ATLAS OF FLOW COMPUTATIONS AT HYDRAULIC STRUCTURES IN THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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EXECUTIVE SUMMARY

The Flow Atlas report describes current flow computation procedures at the South Florida Water Management District (SFWMD or District) for hydraulic structures (e.g., spillways, pumps, culverts, and weirs). The Flow Atlas documents flow equations as well as all relevant physical and hydraulic parameters for each site.

Historically, most spillway flows were computed using equations developed by the U.S. Army Corps of Engineers (USACE) in the 1960s from reduced scale model testing of central and south Florida spillways (Grace, 1963). Depending on the head water stage, the tail water stage, and the gate openings, flows through gated spillways are classified into the following five categories:

- Controlled-free;
- Controlled-submerged;
- Uncontrolled-free;
- Uncontrolled-submerged; and
- Over-the-top flows.

Flow computations based on the USACE equations have resulted in large errors at some spillways when compared to field flow measurements. Using dimensional analysis, Ferro (2000), Ansar et al. (2002), and Chen et al. (2006a,b) proposed new flow equations for the first four categories of flow. The new flow equations improve flow computation and have been implemented at selected spillways. Ansar and Chen (2009) developed a generalized equation applicable to the first four flow categories and the transitional zones between them. This equation was successfully applied to selected spillways located in the upper Kissimmee Basin (Damisse and Ma, 2008). Additional modifications to the generalized equation were carried out by Gonzalez-Castro and Mohamed (2009).

For flow computation purposes, most spillways are classified as one of six cases. For Case 1 spillways, the flow rate is obtained from the USACE standard spillway equations with the discharge coefficient equal to a constant within each flow category. Case 2 is the same as Case 1 except that a variable discharge coefficient is used in at least one flow category. In Case 3, the flow rate is obtained from non-standardized equations developed primarily through regression analyses of flow measurements. Case 4 is the same as Case 1 but is reserved for one particular spillway that has different sill elevations for each gate. In Case 5, flow rates are computed using the category-specific equations that were developed through dimensional analysis. Case 6 flows are computed with the generalized flow equation. In addition to these six cases, special flow computational procedures are used at selected spillways where the standard equations for Cases 1 through 6 do not accurately characterize the discharges.

SFWMD pumping stations are categorized into eight cases. Cases 1 and 5 pertain to constant-speed pumps, where flow is computed using a polynomial fit to measured flows and static heads. In Case 5, provisions are made for the possibility of free or partially submerged discharge pipes. Cases 2 and 4 are composed of highly variable speed pumps, where flow is computed using a two-variable polynomial fit to measured flows, static heads, and engine speeds. Similarly, Case 3 includes variable-speed pumps whose flows are computed through interpolation between upper and lower discharge curves that are expressed as third-order polynomial functions of the static head. The weighting coefficient of this interpolation is a function of the pump engine speed. Case 6 was developed for the variable-speed pumps at G600I and ACME2, where flows are computed using a customized function of the static head and the pump engine speed. Case 7 flow equations apply only to pump stations S13 and S332D and are based on the pump affinity laws. Currently, they are only used at S332D. The Case 8 model is the most universally applicable and is based on hydraulic principles, dimensional analysis, and the pump affinity laws.

District weirs are classified into three primary types: ogee, trapezoidal, and variable crest. Free-flow weir equations are used to predict unsubmerged flows over these weir types while Villemonte's (1947) equation is used to account for submergence. At trapezoidal weirs, combinations of V-notch and rectangular weir flows are used to predict the discharge. At variable crest weirs, a distinction is made between sharp- and broad-crested weir flows based on the ratio of the head water depth above the sill and the crest width in the direction of the flow.

