) and some of the experimental data are plotted in Fig. 3.

The value of C_d does not vary significantly with a small change of α. Therefore, each of the equations can be used for angles close to those listed. For angles different by more than about $\pm 1°$ from the values listed for (2)–(9), a new regression equation should be developed or the data interpolated from Fig. 3.

An analysis was made to determine the accuracy of the regression equations compared to the experimental data from which they were developed. The standard deviation between the measured and calculated data for angles between 6° and 18° was less than $\pm 3\%$ with the maximum difference about $\pm 6\%$. Therefore, (2)–(6) provide sufficient accuracy for $0.1 \leq H_t/P \leq 0.9$. No data were used above $H_t/P = 0.9$ because the labyrinth becomes increasingly inefficient with increased head. Below $H_t/P = 0.1$, the value of C_d is very difficult to evaluate experimentally. For a reduced-scale model operating at $H_t/P < 0.1$, a slight error in measuring the water-surface elevation or the crest elevation can cause a significant change in the crest coefficient. The model crests tested by the writers were 15- and 30-cm high.

The data for 25° and 35° are interpolated values and are accurate only to about $\pm 10\%$. This is because the experimental data were for a different crest shape. Therefore, the data points for those angles are not plotted in Fig. 3.

DESIGN PROCEDURE

The recommended design procedure is demonstrated using an example based on data from a model study conducted at the UWRL of the Standley Lake labyrinth spillway, located near Denver (Tullis 1993). The original design of the spillway for Standley Lake, which is used in Table 1 to demonstrate the design procedure, was based on a model study of the Ritschard Dam labyrinth (Vermeyen 1991). Table 1 provides the design calculations setup in a spreadsheet format.

The upper block lists typical input data that would come from a hydrologic analysis of the system. This includes the maximum required spillway flow ($Q_{max} = 1{,}539$ m³/s for this example), the corresponding maximum reservoir elevation ($res = 1680.91$ m), and the normal pool ele-

TABLE 1. Spreadsheet for Designing Labyrinth Weirs

Parameter (1)	Symbol (2)	Value (3)	Units (4)	Source/equation/notes (5)
		(a) Given input-system data		
Maximum flow	Q_{max}	1,538	(m^3/s)	Input
Maximum reservoir elevation	*res*	1,680.91	(m)	Input
Approach channel elevation	—	1,675.75	(m)	Input
Crest elevation	el	1,678.80	(m)	Input
Total head	H_t	1.975	(m)	H_t = res-crest-loss
		(b) Assumed data		
Estimated inlet loss at Q_{max}	Loss	0.13	(m)	Estimated
Number of cycles	N	13	—	Select to keep $w/P \sim 3$ to 4
Crest height	P	3.05	(m)	Set $P \sim 1.4\ H_t$
Angle of side legs	α	8.0	(deg)	Normally 8°–16°
		(c) Calculated data		
Thickness of wall	t	0.51	(m)	$t = P/6$
Inside width at apex	A	0.95	(m)	Select between t and $2t$
Outside width of apex	D	1.83	(m)	$D = A + 2t \cdot \tan(45 - \alpha/2)$
Total head/crest height	H_t/P	0.648	—	—
Crest coefficient	C_d	0.3255	—	Eq. (3)
Effective crest length	L	576.6	(m)	$1.5Q_{max}/[(C_d \cdot H_t^{1.5}) \cdot (2g)^{0.5}]$
Length of apron (parallel to flow)	B	22.72	(m)	$B = [L/(2N) + t \cdot \tan(45\text{-}\alpha/2)]\cos(\alpha) + t$
Actual length of side leg	L_1	22.45	(m)	$L_1 = (B - t)/\cos(\alpha)$
Effective length of side leg	L_2	22.02	(m)	$L_2 = L_1 - t \cdot \tan(45 - \alpha/2)$
Total length of walls	L_3	620	(m)	$L_3 = N(2L_1 + D + A)$
Distance between cycles	w	9.42	(m)	$w = 2L_1 \cdot \sin(\alpha) + A + D$
Width of labyrinth (normal to flow)	W	123	(m)	$W = N \cdot w$
Length of linear weir for same flow	—	249	(m)	$1.5 \cdot Q_{max}/[(C_d \cdot H_t^{1.5}) \cdot (2g)^{0.5}]$; ($C_d$ for linear w
Distance between cycles/crest height	w/P	3.09	—	Normally between 3 and 4
		(d) Concrete volume		
Wall concrete volume	—	293	(m^3)	vol. = $L_3 \cdot P \cdot t$
Apron concrete volume[a]	—	431	(m^3)	vol. = $W \cdot B \cdot t$
Total	—	655	(m^3)	—

[a]For apron concrete volume it is assumed that apron thickness is the same as wall thickness.

TABLE 2. Influence of Labyrinth Angle on Spillway Width

Angle (α) (1)	Width (W) (m) (2)	Length (B) (m) (3)	Number of cycles (4)	C_d (5)	Effective leng (L) (m) (6)
6°	139	20.2	20.0	0.232	811
7°	126	20.1	16.5	0.280	670
8°	122	20.2	14.0	0.327	572
9°	120	19.9	13.5	0.346	543
10°	127	20.6	12.5	0.359	523
12°	133	20.1	12.0	0.381	493
16°	136	20.3	10.0	0.445	421
32°	176	20.2	6.5	0.604	311
49°	213	20.1	4.5	0.682	275
Linear	249	—[a]	—[a]	0.755	249

[a]Not applicable.

vation that would generally correspond to the weir crest elevation of the labyrinth (el = 1678. m).

The second block contains assumed data. The inlet loss at maximum flow can either be s to zero or estimated from preliminary calculations. For this example, a loss of 13 cm is assum at maximum flow. The number of cycles has a significant effect on the overall layout of t labyrinth. The value of N is varied to determine the most appropriate number of cycles th gives the least cost and a hydraulically effective layout. The example uses N = 13 and an ang of 8.0°.

The third block of data contains the detailed calculations identifying the geometry of t labyrinth and equations used for each calculation. Such calculations are most efficiently do using a spreadsheet. Table 1 also contains two guides regarding the acceptable ranges of variable $H_t/P < 0.9$, and $3 \leq w/P \leq 4$. It is the opinion of the writers that these limitations help ke the design in an economical and hydraulically efficient range.

The bottom set of data in Table 1 provides a rudimentary economic analysis based on concre volume only. The volume of the concrete in the walls is easily calculated from the data in the table. The volume of concrete in the apron assumes that the apron thickness is equal to the wall thickness. The total volume is listed as a sum of the two. One can do a preliminary economic analysis by varying the number of cycles and/or the angle of the side legs and comparing the total concrete volume.

The angle α of the side legs significantly affects both the capacity and the layout of the labyrinth. Table 2 shows calculated spillway width based on different angles for the following prototype conditions: Q_{max} = 1,538 m³/s, P = 3.05 m, H_t = 1.975 m, and the recommended weir configuration and apex width [see limitations for (2)–(9)]. The number of cycles was varied for each angle to maintain the length of the apron B essentially constant.

The angle has an impact on both the economics and the performance. The data in Table 2 show that the optimal range of angle, based on minimizing W (the width of the labyrinth) for a given discharge and B, is between 7° and 16°. Below 7° and above 16°, the width increases. The total length of the weir wall is also a factor in the economics. As the angle increases, the length of the weir decreases so the least cost may not be obtained by minimizing the width.

A small α produces a high spillway capacity at lower reservoir elevations. The spillway capacity increases as α is reduced because of the increase in effective length of the spillway. With the values of C_d defined by (2)–(9) or obtained from Fig. 3, a rating curve for the complete range of operation can be constructed. The results show that at low reservoir elevations, the capacity is noticeably greater for smaller α. If the reservoir elevation is to be limited at flows less than the design flow, the design with a smaller angle is preferred. On the other hand, if the outflow must be restricted at low reservoir elevations, then a larger angle is better.

A large angle may be chosen in the case of a spillway replacement where there is an existing apron width available and it is desirable to use the full width to minimize changes to the upstream and downstream channels. For such an installation, efficiency may not be the controlling criteria. The largest labyrinth angle is selected that provides the required flow and the best layout for the given width of apron.

Another important variable that influences the general layout and economy of a labyrinth is the number of cycles, N. Past test results (Waldron 1994) have shown that the crest coefficient is not influenced by the number of apexes. This simplifies the design process and allows (2)–(9) to be used without concern for the influence of N. As the number of cycles N is reduced, the length of the apron B gets large and can equal or exceed the width of the apron W. This increases concrete volume and cost. The data in Table 3 were generated using the spreadsheet in Table 2 keeping everything constant but N. The data show that increasing N has little effect on the actual weir length but it decreases B, increases W, and reduces the concrete volume. Selecting either too few or too many cycles produces a layout that may not be hydraulically efficient or cost-effective. Following the criteria $3 \leq w/P \leq 4$ keeps the length and width in proper proportion.

The cost of the approach and discharge channels is a significant cost factor not included in the simplified analysis. Even though the concrete volume decreases with increased N and α, the cost of the channels increases as W increases. There will be a number of designs that pass the required flow. The final design must be based on a complete economic analysis and an evaluation of any site conditions that may limit the maximum width of the structure.

Another factor related to selection of the preferred labyrinth design is the unit discharge in the approach and discharge channels. If the head is high and α and N are selected to give the minimum spillway width, the result is large depths and high velocities. This increases scour potential and may increase the difficulty of designing energy dissipating structures. These factors

TABLE 3. Influence of Number of Cycles on Spillway Layout

Number of cycles[a] N (1)	Length of apron B (m) (2)	Width of apron W (m) (3)	Weir length L_3 (m) (4)	Concrete volume (m³) (5)	w/P (6)
7	40.5	103	1,209	3,034	4.83
8	35.4	106	1,124	2,821	4.34
9	31.4	108	1,058	2,655	3.95
10	28.3	111	1,006	2,525	3.64
11	25.6	114	963	2,417	3.39
12	23.5	116	928	2,329	3.18
13	21.6	119	899	2,255	3.00
14	20.1	122	874	2,192	2.85
15	18.9	124	852	2,138	2.71
16	17.7	127	833	2,092	2.60

[a] N = 10 – 13 is the preferred range; α = 8°.

must be compared to the increased excavation and construction cost for the approach a discharge channels if the spillway is made wider.

FLOOD ROUTING

As part of the spillway design procedure, the maximum flood should be routed through t reservoir with the design layout. A preliminary assumption about spillway capacity as a functi of reservoir elevation must be made to generate the preliminary outflow hydrograph. If the fi spillway design is significantly different from the one originally assumed, the outflow hydrogra will need to be recalculated because the outflow hydrograph and the corresponding desi spillway flow will change.

Assume that the original flood routing was done using a spillway with a large labyrinth an and the preferred design has a small angle. The spillway with a small angle has significan more capacity at low reservoir elevations. With the increased spillway capacity, more of t flood is passed through the reservoir, which reduces the maximum reservoir elevation. This n allow the spillway length to be reduced, saving construction costs.

The other side of the problem is matching the outflow to downstream flow limitations. example would be where previous water rights limit releases from the reservoir at floods bel the hundred-year flood. If the labyrinth is to be added to an existing reservoir where downstream requirements limit the flows at low water-surface elevations, a labyrinth witl small angle may provide more capacity than can be tolerated. For such an installation, a lar angle labyrinth may better fit the outflow requirements. If the low flow requirement is extrem small, a short section of weir at a lower elevation could be used to pass small flows. The labyrinth would not activate until the flood exceeds some predetermined level, such as hundred-year flood.

DESIGN VERIFICATION

Before recommending the design procedure proposed herein, its accuracy was verified comparing it to the flows estimated for nine other labyrinth designs. Table 4 shows the co parisons. The comparisons shown are only at design flow. The difference between the estima flow and the flow calculated with the recommended design procedure varies by less than 1(In making the comparisons, slight modifications to the design procedure were needed to acco for differences in crest configuration and head. For Ute Dam, the radius of curvature for c is $P/30$, which is significantly smaller than the $P/12$ specified for our design procedure. This cause more separation and make the crest coefficient and the flow for the Ute model sma than the values predicted by the equations in the present paper. It was assumed that the c coefficient would fall between that for the quarter-round and a flat crest weir. The coeffic listed in Table 4 is the average of these two values. With this assumed coefficient, the flow the Ute Dam data is within 3.3% of the calculated flow.

For Bartletts Ferry, the head given was the measured piezometric head. The approach velo head was estimated and the total head of 2.44 m was used for the calculations.

The total crest length was reduced using the procedure identified in Fig. 1 to obtain effective length. The difference is basically the short outside lengths at the apex where thei essentially no flow.

Comparisons were also made by calculating the flow over the full range of H_t/P. Above P = 0.3, the calculated values were within 10% of the reported values. At small heads, calculated flows were as much as 20% smaller than the reported values. This is because crest coefficients calculated by (2)–(9) are for aerated nappes and will be too low if the protot nappe is not aerated. This is one reason why it is advisable to generate the final rating cu with a model study.

TABLE 4. Evaluation of Recommended Design Procedure

Location (1)	Reference (2)	Angle of side legs (α) (3)	Weir height (P) (m) (4)	Total head (H_t) (m) (5)	Total crest length (m) (6)	Effective crest length (m) (7)	Maximum design discharge (m^3/s) (8)	Calculated flow (m^3/s) (9)	Perc differe (10
Bartletts ferry	Meeks (1983)	14.5°	3.43	2.44	1,441	1,412	6,796	6,740	−0.
Ute Dam	Houston (1982)	12.15°	9.14	5.80	1,024	1,020	15,574	15,065	−3
Avon Dam	Hinchliff (1984)	27.5°	3.05	2.16	265	252	1,416	1,417	+0
Boardman	Cassidy (1985)	19.44°	3.51	1.77	107	104	387	399	+3.
Woronora	Hinchliff (1984)	25.4°	2.23	1.36	344	344	1,019	991	−6.
Navet	Hinchliff (1984)	23.58°	3.05	1.52	137	137	481	477	−3.
Rollins Dam	Tullis (1986)	9.23°	3.35	2.74	472	457	1,841	1,890	+2.
Ritchsard Dam	Vermeyen (1991)	8.13°	3.05	2.74	411	399	1,555	1,549	−0.

CONCLUSIONS

The capacity of a labyrinth spillway is a function of the total head H_t, the effective crest length L and the crest coefficient C_d. C_d depends on weir height P, total head H_t, weir wall thickness t, crest shape, apex configuration, and the angle of the side legs α. The design procedure is based on a weir with a of height $H_t/P \approx 0.9$ (at maximum flow), and with $t = P/6$, which is rounded on the upstream corner at a radius of $P/12$. The crest coefficients should be valid for a battered wall as long as the radius of the crest is still $P/12$. With the crest geometry fixed, C_d is only a function of α and head. Values of the crest coefficient for α between 6° and 35°, for the recommended weir configuration, can be determined from Fig. 3 or from polynomial equations [(2)–(9)] for eight different labyrinth angles and a linear weir. The choice of α and the number of cycles N significantly influences the width, length, and other details of the labyrinth. With complete freedom to vary α and N, numerous layouts can be generated. The most appropriate design is determined after considering site-specific limitations, completing an economic analysis in parallel with the hydraulic analysis, and routing the flood through the reservoir using the final spillway design.

Even though the design procedure gives an accurate analysis of the labyrinth's capacity, it is still advisable to verify the performance of the spillway with a model study. The model accounts for site-specific factors outside the scope of the spillway design, such as flow conditions in the approach and discharge channels, inlet losses, scour, submergence, and energy dissipation. If the flow in the discharge channel is supercritical, the model can also provide valuable information on wave heights and superelevation caused by channel convergence or bends.

APPENDIX I. REFERENCES

Amanian, N. (1987). "Performance and design of labyrinth spillway," MSc thesis, Utah State University, Logan, Utah.

Cassidy, J. J., Gardner, C. A., and Peacock, R. T. (1985). "Boardman labyrinth crest." *J. Hydr. Engrg.*, ASCE 111(3), 398–416.

Darvas, L. A. (1971). "Performance and design of labyrinth weirs." *J. Hydr. Engrg.*, ASCE, 97(8), 1246–1251.

Hay, N., and Taylor, G. (1970). "Performance and design of labyrinth weirs." *J. Hydr. Engrg.*, ASCE, 96(11), 2337–2357.

Hinchliff, D. L., and Houston, K. L. (1984). "Hydraulic design and application of labyrinth spillways." *Proc., USCOLD Lecture Dam Safety and Rehabilitation*, USCOLD, Denver, Colo.

Houston, K. L. (1982). "Hydraulic model study of the Ute Dam labyrinth spillway." *Rep. No. GR-82-7*, Bureau of Reclamation, Denver, Colo.

Houston, K. L. (1983). "Hydraulic model study of Hyrum auxiliary labyrinth spillway." *Rep. No. GR-82-13*, Bureau of Reclamation, Denver, Colo.

Lux, F. III. (1984). "Discharge characteristics of labyrinth weirs." *Proc., ASCE Hydr. Div. Specialty Conf.*, ASCE, New York, N.Y.

Mayer, P. G. (1980). "Bartletts Ferry project labyrinth weir model studies." *Proj. No. E-20-610* (with 2 addenda), Georgia Institute of Technology, Atlanta, Ga.

Meeks, M. C. (1983). "The design and construction of the Bartletts Ferry labyrinth weir spillway." *Occasional Paper*, Power Supply Engrg. and Services Dept., Georgia Power Company, Atlanta, Ga.

Taylor, G. (1968). "The performance of labyrinth weirs," PhD thesis, University of Nottingham, Nottingham, England.

Tullis, J. P. (1993). "Standley Lake service spillway model study." *Hydr. Rep. Number 341*, Utah State University Foundation, Utah Water Research Laboratory, Logan, Utah.

Vermeyen, T. (1991). "Hydraulic model study of Ritschard Dam spillways." *Rep. No. R-91-08*, Bureau of Reclamation, Denver, Colo., 1–18.

Waldron, D. R. (1994). "Design of labyrinth weirs," MSc thesis, Utah State University, Logan, Utah.

APPENDIX II. NOTATION

The following symbols are used in this paper:

- A = inside apex width;
- B = length of labyrinth apron;
- C_d = crest coefficient;
- el = crest elevation;
- H_t = total head on crest;
- L = effective length;
- N = number of cycles;
- P = weir height;
- Q = flow;
- Q_{max} = design flow;
- R = radius of crest curvature;
- res = maximum reservoir elevation;
- t = wall thickness at crest;
- W = total width of labyrinth;
- w = width of one cycle;
- α = labyrinth angle; and
- β = angle of approach flow.

APPENDIX G

Revised design package

NEWTOWN CREEK WPCP
FACILITIES UPGRADING
CONTRACT NC-32G

EFFLUENT FLUME ANALYSIS
REVISIONS FOR ANALYSIS

GREELEY AND HANSEN
January 29, 1999

FLUME REVISIONS:

1. VERIFY GAUGING STATION LOCATION AT 6'-9" FROM UPSTREAM EDGE OF FLUME CREST.

2. VERIFY REVISIONS OF FLUME DOWNSTREAM SLOPE AND CREST HEIGHT MEET RECOMMENDATIONS FROM WRRL FOR OPTIMUM PERFORMANCE.

3. COMMENT ON SUGGESTION OF ADDING A STEEL PLATE OVER FLUME CREST FOR MAINTAINING A UNIFORM SMOOTH SURFACE AT CREST.

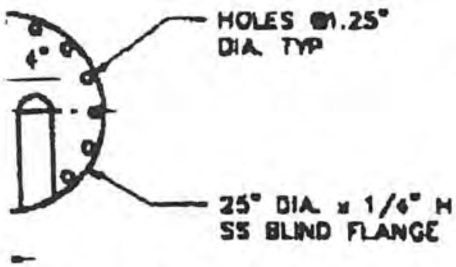
LABYRINTH WEIRS AND TROUGH:

4. ANALYSE THE TROUGH REVISIONS AS MARKED FOR DEEPENING THE UPSTREAM HALF TO ELEVATION 0.00 AND THEN SLOPING FROM THE CENTER POINT UP TO ELEVATION 5.50 AT APPROXIMATELY 1:6 OR 1:8 SLOPE.

5. WEIRS TO REMAIN AS SHARP CRESTED DUE TO DESIRE FOR ADJUSTABILITY AND CONSTRUCTABILITY TO CREST ELEVATION WITHIN TIGHT TOLERANCES. ANALYZE THE EFFECT OF THIS ON UPSTREAM HEAD.

ADDITION OF PROBES AND SAMPLING PUMPS ON GAUGING STATION BRIDGE:

6. ANALYZE THE EFFECT OF UPSTREAM 1" DIA pH, D.O. AND TEMP. PROBES AND 18" DIA SUBMERSIBLE SAMPLING PUMPS ON FLUME FLOW DISTRIBUTION. WILL THESE PROBES AND PUMPS AFFECT FLUME MEASUREMENT AT DISTANCES FROM FLUME SHOWN? IF SO, WHAT DISTANCE UPSTREAM IS REQUIRED TO ELIMINATE EDDIES CREATED BY THESE ITEMS?



D FLANGE DETAIL

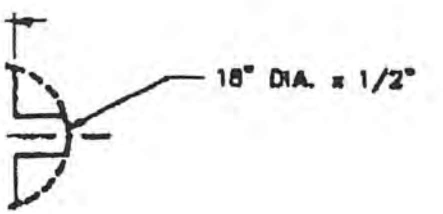
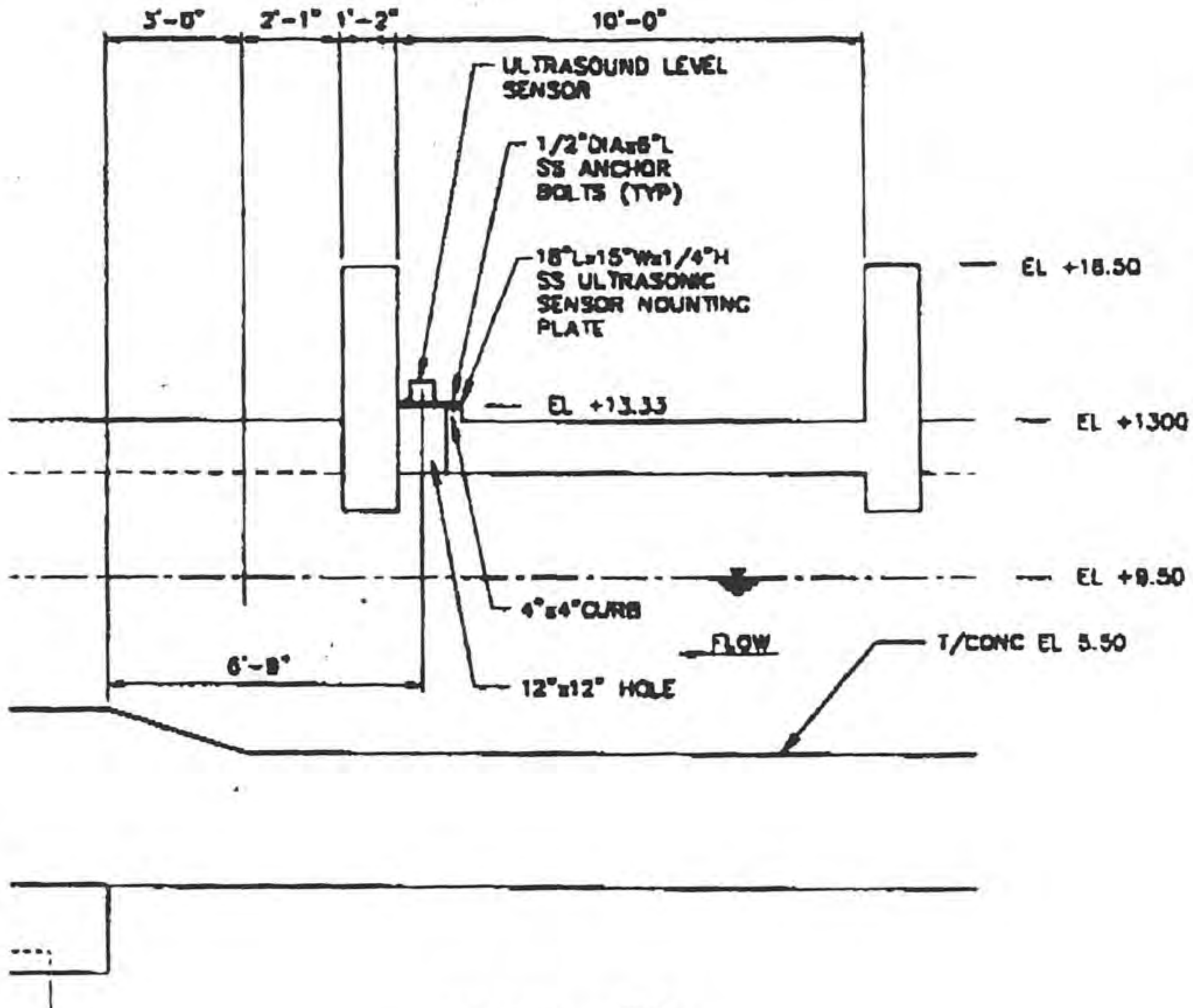
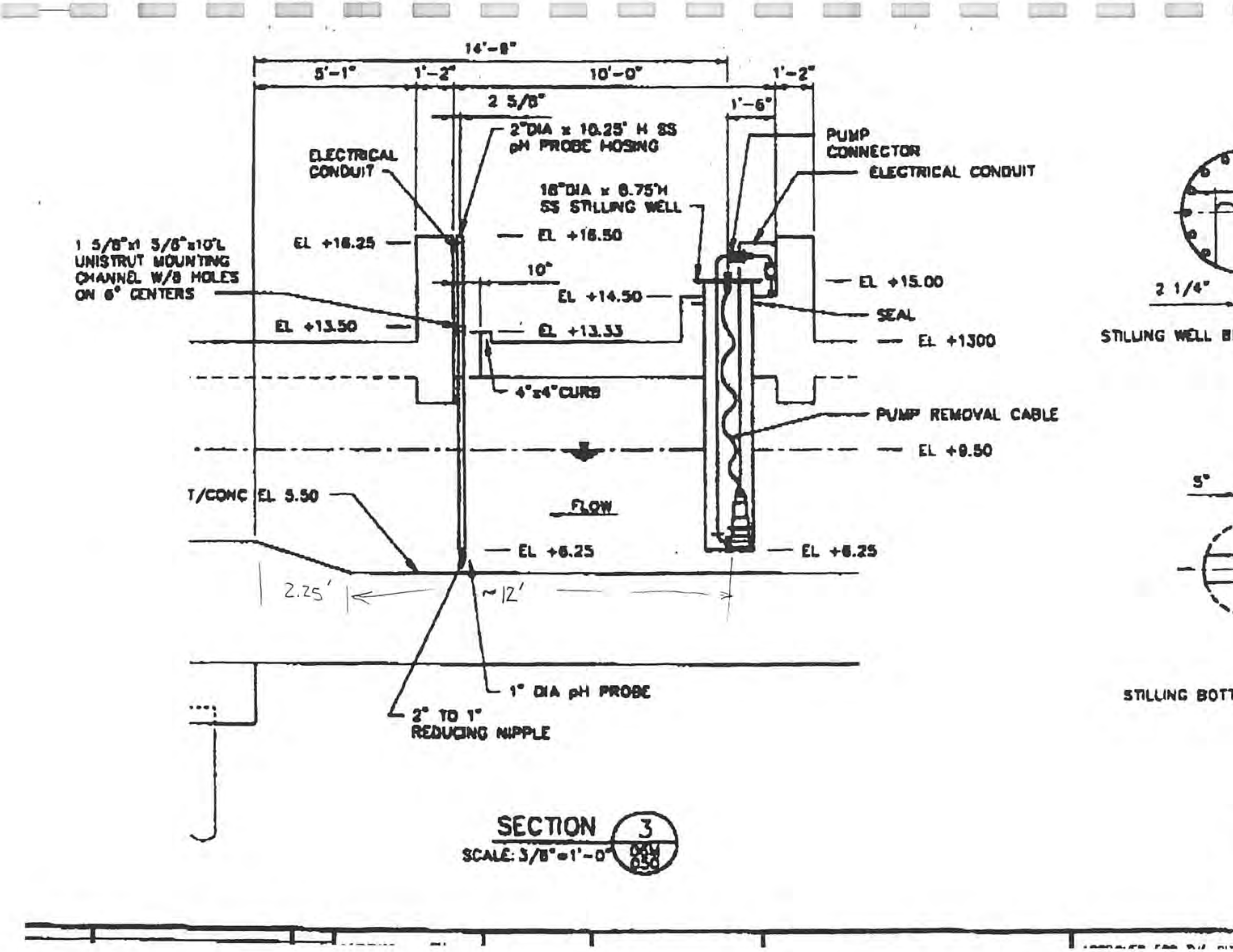