Culverts are categorized as simple or compound. Simple culverts generally are composed of standard box- and circular-gated culverts with no adjoining structures upstream of the barrels. Three primary types of flow occur in simple culverts: open channel flow, orifice flow, and full-barrel flow, depending on the relative values of headwater, tailwater, and gate opening. In the old culvert flow algorithm, orifice flow is classified as free orifice flow or full/part-full pipe flow. Additionally, full-barrel flows are categorized as having a submerged inlet or an unsubmerged inlet. Open channel flow is divided into inlet control, outlet control, and tailwater control flows, depending on whether critical depth occurs at the culvert inlet, outlet, or nowhere (i.e., flow is subcritical throughout the culvert). Flow equations are derived separately for each type of culvert flow based on the principles of mass and energy conservation.

In 2006, the District began improving its computation of flow through simple culverts by implementing new flow algorithms (Damisse and Fru, 2006) that classify flow into five types based on United States Geological Survey criteria (Bodhaine, 1968):

- Critical depth at the inlet;
- Critical depth at the outlet;
- Subcritical flow throughout;
- Full pipe flow; and
- Orifice flow.

When applied to District culverts, this new flow classification scheme takes into consideration the prevailing head water, tail water, and gate opening conditions. Damisse et al. (2009) identified a sixth flow type that is similar to the fifth type except that the culvert barrel flows full over only part of its length.

Compound culverts include a special inlet structure such as a weir or spillway installed at the upstream end of the barrel. Compound culverts include double-leaf culverts, weir-gate culverts, flashboard culverts, and weir-box culverts. Flow through these types of structures can be controlled by the inlet structure, the gate installed at the upstream end of the barrel, or the culvert barrel itself. In this report, flow equations for compound culverts developed by Gonzalez (2005) and Zeng et al. (2008) are presented along with their applications.

This report also discusses the limitations of the current NEXFLOW program and the need for further research. At gated spillways, improvement is needed in the computation of transitional flows, reverse flows, and tidal flows. At pump stations, issues that deserve further attention include pumping through multiple pipes into a common header, head losses due to flap gates, and pumping against a negative static head. At culverts, additional investigations into the computation of transitional and reverse flows are needed. At weirs, flow conditions requiring further study include the transition from free to submerged flows and the distinction between sharp- and broad-crested weir flow for all weir types.

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1.0 INTRODUCTION

The South Florida Water Management District (SFWMD or District) maintains and operates approximately 700 hydraulic structures, including spillways, pump stations, culverts, and weirs. Examples of District water control structures are displayed in **Appendix B**, and **Appendix C** provides typical design details for various types of structures. Using instantaneous stage and control information, instantaneous flow values at these structures are calculated using an in-house Java program called NEXFLOW. NEXFLOW was implemented in 2010 and supersedes its predecessor, the FLOW program, which written in Fortran Pro/E with embedded SQL scripts. Currently, NEXFLOW serves the following purposes:

- Computing flows through control structures;
- Verifying the validity of stream-gauging records using physically based equations;
- Calibrating discharge coefficients of the control structures under various flow conditions and structure operation;
- Testing and developing new and more robust computational algorithms for the purpose of improving existing flow records; and
- Performing quality assurance of existing data.

Discharges computed from the NEXFLOW program are used for water budget analyses, water quality analyses, flood studies, hydrologic modeling, and the design of new water management facilities.

In the first Flow Atlas, Otero (1995) described the FLOW program equations at gated spillways, pumps, culverts, and weirs. After a number of new structures were constructed within the District, Ansar and Alexis (2003) provided an updated atlas of the flow computation equations that were in use at the time. After the 2003 Flow Atlas was completed, additional structures were constructed and improvements to flow computations at spillways, culverts, and pumps continued. One of the key improvements to flow computations was the development of the NFLOW routines for computing flows through culvert structures (Damisse and Fru, 2006; Zeng et al., 2008). A more recent Flow Atlas by Wilsnack et al. (2010) discussed these changes and summarized the legacy information.

The present Flow Atlas is a compilation and exposition of the flow equations currently used to compute flow through all SFWMD structures. Most of the equations described herein are physically based, derived from the principles of fluid mechanics. A number of the equations, however, are empirical in nature, obtained from regression analyses. Additionally, this report tabulates the associated flow parameters for each structure. One new flow computation procedure introduced in this report pertains to Case 6 spillway flows. These flows are computed by a single equation that is applicable to all spillway flow regimes along with the transition regions between them. This flow rating model was first developed and introduced by Ansar and Chen (2009) and later enhanced by Gonzalez-Castro and Mohamed (2009).