PLATE DETAIL

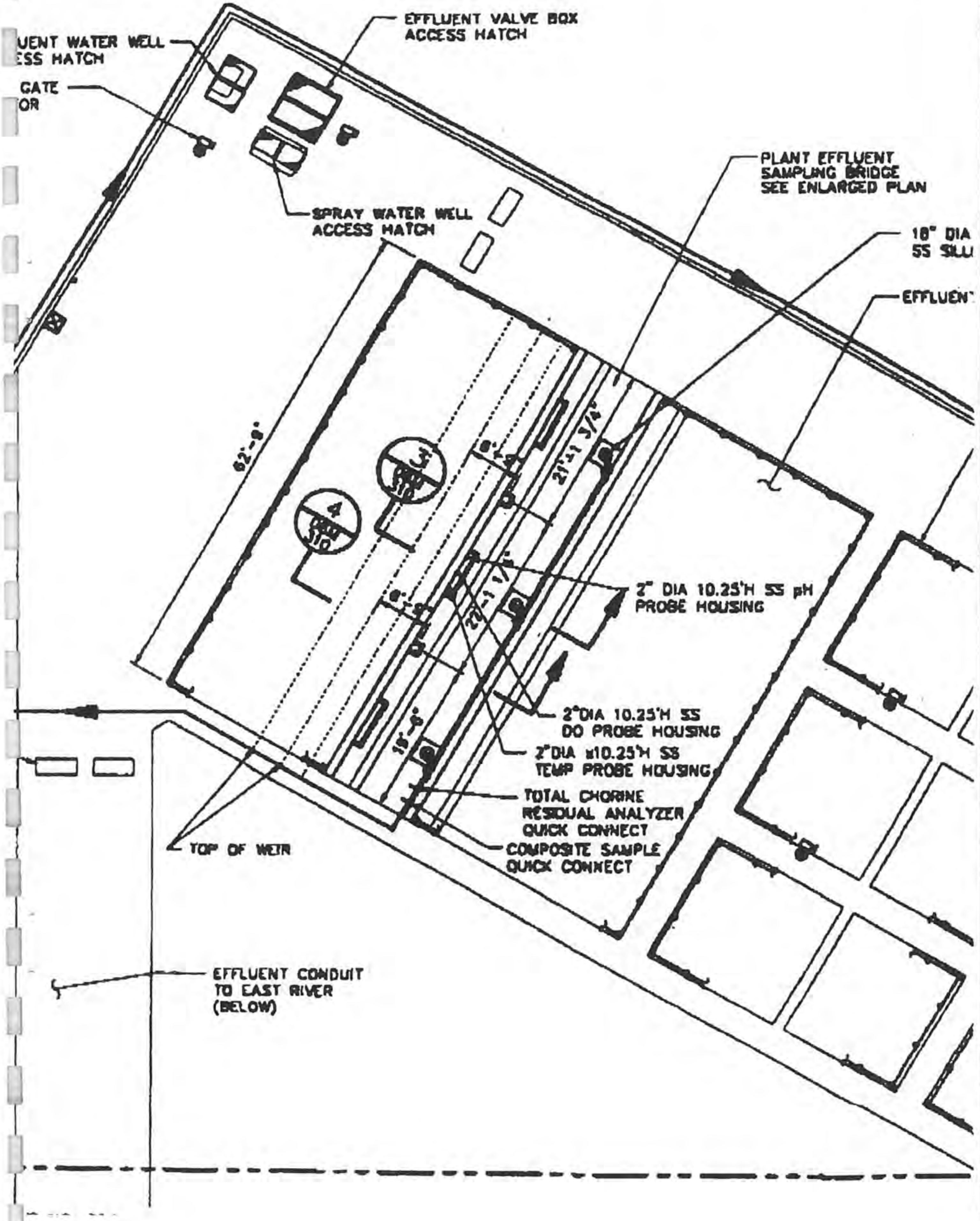


SECTION 4
SCALE: 3/8"=1'-0"

01/29/99 12:09 GREELEY AND HANSEN → 303 445 6324 NO.591 P007/008

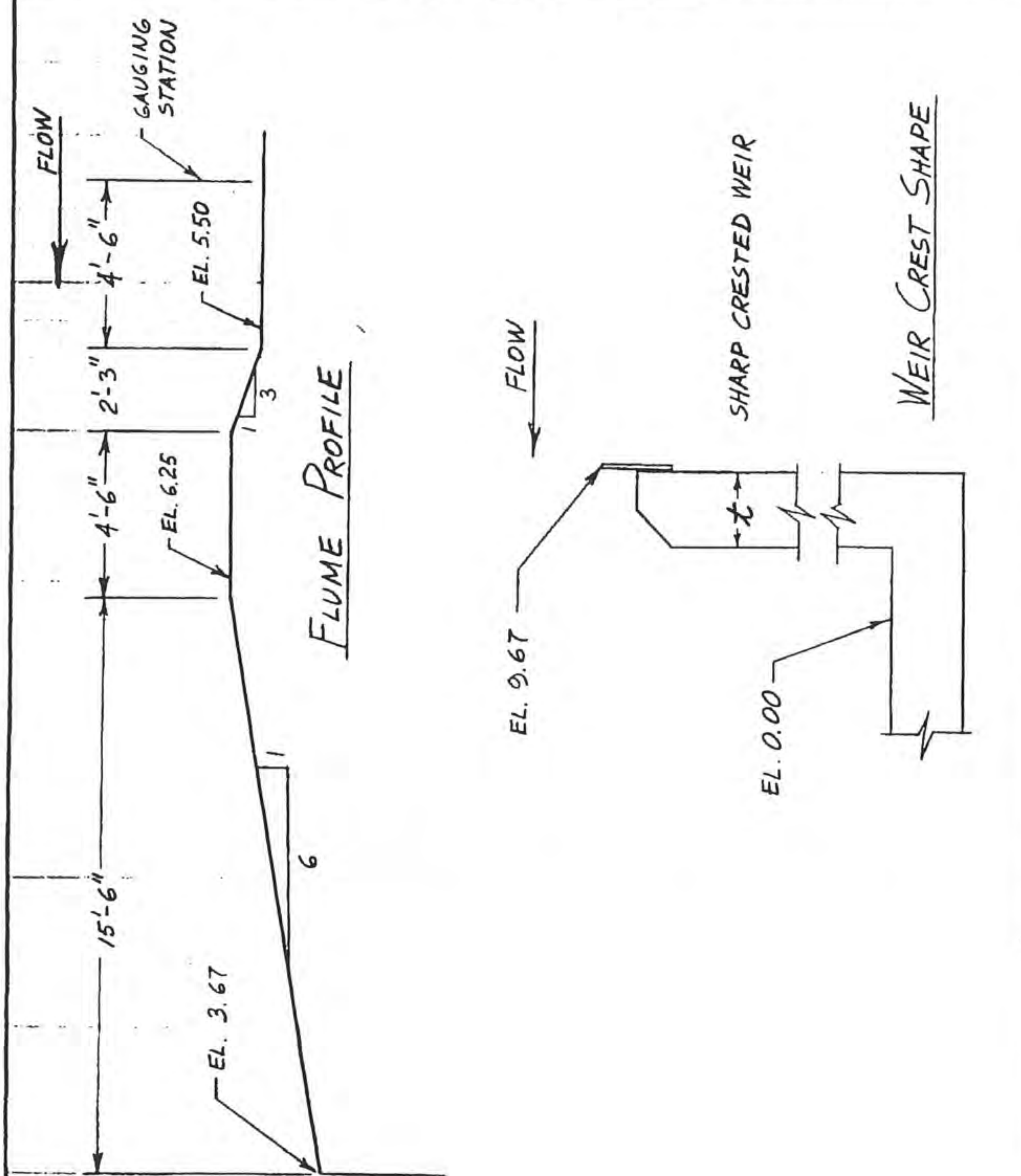


SECTION 3
SCALE: 3/8"=1'-0"

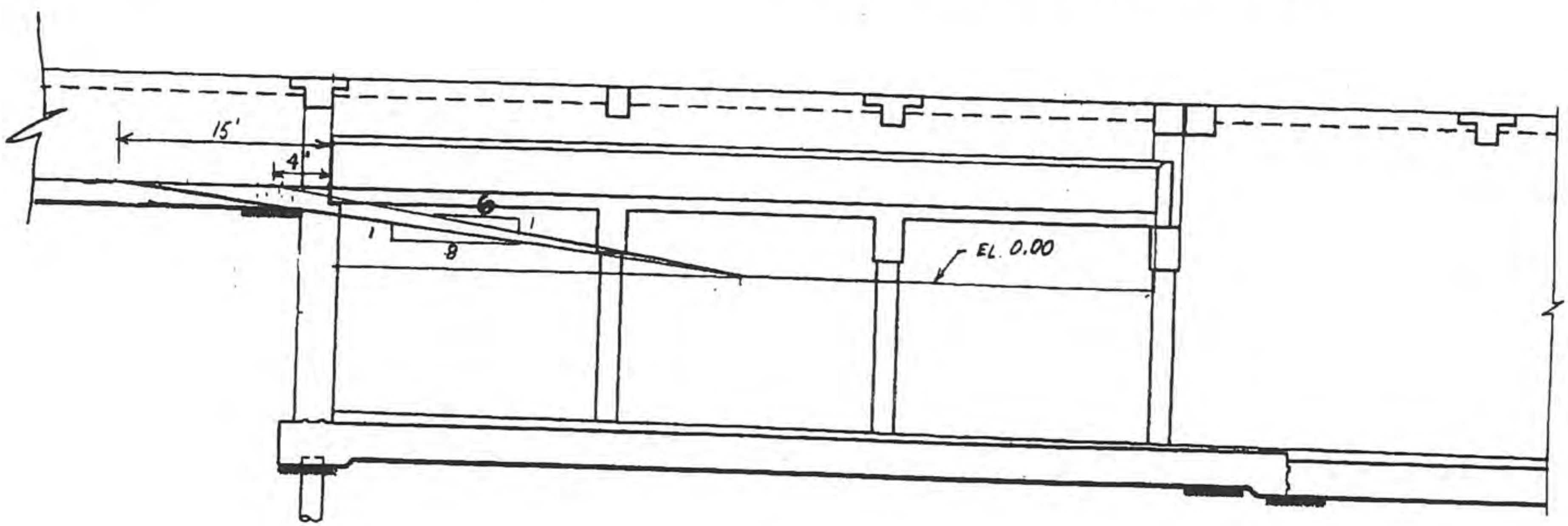

UENT WATER WELL
ESS HATCH
GATE
OR
EFFLUENT VALVE BOX
ACCESS HATCH
SPRAY WATER WELL
ACCESS HATCH
PLANT EFFLUENT
SAMPLING BRIDGE
SEE ENLARGED PLAN
18" DIA
SS SLU
EFFLUEN
62'-8"
21'-11 3/4"
6"
22'-1 1/2"
15'-8"
2" DIA 10.25'H SS pH
PROBE HOUSING
2"DIA 10.25'H SS
DO PROBE HOUSING
2"DIA x10.25'H SS
TEMP PROBE HOUSING
TOTAL CHORINE
RESIDUAL ANALYZER
QUICK CONNECT
COMPOSITE SAMPLE
QUICK CONNECT
TOP OF WEIR
EFFLUENT CONDUIT
TO EAST RIVER
(BELOW)

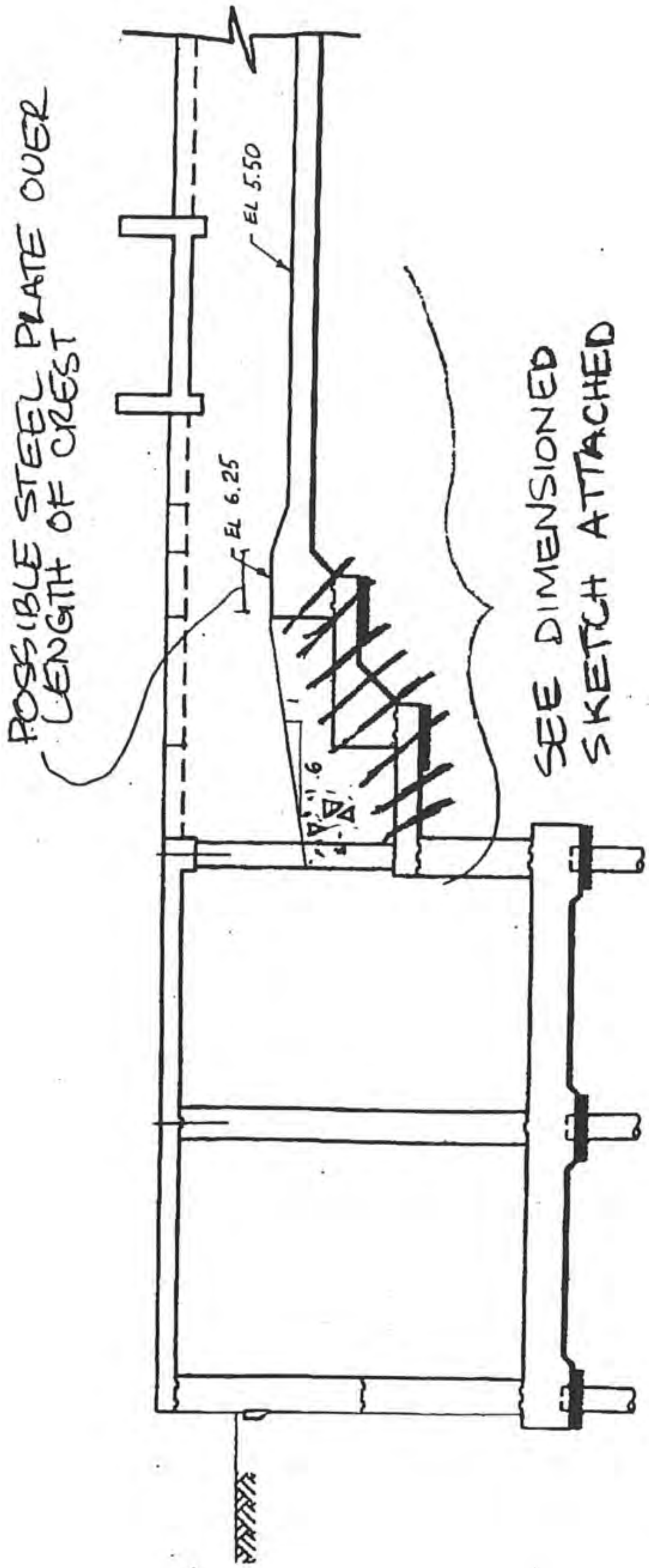
GREELEY AND HANSEN ENGINEERS

PROJECT: NEWTOWN CREEK	PROJ NO. 9200-332-03
SUBJECT: FLUME PROFILE AND WEIR CREST SHAPE	CLIENT: DEP-NYC
COMP BY: MG DATE: 12/10/98 CKD BY: ______ DATE: ______	SHEET 1 OF 1



EXPLORE 1:6 SLOPE OR 1:8 IN ANALYSIS.
(1:6 IS PREFERED FROM A DESIGN STANDPOINT.)

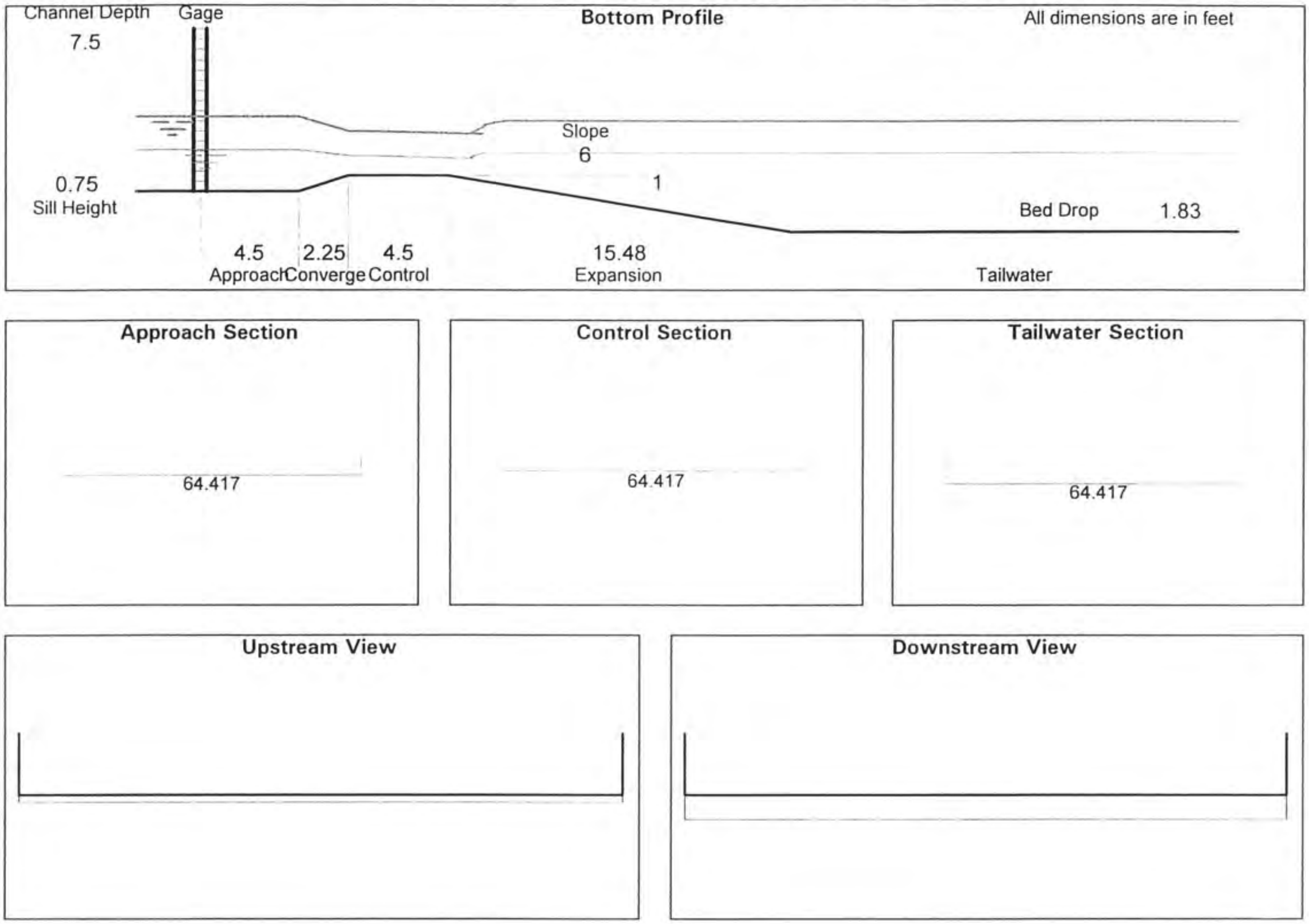



POSSIBLE STEEL PLATE OVER LENGTH OF CREST
EL 5.50
EL 6.25
SEE DIMENSIONED SKETCH ATTACHED

APPENDIX H

Analysis of revised long-throated flume

Minimum headloss flume for Newtown Creek WPCP - Revision 16



```
User: Tony L. Wahl          WinFlume32 - Version 0.63 (1/25/99)
D:\NEWTOWN\Final.Newtown.Creek.Flm - Revision 16
Minimum headloss flume for Newtown Creek WPCP
Printed: 2/5/99
                               FLUME DATA REPORT
------------------------------------------------------------------------------
                             GENERAL DATA ON FLUME
Type of structure: Stationary Crest
Type of lining: Metal - smooth
Roughness height of flume: 0.000197 ft

                              BOTTOM PROFILE DATA
Length per section:  Approach section = 4.500 ft
                      Converging ramp = 2.250 ft
                      Control section = 4.500 ft
                       Expansion ramp = 15.480 ft

Vertical dimensions: Upstream channel depth = 7.500 ft
                             Height of sill = 0.750 ft
                                   Bed drop = 1.830 ft
                       Expansion ramp slope = 6.000:1

                          -- APPROACH SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft

                          -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft

                          -- TAILWATER SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft
```

```
User: Tony L. Wahl          WinFlume32 - Version 0.63 (1/25/99)
D:\NEWTOWN\Final.Newtown.Creek.Flm - Revision 16
Minimum headloss flume for Newtown Creek WPCP
Printed: 2/5/99

                           EVALUATION OF FLUME DESIGN
-----------------------------------------------------------------------------------
GENERAL RESULT:  Design is acceptable.
                 Zero errors or warnings.


             EVALUATION OF FLUME DESIGN FOR EACH DESIGN REQUIREMENT

Ok.          Freeboard at Qmax = 4.020 ft          Minimum allowed = 3.580 ft

Ok.               Head at Qmax = 2.730 ft    Minimum for precision = 0.852 ft
                 Estimated discharge measurement precision at Qmax = ±2.19 %

Ok.               Head at Qmin = 1.182 ft    Minimum for precision = 0.386 ft
                 Estimated discharge measurement precision at Qmin = ±3.17 %

Ok.          Tailwater at Qmax = 5.080 ft          Maximum allowed = 5.261 ft
                                   Submergence Protection at Qmax = 0.181 ft

Ok.          Tailwater at Qmin = 3.590 ft          Maximum allowed = 3.644 ft
                                   Submergence Protection at Qmin = 0.054 ft

Ok.      Froude number at Qmax = 0.457             Maximum allowed = 0.500


                              RESULTING STRUCTURE
Sill Height = 0.750 ft
                         -- CONTROL SECTION DATA --
Section shape = RECTANGULAR
Bed width = 64.417 ft


                                DESIGN CRITERIA

Structure Type:  Stationary Crest
Freeboard design criterion:  Fixed freeboard height = 3.580 ft
Allowable discharge measurement errors for a single measurement:
     At minimum discharge: 8 %
     At maximum discharge: 4 %
Head detection method: Ultrasonic level sensor
     Gage readout precision = 0.020000 ft
Design discharges and associated tailwater levels:
     Minimum discharge = 180.000 mgd     Minimum tailwater depth = 3.590 ft
     Maximum discharge = 700.000 mgd     Maximum tailwater depth = 5.080 ft
  Bed drop at structure site = 1.830 ft
Tailwater calculation method:  Linear fit to Q-H lookup table
     Q = 180.000 mgd  --->  y2 = 3.590 ft
     Q = 310.000 mgd  --->  y2 = 3.900 ft
     Q = 465.000 mgd  --->  y2 = 4.290 ft
     Q = 700.000 mgd  --->  y2 = 5.080 ft
```

User: Tony L. Wahl WinFlume32 - Version 0.63 (1/25/99)
D:\NEWTOWN\Final Newtown.Creek.Flm - Revision 16
Minimum headloss flume for Newtown Creek WPCP
Flume Rating Table, Printed: 2/5/99
Page 1