Also discussed are the current limitations of the flow computational procedures along with possible improvements. Discussions of topics that require further research are provided as well.

2.0 SPILLWAYS

Symbol	Definition
a	Case 5 flow computation parameter
b	Case 5 flow computation parameter
A	Trunnion Height of the gate, above sill (ft)
c_1, c_2, c_3	Case 6 flow computation parameters
Cc	Contraction coefficient
Cd	Discharge coefficient
C_{dfw}	Dimensionless weir discharge coefficient
CFFC	Controlled-free flow coefficient
CSFC	Controlled-submerged flow coefficient
g	Gravitational acceleration (32.2 ft/s^2)
G_0	Gate opening (ft)
Goe	Effective gate opening (ft)
h	Tailwater depth above sill crest (ft)
h_d	Distance between the upstream energy grade line and the downstream stage (ft)
H	Headwater depth above sill crest (ft)
H_e	Total headwater energy with respect to the spillway crest (ft)
H_g	Headwater depth above the gate top (ft)
HW	Headwater stage (ft)
L	Gate width (ft)
OTFC	Over-the-top flow coefficient
Q	Flow rate (cfs)
SE	Sill Elevation (ft)
TW	Tailwater stage (ft)
UFFC	Uncontrolled-free flow coefficient
USFC	Uncontrolled-submerged flow coefficient
V	Velocity (ft/s)
Vc	Villemonte coefficient
y_c	Critical depth (ft)
y_s	Flow depth at spillway crest (ft)

2.1 Models and Equations for Flow Computation

2.1.1 Background

Flows through a gated spillway are divided into the following five flow regimes with transition zones between them: controlled-submerged, controlled-free, uncontrolled-submerged, uncontrolled-free, and over-the-top flows. Gated spillway flow equations based on discharge coefficients were developed for each flow regime by the U.S. Army Corps of Engineers (USACE) in a laboratory study of Central and Southern Florida spillways (Grace, 1963). Unfortunately, the flow equations sometimes produce erroneous results. To address this, Ferro (2000), Ansar et al. (2002), and Chen et al. (2006a,b) developed new flow equations for each flow condition based on dimensional analysis. The new flow equations can noticeably improve flow computation under certain flow conditions.

In order to facilitate the computation of transition flows and make the computation of the first four flow types more seamless, Ansar and Chen (2009) later developed a single flow equation that is applicable to all flow conditions. This model can greatly enhance the accuracy of flow computations when spillways operate within a transition zone between flow regimes. It has been successfully used to enhance the accuracy of hydraulic ratings for spillways located within the upper Kissimmee River basin (Damisse and Ma, 2008). The formulation of Ansar and Chen (2009) was later enhanced by Gonzalez-Castro and Mohamed (2009) to account for differences between the upstream spillway head and the flow depth at the spillway crest. The resultant model was successfully applied by Dessalegne (2011b) to spillway S-65A.

The flow computation procedures introduced above are discussed in the following subsections. Also discussed are their applications to District structures.

2.1.2 USACE Flow Equations

The USACE flow equations rely on discharge coefficients that reflect both theoretical and empirical factors. The model for each flow condition is explained in the following subsections.