Discharge mgd	Head at Gage, h1 ft	Froude Number	Required Head Loss ft	H1/L Ratio	Upstream Energy Head, ft	Upstream Depth ft	Upstream Velocity ft/s	Discharge Coeff.	Velocity Coeff.	Allowable Tailwater h2, ft	Tailwater Head, h2 ft	Tailwater Depth, y2 ft	Submerge Ratio	Modular Limit	Errors
180.0	1.182	0.284	0.178	0.281	1.263	1.932	2.238	0.988	1.104	1.064	1.010	3.590	0.818	0.859	
185.0	1.202	0.287	0.179	0.286	1.286	1.952	2.276	0.988	1.106	1.084	1.022	3.602	0.813	0.861	
190.0	1.222	0.290	0.181	0.291	1.309	1.972	2.314	0.989	1.108	1.104	1.034	3.614	0.809	0.862	
195.0	1.242	0.294	0.183	0.296	1.332	1.992	2.351	0.989	1.110	1.124	1.046	3.626	0.805	0.863	
200.0	1.262	0.297	0.184	0.301	1.354	2.012	2.388	0.989	1.112	1.144	1.058	3.638	0.801	0.864	
205.0	1.281	0.300	0.186	0.306	1.376	2.031	2.424	0.989	1.113	1.164	1.070	3.650	0.798	0.865	
210.0	1.301	0.303	0.188	0.311	1.399	2.051	2.460	0.990	1.115	1.183	1.082	3.662	0.794	0.866	
215.0	1.320	0.306	0.189	0.316	1.420	2.070	2.495	0.990	1.117	1.202	1.093	3.673	0.791	0.867	
220.0	1.339	0.309	0.191	0.320	1.442	2.089	2.530	0.990	1.118	1.222	1.105	3.685	0.789	0.868	
225.0	1.358	0.311	0.192	0.325	1.464	2.108	2.564	0.991	1.120	1.241	1.117	3.697	0.786	0.869	
230.0	1.376	0.314	0.193	0.330	1.485	2.126	2.598	0.991	1.121	1.260	1.129	3.709	0.783	0.870	
235.0	1.395	0.317	0.195	0.335	1.507	2.145	2.632	0.991	1.123	1.278	1.141	3.721	0.781	0.871	
240.0	1.413	0.320	0.196	0.339	1.528	2.163	2.665	0.991	1.124	1.297	1.153	3.733	0.779	0.872	
245.0	1.431	0.322	0.198	0.344	1.549	2.181	2.698	0.991	1.126	1.316	1.165	3.745	0.777	0.872	
250.0	1.449	0.325	0.199	0.349	1.570	2.199	2.731	0.992	1.127	1.334	1.177	3.757	0.775	0.873	
255.0	1.467	0.327	0.200	0.353	1.590	2.217	2.763	0.992	1.129	1.352	1.189	3.769	0.773	0.874	
260.0	1.485	0.330	0.202	0.358	1.611	2.235	2.795	0.992	1.130	1.370	1.201	3.781	0.772	0.875	
265.0	1.502	0.332	0.203	0.363	1.631	2.252	2.826	0.992	1.132	1.389	1.213	3.793	0.770	0.876	
270.0	1.520	0.334	0.204	0.367	1.652	2.270	2.857	0.992	1.133	1.406	1.225	3.805	0.769	0.876	
275.0	1.537	0.337	0.205	0.372	1.672	2.287	2.888	0.993	1.134	1.424	1.237	3.817	0.767	0.877	
280.0	1.554	0.339	0.207	0.376	1.692	2.304	2.919	0.993	1.136	1.442	1.248	3.828	0.766	0.878	
285.0	1.571	0.341	0.208	0.380	1.712	2.321	2.949	0.993	1.137	1.460	1.260	3.840	0.765	0.879	
290.0	1.588	0.343	0.209	0.385	1.732	2.338	2.979	0.993	1.139	1.477	1.272	3.852	0.764	0.879	
295.0	1.605	0.346	0.210	0.389	1.751	2.355	3.009	0.993	1.140	1.494	1.284	3.864	0.763	0.880	
300.0	1.622	0.348	0.211	0.394	1.771	2.372	3.038	0.993	1.141	1.512	1.296	3.876	0.762	0.881	
305.0	1.638	0.350	0.212	0.398	1.791	2.388	3.067	0.994	1.142	1.529	1.308	3.888	0.761	0.881	
310.0	1.655	0.352	0.213	0.402	1.810	2.405	3.096	0.994	1.144	1.546	1.320	3.900	0.761	0.882	
315.0	1.671	0.354	0.214	0.406	1.829	2.421	3.125	0.994	1.145	1.563	1.333	3.913	0.760	0.883	
320.0	1.688	0.356	0.215	0.411	1.848	2.438	3.153	0.994	1.146	1.580	1.345	3.925	0.760	0.883	
325.0	1.704	0.358	0.217	0.415	1.867	2.454	3.181	0.994	1.147	1.597	1.358	3.938	0.760	0.884	
330.0	1.720	0.360	0.218	0.419	1.886	2.470	3.209	0.994	1.149	1.613	1.370	3.950	0.760	0.885	
335.0	1.736	0.362	0.219	0.423	1.905	2.486	3.237	0.995	1.150	1.630	1.383	3.963	0.759	0.885	
340.0	1.752	0.364	0.220	0.428	1.924	2.502	3.264	0.995	1.151	1.647	1.395	3.975	0.759	0.886	
345.0	1.768	0.366	0.221	0.432	1.943	2.518	3.291	0.995	1.152	1.663	1.408	3.988	0.759	0.886	
350.0	1.783	0.368	0.221	0.436	1.962	2.533	3.318	0.995	1.153	1.679	1.421	4.001	0.759	0.887	
355.0	1.799	0.369	0.222	0.440	1.980	2.549	3.345	0.995	1.155	1.696	1.433	4.013	0.759	0.888	
360.0	1.815	0.371	0.223	0.444	1.998	2.565	3.371	0.995	1.156	1.712	1.446	4.026	0.759	0.888	
365.0	1.830	0.373	0.224	0.448	2.017	2.580	3.398	0.995	1.157	1.728	1.458	4.038	0.759	0.889	
370.0	1.846	0.375	0.225	0.452	2.035	2.596	3.424	0.996	1.158	1.744	1.471	4.051	0.760	0.889	
375.0	1.861	0.376	0.226	0.456	2.053	2.611	3.450	0.996	1.159	1.760	1.484	4.064	0.760	0.890	
380.0	1.876	0.378	0.227	0.460	2.071	2.626	3.476	0.996	1.160	1.776	1.496	4.076	0.760	0.890	
385.0	1.891	0.380	0.228	0.464	2.089	2.641	3.501	0.996	1.161	1.792	1.509	4.089	0.760	0.891	
390.0	1.906	0.381	0.229	0.468	2.107	2.656	3.526	0.996	1.162	1.808	1.521	4.101	0.760	0.891	
395.0	1.921	0.383	0.230	0.472	2.125	2.671	3.552	0.996	1.163	1.824	1.534	4.114	0.761	0.892	
400.0	1.936	0.385	0.230	0.476	2.143	2.686	3.577	0.996	1.164	1.839	1.546	4.126	0.761	0.892	
405.0	1.951	0.386	0.231	0.480	2.161	2.701	3.601	0.997	1.165	1.855	1.559	4.139	0.761	0.893	
410.0	1.966	0.388	0.232	0.484	2.178	2.716	3.626	0.997	1.166	1.870	1.572	4.152	0.762	0.893	
415.0	1.981	0.389	0.233	0.488	2.196	2.731	3.650	0.997	1.168	1.886	1.584	4.164	0.762	0.894	
420.0	1.995	0.391	0.234	0.492	2.214	2.745	3.675	0.997	1.169	1.901	1.597	4.177	0.762	0.894	
425.0	2.010	0.393	0.235	0.496	2.231	2.760	3.699	0.997	1.170	1.916	1.609	4.189	0.763	0.895	
430.0	2.024	0.394	0.235	0.500	2.248	2.774	3.723	0.997	1.171	1.932	1.622	4.202	0.763	0.895	
435.0	2.039	0.396	0.236	0.503	2.266	2.789	3.747	0.997	1.172	1.947	1.635	4.215	0.764	0.896	
440.0	2.053	0.397	0.237	0.507	2.283	2.803	3.770	0.997	1.172	1.962	1.647	4.227	0.764	0.896	
445.0	2.067	0.399	0.238	0.511	2.300	2.817	3.794	0.998	1.174	1.977	1.660	4.240	0.765	0.897	
450.0	2.082	0.400	0.238	0.515	2.317	2.832	3.817	0.998	1.174	1.992	1.672	4.252	0.765	0.897	
455.0	2.096	0.401	0.239	0.519	2.334	2.846	3.840	0.998	1.175	2.007	1.685	4.265	0.766	0.898	
460.0	2.110	0.403	0.240	0.522	2.351	2.860	3.863	0.998	1.176	2.022	1.697	4.277	0.766	0.898	
465.0	2.124	0.404	0.241	0.526	2.368	2.874	3.887	0.998	1.178	2.036	1.710	4.290	0.767	0.898	
470.0	2.138	0.406	0.241	0.530	2.385	2.888	3.909	0.998	1.179	2.051	1.727	4.307	0.769	0.899	
475.0	2.152	0.407	0.242	0.534	2.402	2.902	3.932	0.999	1.179	2.066	1.744	4.324	0.771	0.899	
480.0	2.165	0.408	0.243	0.537	2.418	2.915	3.954	0.999	1.180	2.081	1.760	4.340	0.773	0.900	
485.0	2.179	0.410	0.243	0.541	2.435	2.929	3.977	0.999	1.181	2.095	1.777	4.357	0.775	0.900	
490.0	2.193	0.411	0.244	0.545	2.452	2.943	3.999	0.999	1.182	2.110	1.794	4.374	0.778	0.900	
495.0	2.207	0.412	0.245	0.549	2.468	2.957	4.021	0.999	1.183	2.124	1.811	4.391	0.780	0.901	
500.0	2.221	0.414	0.245	0.552	2.485	2.971	4.043	0.999	1.184	2.139	1.828	4.408	0.782	0.901	
505.0	2.234	0.415	0.246	0.556	2.501	2.984	4.065	0.999	1.185	2.153	1.844	4.424	0.784	0.902	
510.0	2.248	0.416	0.247	0.560	2.518	2.998	4.086	0.999	1.186	2.167	1.861	4.441	0.786	0.902	
515.0	2.261	0.417	0.247	0.563	2.534	3.011	4.108	0.999	1.186	2.182	1.878	4.458	0.788	0.902	
520.0	2.275	0.419	0.248	0.567	2.550	3.025	4.129	0.999	1.187	2.196	1.895	4.475	0.790	0.903	
525.0	2.288	0.420	0.249	0.570	2.567	3.038	4.151	0.999	1.188	2.210	1.912	4.492	0.793	0.903	
530.0	2.302	0.421	0.249	0.574	2.583	3.052	4.172	1.000	1.189	2.224	1.929	4.509	0.795	0.903	
535.0	2.315	0.422	0.250	0.578	2.599	3.065	4.193	1.000	1.190	2.239	1.945	4.525	0.797	0.904	
540.0	2.328	0.423	0.251	0.581	2.615	3.078	4.214	1.000	1.191	2.253	1.962	4.542	0.799	0.904	
545.0	2.341	0.425	0.251	0.585	2.631	3.091	4.234	1.000	1.191	2.267	1.979	4.559	0.801	0.905	
550.0	2.355	0.426	0.252	0.588	2.647	3.105	4.255	1.000	1.192	2.281	1.996	4.576	0.803	0.905	
555.0	2.368	0.427	0.252	0.592	2.663	3.118	4.276	1.000	1.193	2.295	2.013	4.593	0.805	0.905	
560.0	2.381	0.428	0.253	0.595	2.679	3.131	4.296	1.000	1.194	2.308	2.029	4.609	0.807	0.906	
565.0	2.394	0.429	0.254	0.599	2.695	3.144	4.317	1.000	1.195	2.322	2.046	4.626	0.809	0.906	
570.0	2.407	0.430	0.254	0.602	2.711	3.157	4.337	1.000	1.195	2.336	2.063	4.643	0.811	0.906	
575.0	2.420	0.431	0.255	0.606	2.727	3.170	4.357	1.000	1.196	2.350	2.080	4.660	0.813	0.907	
580.0	2.433	0.433	0.255	0.609	2.742	3.183	4.377	1.000	1.197	2.363	2.097	4.677	0.815	0.907	
585.0	2.446	0.434	0.256	0.613	2.758	3.196	4.397	1.000	1.198	2.377	2.113	4.693	0.817	0.907	
590.0	2.458	0.435	0.256	0.616	2.774	3.208	4.417	1.000	1.198	2.391	2.130	4.710	0.819	0.908	
595.0	2.471	0.436	0.257	0.620	2.789	3.221	4.437	1.000	1.199	2.404	2.147	4.727	0.821	0.908	
600.0	2.484	0.437	0.258	0.623	2.805	3.234	4.456	1.000	1.200	2.418	2.164	4.744	0.823	0.908	
605.0	2.497	0.438	0.258	0.627	2.820	3.247	4.476	1.000	1.201	2.431	2.181	4.761	0.825	0.908	
610.0	2.509	0.439	0.259	0.630	2.836	3.259	4.495	1.001	1.201	2.445	2.197	4.777	0.826	0.909	
615.0	2.522	0.440	0.259	0.634	2.851	3.272	4.515	1.001	1.202	2.458	2.214	4.794	0.828	0.909	
620.0	2.534	0.441	0.260	0.637	2.866	3.284	4.534	1.001	1.203	2.472	2.231	4.811	0.830	0.909	
625.0	2.547	0.442	0.260	0.640	2.882	3.297	4.553	1.001	1.204	2.485	2.248	4.828	0.832	0.910	
630.0	2.559	0.443	0.261	0.644	2.897	3.309	4.572	1.001	1.204	2.498	2.265	4.845	0.834	0.910	
635.0	2.572	0.444	0.261	0.647	2.912	3.322	4.591	1.001	1.205	2.512	2.281	4.861	0.836	0.910	
640.0	2.584	0.445	0.262	0.651	2.927	3.334	4.610	1.001	1.206	2.525	2.298	4.878	0.838	0.911	
645.0	2.597	0.446	0.262	0.654	2.943	3.347	4.629	1.001	1.206	2.538	2.315	4.895	0.840	0.911	
650.0	2.609	0.447	0.263	0.657	2.958	3.359	4.648	1.001	1.207	2.551	2.332	4.912	0.841	0.911	
655.0	2.621	0.448	0.263	0.661	2.973	3.371	4.666	1.001	1.208	2.564	2.349	4.929	0.843	0.911	
660.0	2.634	0.449	0.264	0.664	2.988	3.384	4.685	1.001	1.208	2.577	2.366	4.946	0.845	0.912	
665.0	2.646	0.450	0.264	0.667	3.003	3.396	4.704	1.001	1.209	2.590	2.382	4.962	0.847	0.912	
670.0	2.658	0.451	0.265	0.671	3.018	3.408	4.722	1.001	1.210	2.603	2.399	4.979	0.849	0.912	
675.0	2.670	0.452	0.265	0.674	3.033	3.420	4.740	1.001	1.210	2.616	2.416	4.996	0.851	0.913	
680.0	2.682	0.453	0.266	0.677	3.048	3.432	4.759	1.002	1.212	2.629	2.433	5.013	0.852	0.913	
685.0	2.694	0.454	0.266	0.681	3.063	3.444	4.777	1.002	1.212	2.642	2.450	5.030	0.854	0.913	
690.0	2.706	0.455	0.267	0.684	3.077	3.456	4.796	1.002	1.213	2.655	2.466	5.046	0.856	0.913	
695.0	2.718	0.456	0.267	0.687	3.092	3.468	4.814	1.002	1.214	2.668	2.483	5.063	0.858	0.914	
700.0	2.730	0.457	0.268	0.690	3.107	3.480	4.832	1.002	1.214	2.681	2.500	5.080	0.859	0.914	

Error Summary

No errors.

User: Tony L. Wahl WinFlume32 - Version 0.63 (1/25/99)
D:\NEWTOWN\Final.Newtown.Creek.Flm - Revision 16
Minimum headloss flume for Newtown Creek WPCP
Rating Equation Report, Printed: 2/5/99

Head at Gage, h1 feet	Discharge mgd	Equation Discharge mgd	Equation Error mgd	Equation Error %	Hydraulic Errors
1.180	179.5	179.5	-0.019	-0.01	
1.190	181.9	181.9	-0.018	-0.01	
1.200	184.4	184.4	-0.018	-0.01	
1.210	186.9	186.9	-0.017	-0.01	
1.220	189.4	189.4	-0.017	-0.01	
1.230	191.9	191.9	-0.016	-0.01	
1.240	194.4	194.4	-0.015	-0.01	
1.250	196.9	196.9	-0.015	-0.01	
1.260	199.5	199.5	-0.014	-0.01	
1.270	202.0	202.0	-0.013	-0.01	
1.280	204.6	204.6	-0.013	-0.01	
1.290	207.2	207.2	-0.012	-0.01	
1.300	209.8	209.8	-0.011	-0.01	
1.310	212.4	212.4	-0.010	0.00	
1.320	215.0	215.0	-0.010	0.00	
1.330	217.7	217.7	-0.009	0.00	
1.340	220.3	220.3	-0.008	0.00	
1.350	223.0	223.0	-0.007	0.00	
1.360	225.6	225.6	-0.006	0.00	
1.370	228.3	228.3	-0.006	0.00	
1.380	231.0	231.0	-0.005	0.00	
1.390	233.7	233.7	-0.004	0.00	
1.400	236.5	236.5	-0.003	0.00	
1.410	239.2	239.2	-0.002	0.00	
1.420	241.9	241.9	-0.001	0.00	
1.430	244.7	244.7	-0.001	0.00	
1.440	247.5	247.5	0.000	0.00	
1.450	250.3	250.3	+0.001	0.00	
1.460	253.1	253.1	+0.002	0.00	
1.470	255.9	255.9	+0.003	0.00	
1.480	258.7	258.7	+0.004	0.00	
1.490	261.5	261.5	+0.004	0.00	
1.500	264.4	264.4	+0.005	0.00	
1.510	267.2	267.2	-0.008	0.00	
1.520	270.1	270.1	-0.007	0.00	
1.530	273.0	273.0	-0.006	0.00	
1.540	275.9	275.9	-0.005	0.00	
1.550	278.8	278.8	-0.005	0.00	
1.560	281.7	281.7	-0.004	0.00	
1.570	284.6	284.6	-0.003	0.00	
1.580	287.6	287.6	-0.002	0.00	
1.590	290.5	290.5	-0.001	0.00	
1.600	293.5	293.5	-0.001	0.00	
1.610	296.4	296.5	+0.017	+0.01	
1.620	299.4	299.5	+0.018	+0.01	
1.630	302.4	302.5	+0.019	+0.01	

Head at Gage, h1 feet	Discharge mgd	Equation Discharge mgd	Equation Error mgd	Equation Error %	Hydraulic Errors
1.640	305.5	305.5	+0.019	+0.01	
1.650	308.5	308.5	+0.019	+0.01	
1.660	311.5	311.5	+0.020	+0.01	
1.670	314.6	314.6	+0.020	+0.01	
1.680	317.6	317.6	+0.020	+0.01	
1.690	320.7	320.7	+0.021	+0.01	
1.700	323.8	323.8	+0.021	+0.01	
1.710	326.9	326.9	+0.021	+0.01	
1.720	330.0	330.0	+0.022	+0.01	
1.730	333.1	333.1	+0.022	+0.01	
1.740	336.2	336.2	+0.022	+0.01	
1.750	339.4	339.4	+0.022	+0.01	
1.760	342.5	342.5	+0.023	+0.01	
1.770	345.7	345.7	+0.023	+0.01	
1.780	348.9	348.9	+0.023	+0.01	
1.790	352.0	352.1	+0.023	+0.01	
1.800	355.2	355.3	+0.023	+0.01	
1.810	358.5	358.5	+0.023	+0.01	
1.820	361.7	361.7	+0.023	+0.01	
1.830	364.9	364.9	+0.023	+0.01	
1.840	368.2	368.2	+0.023	+0.01	
1.850	371.4	371.4	+0.023	+0.01	
1.860	374.7	374.7	+0.023	+0.01	
1.870	378.0	378.0	+0.023	+0.01	
1.880	381.2	381.3	+0.023	+0.01	
1.890	384.5	384.6	+0.023	+0.01	
1.900	387.9	387.9	+0.023	+0.01	
1.910	391.2	391.2	+0.023	+0.01	
1.920	394.5	394.5	+0.023	+0.01	
1.930	397.9	397.9	+0.023	+0.01	
1.940	401.2	401.2	+0.023	+0.01	
1.950	404.6	404.6	+0.022	+0.01	
1.960	408.0	408.0	+0.022	+0.01	
1.970	411.4	411.4	+0.022	+0.01	
1.980	414.8	414.8	+0.021	+0.01	
1.990	418.2	418.2	+0.010	0.00	
2.000	421.6	421.6	+0.010	0.00	
2.010	425.0	425.0	+0.010	0.00	
2.020	428.5	428.5	+0.010	0.00	
2.030	431.9	431.9	+0.010	0.00	
2.040	435.4	435.4	+0.009	0.00	
2.050	438.9	438.9	+0.017	0.00	
2.060	442.4	442.4	+0.017	0.00	
2.070	445.9	445.9	+0.016	0.00	
2.080	449.4	449.4	+0.016	0.00	
2.090	452.9	452.9	+0.015	0.00	

Head at Gage, h1 feet	Discharge mgd	Equation Discharge mgd	Equation Error mgd	Equation Error %	Hydraulic Errors
2.100	456.4	456.4	+0.015	0.00	
2.110	460.0	460.0	+0.014	0.00	
2.120	463.5	463.5	+0.014	0.00	
2.130	467.1	467.1	+0.014	0.00	
2.140	470.7	470.7	+0.013	0.00	
2.150	474.2	474.3	+0.012	0.00	
2.160	477.8	477.9	+0.012	0.00	
2.170	481.5	481.5	+0.011	0.00	
2.180	485.1	485.1	+0.010	0.00	
2.190	488.7	488.7	+0.010	0.00	
2.200	492.3	492.3	+0.009	0.00	
2.210	496.0	496.0	+0.008	0.00	
2.220	499.7	499.7	+0.008	0.00	
2.230	503.3	503.3	+0.007	0.00	
2.240	507.0	507.0	+0.006	0.00	
2.250	510.7	510.7	+0.005	0.00	
2.260	514.4	514.4	+0.004	0.00	
2.270	518.1	518.1	+0.003	0.00	
2.280	521.8	521.8	+0.001	0.00	
2.290	525.6	525.6	0.000	0.00	
2.300	529.3	529.3	-0.001	0.00	
2.310	533.1	533.1	-0.002	0.00	
2.320	536.8	536.8	-0.003	0.00	
2.330	540.6	540.6	-0.004	0.00	
2.340	544.4	544.4	-0.005	0.00	
2.350	548.2	548.2	-0.005	0.00	
2.360	552.0	552.0	-0.006	0.00	
2.370	555.8	555.8	-0.007	0.00	
2.380	559.7	559.7	-0.012	0.00	
2.390	563.5	563.5	-0.009	0.00	
2.400	567.4	567.3	-0.010	0.00	
2.410	571.2	571.2	-0.010	0.00	
2.420	575.1	575.1	-0.011	0.00	
2.430	579.0	579.0	-0.014	0.00	
2.440	582.9	582.8	-0.015	0.00	
2.450	586.8	586.7	-0.016	0.00	
2.460	590.7	590.7	-0.017	0.00	
2.470	594.6	594.6	-0.018	0.00	
2.480	598.5	598.5	-0.019	0.00	
2.490	602.5	602.4	-0.020	0.00	
2.500	606.4	606.4	-0.021	0.00	
2.510	610.4	610.4	-0.023	0.00	
2.520	614.4	614.3	-0.024	0.00	
2.530	618.3	618.3	-0.025	0.00	
2.540	622.3	622.3	-0.026	0.00	
2.550	626.3	626.3	-0.027	0.00	

Head at Gage, h1 feet	Discharge mgd	Equation Discharge mgd	Equation Error mgd	Equation Error %	Hydraulic Errors
2.560	630.3	630.3	-0.028	0.00	
2.570	634.4	634.3	-0.029	0.00	
2.580	638.4	638.4	-0.031	0.00	
2.590	642.4	642.4	-0.032	0.00	
2.600	646.5	646.5	-0.033	-0.01	
2.610	650.6	650.5	-0.034	-0.01	
2.620	654.6	654.6	-0.035	-0.01	
2.630	658.7	658.7	-0.036	-0.01	
2.640	662.8	662.8	-0.037	-0.01	
2.650	666.9	666.9	-0.038	-0.01	
2.660	671.0	671.0	-0.039	-0.01	
2.670	675.2	675.1	-0.040	-0.01	
2.680	679.3	679.2	-0.041	-0.01	
2.690	683.4	683.4	-0.043	-0.01	
2.700	687.6	687.5	-0.044	-0.01	
2.710	691.7	691.7	-0.045	-0.01	
2.720	695.9	695.9	-0.046	-0.01	
2.730	700.1	700.1	-0.049	-0.01	

Equation: Q = K1 * (h1 + K2) ^ U
Parameters: K1 = 131.009
K2 = 0.030
U = 1.651
Coefficient of determination: 0.99999999

Error Summary

No errors.

APPENDIX I

Spreadsheets for computation of backwater curves in long-throated flume approach channel

D:\NEWTOWN\FINALDES\DSTEP1 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	180
Q, cfs =	278.5205
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	0.83423
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4.5 ft upstream of start of ramp) to a distance 42.75 ft upstream (approx. tail of labyrinth weir).

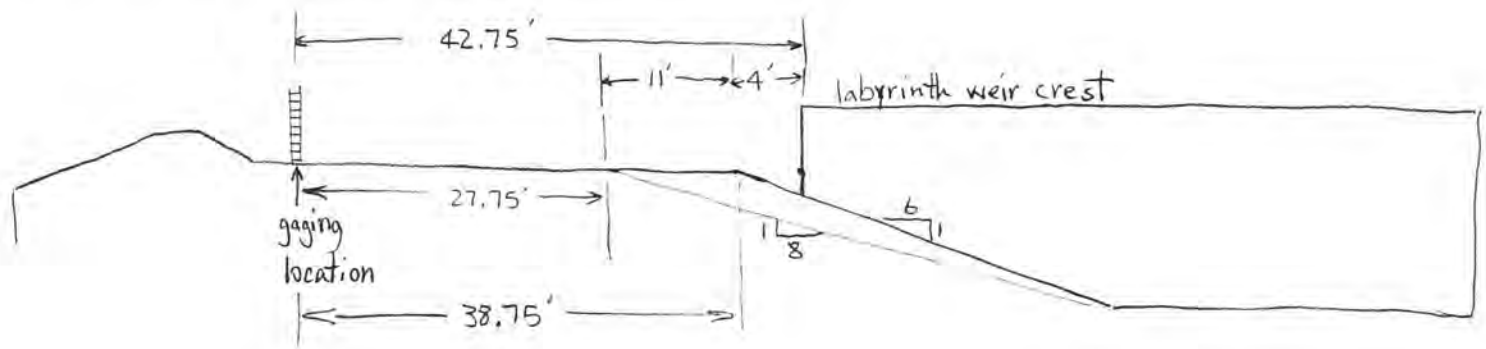
REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
1.932	124.4536	1.82	2.23	2.238	0.0778	2.0098		0.000172				0.0
1.933	124.5181	1.82	2.23	2.237	0.0777	2.0107	-0.0009	0.000172	0.000172	-0.00017	5.35	5.3
1.934	124.5825	1.82	2.23	2.236	0.0776	2.0116	-0.0009	0.000172	0.000172	-0.00017	5.36	10.7
1.935	124.6469	1.83	2.23	2.234	0.0775	2.0125	-0.0009	0.000171	0.000171	-0.00017	5.37	16.1
1.936	124.7113	1.83	2.23	2.233	0.0774	2.0134	-0.0009	0.000171	0.000171	-0.00017	5.37	21.4
1.937	124.7757	1.83	2.23	2.232	0.0774	2.0144	-0.0009	0.000171	0.000171	-0.00017	5.38	26.8
1.938	124.8401	1.83	2.24	2.231	0.0773	2.0153	-0.0009	0.00017	0.000171	-0.00017	5.39	32.2
1.939	124.9046	1.83	2.24	2.230	0.0772	2.0162	-0.0009	0.00017	0.00017	-0.00017	5.40	37.6
1.94	124.969	1.83	2.24	2.229	0.0771	2.0171	-0.0009	0.00017	0.00017	-0.00017	5.41	43.0

end of 6:1 slope out of labyrinth exit troughs

end of 8:1 slope



D:\NEWTOWN\FINALDES\DSTEP3 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	310
Q, cfs =	479.6742
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	1.198612
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4.5 ft upstream of start of ramp) to a distance 42.75 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
2.405	154.9229	2.24	2.93	3.096	0.1489	2.5539		0.000251				0.0
2.406	154.9873	2.24	2.93	3.095	0.1487	2.5547	-0.0009	0.00025	0.00025	-0.00025	3.50	3.5
2.407	155.0517	2.24	2.93	3.094	0.1486	2.5556	-0.0009	0.00025	0.00025	-0.00025	3.50	7.0
2.408	155.1161	2.24	2.93	3.092	0.1485	2.5565	-0.0009	0.00025	0.00025	-0.00025	3.51	10.5
2.409	155.1806	2.24	2.93	3.091	0.1484	2.5574	-0.0009	0.000249	0.000249	-0.00025	3.51	14.0
2.41	155.245	2.24	2.93	3.090	0.1482	2.5582	-0.0009	0.000249	0.000249	-0.00025	3.52	17.5
2.411	155.3094	2.24	2.94	3.089	0.1481	2.5591	-0.0009	0.000249	0.000249	-0.00025	3.53	21.1
2.412	155.3738	2.24	2.94	3.087	0.1480	2.5600	-0.0009	0.000248	0.000248	-0.00025	3.53	24.6
2.413	155.4382	2.24	2.94	3.086	0.1479	2.5609	-0.0009	0.000248	0.000248	-0.00025	3.54	28.1
2.414	155.5026	2.25	2.94	3.085	0.1478	2.5618	-0.0009	0.000248	0.000248	-0.00025	3.54	31.7
2.415	155.5671	2.25	2.94	3.083	0.1476	2.5626	-0.0009	0.000247	0.000247	-0.00025	3.55	35.2
2.416	155.6315	2.25	2.94	3.082	0.1475	2.5635	-0.0009	0.000247	0.000247	-0.00025	3.55	38.8
2.417	155.6959	2.25	2.95	3.081	0.1474	2.5644	-0.0009	0.000247	0.000247	-0.00025	3.56	42.3

D:\NEWTOWN\FINALDES\DSTEP4 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	465
Q, cfs =	719.5113
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	1.570626
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4.5 ft upstream of start of ramp) to a distance 42.75 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
2.874	185.1345	2.64	3.65	3.886	0.2345	3.1085		0.000317				0.0
2.875	185.1989	2.64	3.65	3.885	0.2344	3.1094	-0.0008	0.000317	0.000317	-0.00032	2.64	2.6
2.876	185.2633	2.64	3.65	3.884	0.2342	3.1102	-0.0008	0.000316	0.000317	-0.00032	2.64	5.3
2.877	185.3277	2.64	3.65	3.882	0.2340	3.1110	-0.0008	0.000316	0.000316	-0.00032	2.65	7.9
2.878	185.3921	2.64	3.65	3.881	0.2339	3.1119	-0.0008	0.000316	0.000316	-0.00032	2.65	10.6
2.879	185.4565	2.64	3.65	3.880	0.2337	3.1127	-0.0008	0.000315	0.000315	-0.00032	2.66	13.2
2.88	185.521	2.64	3.66	3.878	0.2336	3.1136	-0.0008	0.000315	0.000315	-0.00032	2.66	15.9
2.881	185.5854	2.64	3.66	3.877	0.2334	3.1144	-0.0008	0.000315	0.000315	-0.00031	2.66	18.6
2.882	185.6498	2.65	3.66	3.876	0.2332	3.1152	-0.0008	0.000314	0.000314	-0.00031	2.67	21.2
2.883	185.7142	2.65	3.66	3.874	0.2331	3.1161	-0.0008	0.000314	0.000314	-0.00031	2.67	23.9
2.884	185.7786	2.65	3.66	3.873	0.2329	3.1169	-0.0008	0.000314	0.000314	-0.00031	2.67	26.6
2.885	185.843	2.65	3.66	3.872	0.2328	3.1178	-0.0008	0.000313	0.000313	-0.00031	2.68	29.2
2.886	185.9075	2.65	3.66	3.870	0.2326	3.1186	-0.0008	0.000313	0.000313	-0.00031	2.68	31.9
2.887	185.9719	2.65	3.67	3.869	0.2324	3.1194	-0.0008	0.000312	0.000313	-0.00031	2.68	34.6
2.888	186.0363	2.65	3.67	3.868	0.2323	3.1203	-0.0008	0.000312	0.000312	-0.00031	2.69	37.3
2.889	186.1007	2.65	3.67	3.866	0.2321	3.1211	-0.0008	0.000312	0.000312	-0.00031	2.69	40.0
2.89	186.1651	2.65	3.67	3.865	0.2319	3.1219	-0.0008	0.000311	0.000312	-0.00031	2.69	42.7

D:\NEWTOWN\FINALDES\DSTEP7 Direct Step Profiles for Trapezoidal Channels

Q, mgd =	700
Q, cfs =	1083.135
n =	0.013
Sbed =	0
alpha =	1
Ycritical =	2.063017
Ynormal =	
b =	64.417
Z =	0
Increment	0.001

Direct step backwater curve from flume gage location (4.5 ft upstream of start of ramp) to a distance 42.75 ft upstream (approx. tail of labyrinth weir).

REFERENCE: Chow, 1959, Open Channel Flow, pg. 263

Delta x = Delta E / (Sbed - Sf)

Initial depth is the head upstream of the ramp flume plus sill height (1 ft)

y	A	R	R^4/3	V	alpha*V^2/2g	E	Delta E	Sf	Sfavg	Sbed-Sfavg	Delta x	x
3.48	224.1712	3.14	4.60	4.832	0.3625	3.8425		0.000388				0.0
3.481	224.2356	3.14	4.60	4.830	0.3623	3.8433	-0.0008	0.000388	0.000388	-0.00039	2.04	2.0
3.482	224.3	3.14	4.60	4.829	0.3621	3.8441	-0.0008	0.000388	0.000388	-0.00039	2.04	4.1
3.483	224.3644	3.14	4.60	4.828	0.3619	3.8449	-0.0008	0.000387	0.000388	-0.00039	2.04	6.1
3.484	224.4288	3.14	4.61	4.826	0.3617	3.8457	-0.0008	0.000387	0.000387	-0.00039	2.05	8.2
3.485	224.4932	3.14	4.61	4.825	0.3615	3.8465	-0.0008	0.000387	0.000387	-0.00039	2.05	10.2
3.486	224.5577	3.15	4.61	4.823	0.3613	3.8473	-0.0008	0.000386	0.000387	-0.00039	2.05	12.3
3.487	224.6221	3.15	4.61	4.822	0.3611	3.8481	-0.0008	0.000386	0.000386	-0.00039	2.05	14.3
3.488	224.6865	3.15	4.61	4.821	0.3608	3.8488	-0.0008	0.000386	0.000386	-0.00039	2.06	16.4
3.489	224.7509	3.15	4.61	4.819	0.3606	3.8496	-0.0008	0.000385	0.000385	-0.00039	2.06	18.4
3.49	224.8153	3.15	4.62	4.818	0.3604	3.8504	-0.0008	0.000385	0.000385	-0.00039	2.06	20.5
3.491	224.8797	3.15	4.62	4.817	0.3602	3.8512	-0.0008	0.000385	0.000385	-0.00038	2.06	22.6
3.492	224.9442	3.15	4.62	4.815	0.3600	3.8520	-0.0008	0.000384	0.000384	-0.00038	2.06	24.6
3.493	225.0086	3.15	4.62	4.814	0.3598	3.8528	-0.0008	0.000384	0.000384	-0.00038	2.07	26.7
3.494	225.073	3.15	4.62	4.812	0.3596	3.8536	-0.0008	0.000384	0.000384	-0.00038	2.07	28.8
3.495	225.1374	3.15	4.62	4.811	0.3594	3.8544	-0.0008	0.000383	0.000383	-0.00038	2.07	30.8
3.496	225.2018	3.15	4.62	4.810	0.3592	3.8552	-0.0008	0.000383	0.000383	-0.00038	2.07	32.9
3.497	225.2662	3.15	4.63	4.808	0.3590	3.8560	-0.0008	0.000382	0.000383	-0.00038	2.08	35.0
3.498	225.3307	3.16	4.63	4.807	0.3588	3.8568	-0.0008	0.000382	0.000382	-0.00038	2.08	37.1
3.499	225.3951	3.16	4.63	4.805	0.3586	3.8576	-0.0008	0.000382	0.000382	-0.00038	2.08	39.1
3.5	225.4595	3.16	4.63	4.804	0.3584	3.8584	-0.0008	0.000381	0.000382	-0.00038	2.08	41.2
3.501	225.5239	3.16	4.63	4.803	0.3582	3.8592	-0.0008	0.000381	0.000381	-0.00038	2.09	43.3

APPENDIX J

Example spreadsheet for computation of backwater curves in labyrinth weir exit channels

D:\NEWTOWN\FINALDES\TROUGH36.WK4

Gradually varied flow in the rectangular exit troughs of varying width...and depth, with 6:1 floor slope
Floor elevation at 0.00 in upstream half (first 29 ft), then rises on 6:1 slope to elev. 5.50

Bed slope So	-0.16667	ft/ft	
Manning's n	0.013		
Gravity	32.2	ft/s^2	
Q	361.05	cfs	233.33 mgd
Length	58	ft	
Inflow per unit length	6.225	cfs/ft	

Analysis of spatially varied flow in conveyance channel downstream of labyrinth weir

Starting WSE	8.999		
Starting invert elevation	5.5		
Upstream Depth	9.842	Max. Convergence Error	0
Upstream WSE	9.842		

x	Q	Invert	WSE	Assumed Depth, y	Width	Area, A	WP	TW	Hyd Depth	Velocity, V	Froude	Sf	Velocity Head Term, ft	Momentum Flux Term, ft	Bed Slope	Friction & Bed Slope Term, ft	Computed Depth, y	Err
First section is for the sloped-floor section downstream of the labyrinth. Q is constant in this reach, and channel is not subdivided into 3 sections by the labyrinth; adjust wetted perimeter accordingly																		
-4	361	5.500	8.999	3.499	21.472	75.132	23.805	21.472	3.499	4.805	0.453	0.000382						
-3	361	5.333	9.038	3.705	21.472	79.549	23.942	21.472	3.705	4.539	0.416	0.000318	0.039	0.000	-0.167	0.167	3.705	0.00E+00
-2	361	5.167	9.070	3.903	21.472	83.816	24.075	21.472	3.903	4.308	0.384	0.000269	0.032	0.000	-0.167	0.167	3.903	0.00E+00
-1	361	5.000	9.097	4.097	21.472	87.970	24.204	21.472	4.097	4.104	0.357	0.000231	0.027	0.000	-0.167	0.167	4.097	0.00E+00
0	361	4.833	9.120	4.286	21.472	92.039	24.330	21.472	4.286	3.923	0.334	0.0002	0.023	0.000	-0.167	0.167	4.286	0.00E+00
Remainder of table is for the labyrinth collector trough portion, in which discharge varies; floor continues to slope down to elev. 0.00																		
Also, must account for loss of the change in velocity head at this transition, which will not be recovered. Force water levels at X=0 to match.																		
0	361.0	4.833	9.120	4.286	17.081	73.216	25.654	17.081	4.286	4.931	0.420	0.00046						
0.58	357.4	4.737	9.150	4.413	16.930	74.711	25.756	16.930	4.413	4.784	0.401	0.000423	0.026	0.004	-0.167	0.097	4.413	0.00E+00
1.16	353.8	4.640	9.177	4.537	16.779	76.124	25.853	16.779	4.537	4.648	0.385	0.000392	0.023	0.004	-0.167	0.097	4.537	0.00E+00
1.74	350.2	4.543	9.202	4.658	16.629	77.463	25.945	16.629	4.658	4.521	0.369	0.000364	0.021	0.003	-0.167	0.097	4.658	0.00E+00
2.32	346.6	4.447	9.225	4.778	16.478	78.733	26.034	16.478	4.778	4.402	0.355	0.000339	0.020	0.003	-0.167	0.097	4.778	0.00E+00
2.9	343.0	4.350	9.246	4.896	16.327	79.940	26.119	16.327	4.896	4.291	0.342	0.000317	0.018	0.003	-0.167	0.097	4.896	0.00E+00
3.48	339.4	4.253	9.266	5.013	16.176	81.088	26.202	16.176	5.013	4.185	0.329	0.000297	0.017	0.003	-0.167	0.097	5.013	0.00E+00
4.06	335.8	4.157	9.285	5.128	16.025	82.180	26.282	16.025	5.128	4.086	0.318	0.000279	0.016	0.003	-0.167	0.097	5.128	0.00E+00
4.64	332.2	4.060	9.302	5.242	15.875	83.218	26.359	15.875	5.242	3.991	0.307	0.000263	0.015	0.003	-0.167	0.097	5.242	0.00E+00
5.22	328.6	3.963	9.319	5.355	15.724	84.206	26.434	15.724	5.355	3.902	0.297	0.000249	0.014	0.003	-0.167	0.097	5.355	0.00E+00
5.8	324.9	3.867	9.334	5.467	15.573	85.145	26.508	15.573	5.467	3.816	0.288	0.000235	0.013	0.003	-0.167	0.097	5.467	0.00E+00
6.38	321.3	3.770	9.349	5.579	15.422	86.037	26.580	15.422	5.579	3.735	0.279	0.000223	0.012	0.002	-0.167	0.097	5.579	0.00E+00
6.96	317.7	3.673	9.363	5.689	15.271	86.883	26.650	15.271	5.689	3.657	0.270	0.000212	0.011	0.002	-0.167	0.097	5.689	0.00E+00
7.54	314.1	3.577	9.376	5.799	15.120	87.686	26.719	15.120	5.799	3.582	0.262	0.000201	0.011	0.002	-0.167	0.097	5.799	0.00E+00
8.12	310.5	3.480	9.388	5.908	14.970	88.446	26.786	14.970	5.908	3.511	0.255	0.000192	0.010	0.002	-0.167	0.097	5.908	0.00E+00
8.7	306.9	3.383	9.400	6.017	14.819	89.164	26.853	14.819	6.017	3.442	0.247	0.000183	0.010	0.002	-0.167	0.097	6.017	0.00E+00
9.28	303.3	3.287	9.412	6.125	14.668	89.841	26.918	14.668	6.125	3.376	0.240	0.000175	0.009	0.002	-0.167	0.097	6.125	0.00E+00
9.86	299.7	3.190	9.423	6.233	14.517	90.479	26.982	14.517	6.233	3.312	0.234	0.000167	0.009	0.002	-0.167	0.097	6.233	0.00E+00
10.4	296.1	3.093	9.433	6.340	14.366	91.077	27.046	14.366	6.340	3.251	0.228	0.00016	0.008	0.002	-0.167	0.097	6.340	0.00E+00
11	292.4	2.997	9.443	6.446	14.216	91.637	27.108	14.216	6.446	3.191	0.222	0.000154	0.008	0.002	-0.167	0.097	6.446	0.00E+00
11.6	288.8	2.900	9.452	6.552	14.065	92.159	27.170	14.065	6.552	3.134	0.216	0.000148	0.008	0.002	-0.167	0.097	6.552	0.00E+00
12.2	285.2	2.803	9.462	6.658	13.914	92.644	27.231	13.914	6.658	3.079	0.210	0.000142	0.007	0.002	-0.167	0.097	6.658	0.00E+00
12.8	281.6	2.707	9.471	6.764	13.763	93.092	27.291	13.763	6.764	3.025	0.205	0.000136	0.007	0.002	-0.167	0.097	6.764	0.00E+00
13.3	278.0	2.610	9.479	6.869	13.612	93.504	27.350	13.612	6.869	2.973	0.200	0.000131	0.007	0.002	-0.167	0.097	6.869	0.00E+00
13.9	274.4	2.513	9.487	6.974	13.462	93.880	27.409	13.462	6.974	2.923	0.195	0.000127	0.006	0.002	-0.167	0.097	6.974	0.00E+00
14.5	270.8	2.417	9.495	7.078	13.311	94.220	27.468	13.311	7.078	2.874	0.190	0.000122	0.006	0.002	-0.167	0.097	7.078	0.00E+00
15.1	267.2	2.320	9.503	7.183	13.160	94.525	27.526	13.160	7.183	2.826	0.186	0.000118	0.006	0.002	-0.167	0.097	7.183	0.00E+00
15.7	263.6	2.223	9.510	7.287	13.009	94.796	27.583	13.009	7.287	2.780	0.182	0.000114	0.006	0.002	-0.167	0.097	7.287	0.00E+00
16.2	260.0	2.127	9.517	7.391	12.858	95.032	27.640	12.858	7.391	2.735	0.177	0.00011	0.005	0.002	-0.167	0.097	7.391	0.00E+00
16.8	256.3	2.030	9.524	7.494	12.708	95.234	27.696	12.708	7.494	2.692	0.173	0.000107	0.005	0.002	-0.167	0.097	7.494	0.00E+00
17.4	252.7	1.933	9.531	7.598	12.557	95.403	27.752	12.557	7.598	2.649	0.169	0.000104	0.005	0.002	-0.167	0.097	7.598	0.00E+00
18	249.1	1.837	9.538	7.701	12.406	95.537	27.808	12.406	7.701	2.608	0.166	0.0001	0.005	0.002	-0.167	0.097	7.701	0.00E+00
18.6	245.5	1.740	9.544	7.804	12.255	95.638	27.863	12.255	7.804	2.567	0.162	0.000097	0.005	0.002	-0.167	0.097	7.804	0.00E+00
19.1	241.9	1.643	9.550	7.907	12.104	95.706	27.918	12.104	7.907	2.528	0.158	0.000095	0.005	0.001	-0.167	0.097	7.907	0.00E+00
19.7	238.3	1.547	9.556	8.009	11.953	95.741	27.972	11.953	8.009	2.489	0.155	0.000092	0.004	0.001	-0.167	0.097	8.009	0.00E+00
20.3	234.7	1.450	9.562	8.112	11.803	95.743	28.027	11.803	8.112	2.451	0.152	0.000089	0.004	0.001	-0.167	0.097	8.112	0.00E+00
20.9	231.1	1.353	9.568	8.214	11.652	95.712	28.080	11.652	8.214	2.414	0.148	0.000087	0.004	0.001	-0.167	0.097	8.214	0.00E+00
21.5	227.5	1.257	9.573	8.317	11.501	95.649	28.134	11.501	8.317	2.378	0.145	0.000085	0.004	0.001	-0.167	0.097	8.317	0.00E+00
22	223.8	1.160	9.579	8.419	11.350	95.553	28.187	11.350	8.419	2.343	0.142	0.000082	0.004	0.001	-0.167	0.097	8.419	0.00E+00
22.6	220.2	1.063	9.584	8.521	11.199	95.425	28.241	11.199	8.521	2.308	0.139	0.00008	0.004	0.001	-0.167	0.097	8.521	0.00E+00
23.2	216.6	0.967	9.589	8.622	11.049	95.265	28.293	11.049	8.622	2.274	0.136	0.000078	0.004	0.001	-0.167	0.097	8.622	0.00E+00
23.8	213.0	0.870	9.594	8.724	10.898	95.074	28.346	10.898	8.724	2.241	0.134	0.000077	0.004	0.001	-0.167	0.097	8.724	0.00E+00
24.4	209.4	0.773	9.599	8.826	10.747	94.850	28.398	10.747	8.826	2.208	0.131	0.000075	0.004	0.001	-0.167	0.097	8.826	0.00E+00
24.9	205.8	0.677	9.604	8.927	10.596	94.594	28.451	10.596	8.927	2.176	0.128	0.000073	0.003	0.001	-0.167	0.097	8.927	0.00E+00
25.5	202.2	0.580	9.609	9.029	10.445	94.307	28.503	10.445	9.029	2.144	0.126	0.000071	0.003	0.001	-0.167	0.097	9.029	0.00E+00
26.1	198.6	0.483	9.613	9.130	10.295	93.988	28.554	10.295	9.130	2.113	0.123	0.00007	0.003	0.001	-0.167	0.097	9.130	0.00E+00
26.7	195.0	0.387	9.618	9.231	10.144	93.638	28.606	10.144	9.231	2.082	0.121	0.000068	0.003	0.001	-0.167	0.097	9.231	0.00E+00
27.3	191.4	0.290	9.622	9.332	9.993	93.256	28.657	9.993	9.332	2.052	0.118	0.000067	0.003	0.001	-0.167	0.097	9.332	0.00E+00
27.8	187.7	0.193	9.627	9.433	9.842	92.843	28.709	9.842	9.433	2.022	0.116	0.000065	0.003	0.001	-0.167	0.097	9.433	0.00E+00
28.4	184.1	0.097	9.631	9.534	9.691	92.399	28.760	9.691	9.534	1.993	0.114	0.000064	0.003	0.001	-0.167	0.097	9.534	0.00E+00
29	180.5	0.000	9.635	9.635	9.541	91.924	28.811	9.541	9.635	1.964	0.111	0.000063	0.003	0.001	-0.167	0.097	9.635	0.00E+00
Remaining portion has a constant channel invert elevation of 0.00 ft																		
29.6	176.9	0.000	9.638	9.638	9.390	90.499	28.666	9.390	9.638	1.955	0.111	0.000063	0.002	0.001	0.000	0.000	9.638	0.00E+00
30.2	173.3	0.000	9.641	9.641	9.239	89.074	28.521	9.239	9.641	1.946	0.110	0.000063	0.002	0.001	0.000	0.000	9.641	0.00E+00
30.7	169.7	0.000	9.644	9.644	9.088	87.647	28.377	9.088	9.644	1.936	0.110	0.000064	0.002	0.001	0.000	0.000	9.644	0.00E+00
31.3	166.1	0.000	9.647	9.647	8.937	86.221	28.232	8.937	9.647	1.926	0.109	0.000064	0.002	0.001	0.000	0.000	9.647	0.00E+00
31.9	162.5	0.000	9.651	9.651	8.786	84.794	28.087	8.786	9.651	1.916	0.109	0.000064	0.002	0.001	0.000	0.000	9.651	0.00E+00
32.5	158.9	0.000	9.654	9.654	8.636	83.366	27.943	8.636	9.654	1.906	0.108	0.000065	0.002	0.001	0.000	0.000	9.654	0.00E+00
33.1	155.2	0.000	9.657	9.657	8.485	81.938	27.799	8.485	9.657	1.895	0.107	0.000065	0.002	0.001	0.000	0.000	9.657	0.00E+00
33.6	151.6	0.000	9.660	9.660	8.334	80.509	27.655	8.334	9.660	1.884	0.107	0.000065	0.002	0.001	0.000	0.000	9.660	0.00E+00
34.2	148.0	0.000	9.664	9.664	8.183	79.080	27.510	8.183	9.664	1.872	0.106	0.000066	0.002	0.001	0.000	0.000	9.664	0.00E+00
34.8	144.4	0.000	9.667	9.667	8.032	77.650	27.366	8.032	9.667	1.860	0.105	0.000066	0.002	0.001	0.000	0.000	9.667	0.00E+00
35.4	140.8	0.000	9.670	9.670	7.882	76.219	27.223	7.882	9.670	1.847	0.105	0.000066	0.002	0.001	0.000	0.000	9.670	0.00E+00
36	137.2	0.000	9.674	9.674	7.731	74.788	27.079	7.731	9.674	1.834	0.104	0.000066	0.002	0.001	0.000	0.000	9.674	0.00E+00
36.5	133.6	0.000	9.678	9.678	7.580	73.356	26.935	7.580	9.678	1.821	0.103	0.000067	0.002	0.001	0.000	0.000	9.678	0.00E+00
37.1	130.0	0.000	9.681	9.681	7.429	71.923	26.792	7.429	9.681	1.807	0.102	0.000067	0.002	0.001	0.000	0.000	9.681	0.00E+00
37.7	126.4	0.000	9.685	9.685	7.278	70.490	26.648	7.278	9.685	1.793	0.102	0.000067	0.002	0.001	0.000	0.000	9.685	0.00E+00
38.3	122.8	0.000	9.689	9.689	7.128	69.056	26.505	7.128	9.689	1.778	0.101	0.000067	0.002	0.001	0.000	0.000	9.689	0.00E+00
38.9	119.1	0.000	9.692	9.692	6.977	67.621	26.362	6.977	9.692	1.762	0.100	0.000068	0.002	0.001	0.000	0.000	9.692	0.00E+00
39.4	115.5	0.000	9.696	9.696	6.826	66.186	26.219	6.826	9.696	1.745	0.099	0.000068	0.002	0.001	0.000	0.000	9.696	0.00E+00
40	111.9	0.000	9.700	9.700	6.675	64.750	26.076	6.675	9.700	1.729	0.098	0.000068	0.002	0.001	0.000	0.000	9.700	0.00E+00
40.6	108.3	0.000	9.704	9.704	6.524	63.313	25.933	6.524	9.704	1.711	0.097	0.000068	0.002	0.002	0.000	0.000	9.704	0.00E+00
41.2	104.7	0.000	9.708	9.708	6.373	61.876	25.790	6.373	9.708	1.692	0.096	0.000068	0.003	0.002	0.000	0.000	9.708	0.00E+00
41.8	101.1	0.000	9.712	9.712	6.223	60.437	25.648	6.223	9.712	1.673	0.095	0.000068	0.003	0.002	0.000	0.000	9.712	0.00E+00
42.3	97.5	0.000	9.717	9.717	6.072	58.998	25.505	6.072	9.717	1.652	0.093	0.000068	0.003	0.002	0.000	0.000	9.717	0.00E+00
42.9	93.9	0.000	9.721	9.721	5.921	57.558	25.363	5.921	9.721	1.631	0.092	0.000068	0.003	0.002	0.000	0.000	9.721	0.00E+00
43.5	90.3	0.000	9.725	9.725	5.770	56.117	25.221	5.770	9.725	1.608	0.091	0.000068	0.003	0.002	0.000	0.000	9.725	0.00E+00
44.1	86.7	0.000	9.730	9.730	5.619	54.676	25.079	5.619	9.730	1.585	0.090	0.000068	0.003	0.002	0.000	0.000	9.730	0.00E+00
44.7	83.0	0.000	9.734	9.734	5.469	53.233	24.937	5.469	9.734	1.560	0.088	0.000068	0.003	0.002	0.000	0.000	9.734	0.00E+00
45.2	79.4	0.000	9.739	9.739	5.318	51.790	24.796	5.318	9.739	1.534	0.087	0.000067	0.003	0.002	0.000	0.000	9.739	0.00E+00
45.8	75.8	0.000	9.744	9.744	5.167	50.345	24.654	5.167	9.744	1.506	0.085	0.000067	0.003	0.002	0.000	0.000	9.744	0.00E+00
46.4	72.2	0.000	9.748	9.748	5.016	48.900	24.513	5.016	9.748	1.477	0.083	0.000066	0.003	0.002	0.000	0.000	9.748	0.00E+00
47	68.6	0.000	9.753	9.753	4.865	47.453	24.372	4.865	9.753	1.446	0.082	0.000066	0.003	0.002	0.000	0.000	9.753	0.00E+00
47.6	65.0	0.000	9.758	9.758	4.715	46.005	24.231	4.715	9.758	1.413	0.080	0.000065	0.003	0.002	0.000	0.000	9.758	0.00E+00
48.1	61.4	0.000	9.763	9.763	4.564	44.557	24.090	4.564	9.763	1.378	0.078	0.000064	0.003	0.002	0.000	0.000	9.763	0.00E+00
48.7	57.8	0.000	9.768	9.768	4.413	43.107	23.949	4.413	9.768	1.340	0.076	0.000063	0.003	0.002	0.000	0.000	9.768	0.00E+00
49.3	54.2	0.000	9.773	9.773	4.262	41.656	23.809	4.262	9.773	1.300	0.073	0.000061	0.003	0.002	0.000	0.000	9.773	0.00E+00
49.9	50.5	0.000	9.779	9.779	4.111	40.203	23.669	4.111	9.779	1.257	0.071	0.00006	0.003	0.002	0.000	0.000	9.779	0.00E+00
50.5	46.9	0.000	9.784	9.784	3.961	38.749	23.528	3.961	9.784	1.211	0.068	0.000058	0.004	0.002	0.000	0.000	9.784	0.00E+00
51	43.3	0.000	9.789	9.789	3.810	37.294	23.388	3.810	9.789	1.162	0.065	0.000055	0.004	0.002	0.000	0.000	9.789	0.00E+00
51.6	39.7	0.000	9.795	9.795	3.659	35.838	23.248	3.659	9.795	1.108	0.062	0.000053	0.004	0.002	0.000	0.000	9.795	0.00E+00
52.2	36.1	0.000	9.800	9.800	3.508	34.380	23.108	3.508	9.800	1.050	0.059	0.00005	0.004	0.002	0.000	0.000	9.800	0.00E+00
52.8	32.5	0.000	9.805	9.805	3.357	32.920	22.968	3.357	9.805	0.987	0.056	0.000046	0.004	0.002	0.000	0.000	9.805	0.00E+00
53.4	28.9	0.000	9.811	9.811	3.206	31.458	22.828	3.206	9.811	0.918	0.052	0.000042	0.004	0.002	0.000	0.000	9.811	0.00E+00
53.9	25.3	0.000	9.816	9.816	3.056	29.995	22.688	3.056	9.816	0.843	0.047	0.000037	0.004	0.002	0.000	0.000	9.816	0.00E+00
54.5	21.7	0.000	9.821	9.821	2.905	28.530	22.548	2.905	9.821	0.759	0.043	0.000032	0.004	0.002	0.000	0.000	9.821	0.00E+00
55.1	18.1	0.000	9.826	9.826	2.754	27.062	22.407	2.754	9.826	0.667	0.038	0.000026	0.003	0.001	0.000	0.000	9.826	0.00E+00
55.7	14.4	0.000	9.831	9.831	2.603	25.592	22.265	2.603	9.831	0.564	0.032	0.00002	0.003	0.001	0.000	0.000	9.831	0.00E+00
56.3	10.8	0.000	9.835	9.835	2.452	24.120	22.122	2.452	9.835	0.449	0.025	0.000014	0.003	0.001	0.000	0.000	9.835	0.00E+00
56.8	7.2	0.000	9.838	9.838	2.302	22.644	21.978	2.302	9.838	0.319	0.018	7.5E-06	0.002	0.001	0.000	0.000	9.838	0.00E+00
57.4	3.6	0.000	9.841	9.841	2.151	21.166	21.832	2.151	9.841	0.171	0.010	2.3E-06	0.002	0.001	0.000	0.000	9.841	0.00E+00
58	0.0	0.000	9.842	9.842	2.000	19.683	21.683	2.000	9.842	0.000	0.000	0	0.001	0.000	0.000	0.000	9.842	0.00E+00