2.1.2.1 Controlled Submerged Flow

In controlled submerged flow, the gate and the downstream pool restrict flow as shown in **Figure 1**. This flow condition is also known as submerged orifice flow. The associated flow equation with its restrictions is:

$$Q = C_d L G_o \sqrt{2g(H-h)}$$ *Equation 1*

Criteria: $\frac{H}{G_0} > 1.7$ and $\frac{h}{G_0} \geq 0.5$

where:

Q is the flow rate in cfs

C_d is the discharge coefficient (dimensionless)

G_0 is the gate opening in ft

H is the headwater depth above sill elevation in ft

h is the tailwater depth above sill elevation in ft

L is the gate width in ft

2.1.2.2 Controlled Free Flow

In controlled free flow, only the gate restricts flow, as shown in **Figure 2**. This flow condition is also known as free orifice flow. The flow equation and the restrictions on the flow in this case are:

$$Q = C_d L G_o \sqrt{2g(H - 0.5G_o)} \qquad \textit{Equation 2}$$

Criteria:

$$\frac{H}{G_o} > 1.7 \text{ and } \frac{h}{G_o} < 0.5$$

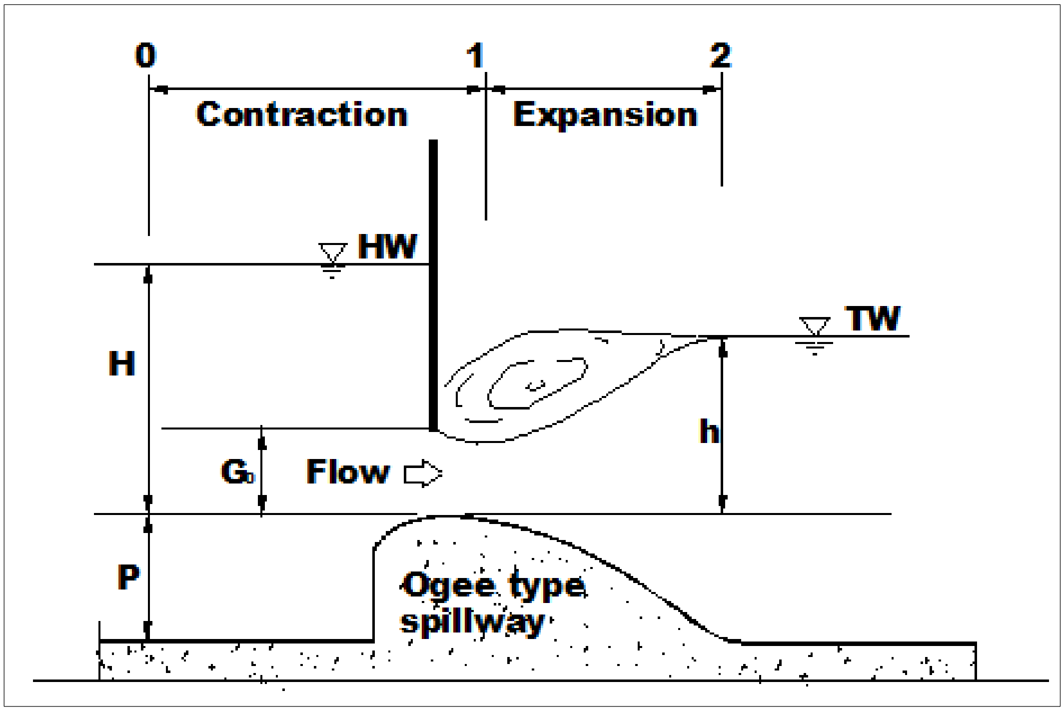


Figure 1. Controlled-submerged flow

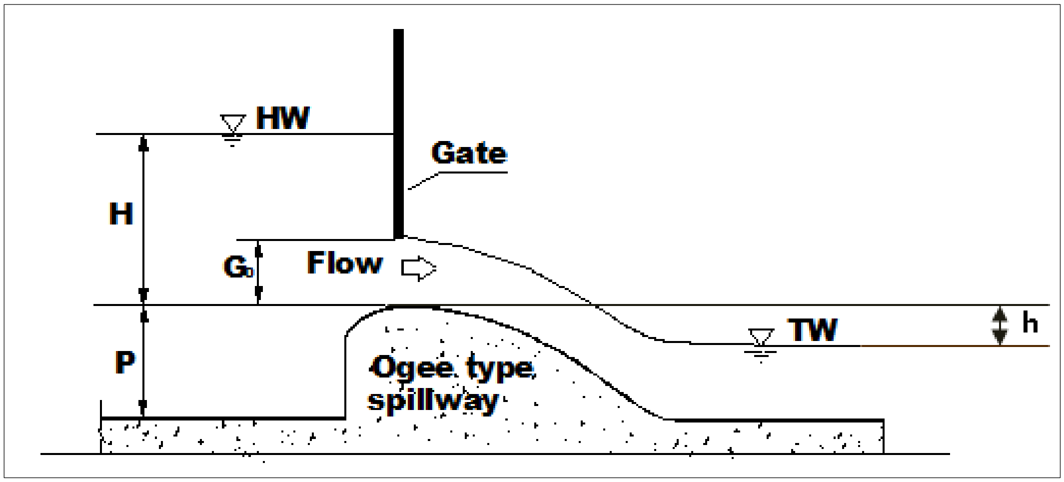


Figure 2. Controlled free flow

2.1.2.3 Uncontrolled Submerged Flow

In uncontrolled submerged flow, only the downstream pool restricts flow, as shown in **Figure 3**. This flow condition is also known as submerged weir flow. The flow equation and its restrictions are:

$$Q = C_d L h \sqrt{2g(H-h)} \qquad \textit{Equation 3}$$

Criteria: $\dfrac{H}{G_o} < 1.0$ and $\dfrac{h}{H} \geq 0.5$

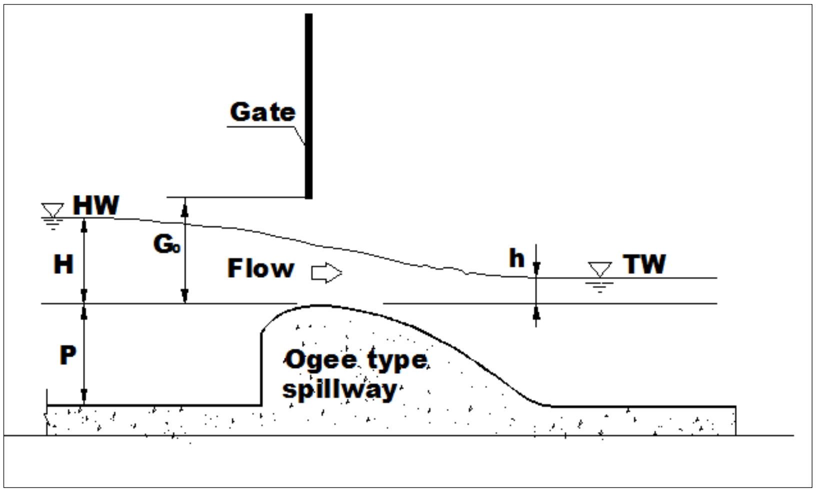


Figure 3. Uncontrolled-submerged flow

2.1.2.4 Uncontrolled Free Flow

In uncontrolled free flow neither the gate nor the downstream pool restricts flow, as shown in **Figure 4**. The flow equation and the restrictions on the flow in this case are:

$$Q = C_d L \sqrt{H^3} \qquad \textit{Equation 4}$$

Criteria: $\dfrac{H}{G_o} < 1.0$ and $\dfrac{h}{H} < 0.5$

If C_d in Equation 4 is taken as a dimensionless coefficient, the equation will be dimensionally inconsistent. C_d in Equation 4 is dimensional, and its relationship to the dimensionless coefficient can be derived from the free weir flow equation:

$$C_d = \frac{2}{3}\sqrt{2g}\ \mathrm{f}\ C_{\mathrm{dfw}} \qquad \textit{Equation 5}$$

where C_{dfw} is the dimensionless free weir discharge coefficient that varies with weir properties. The dimensionless constant *f* is equal to 1 for a sharp-crested weir while *f* is equal to 0.577 for a broad-crested weir. For uncontrolled free flow over an Ogee spillway, the value of C_{dfw} will vary with spillway height and upstream head (US Bureau of Reclamation [USBR], 1977).

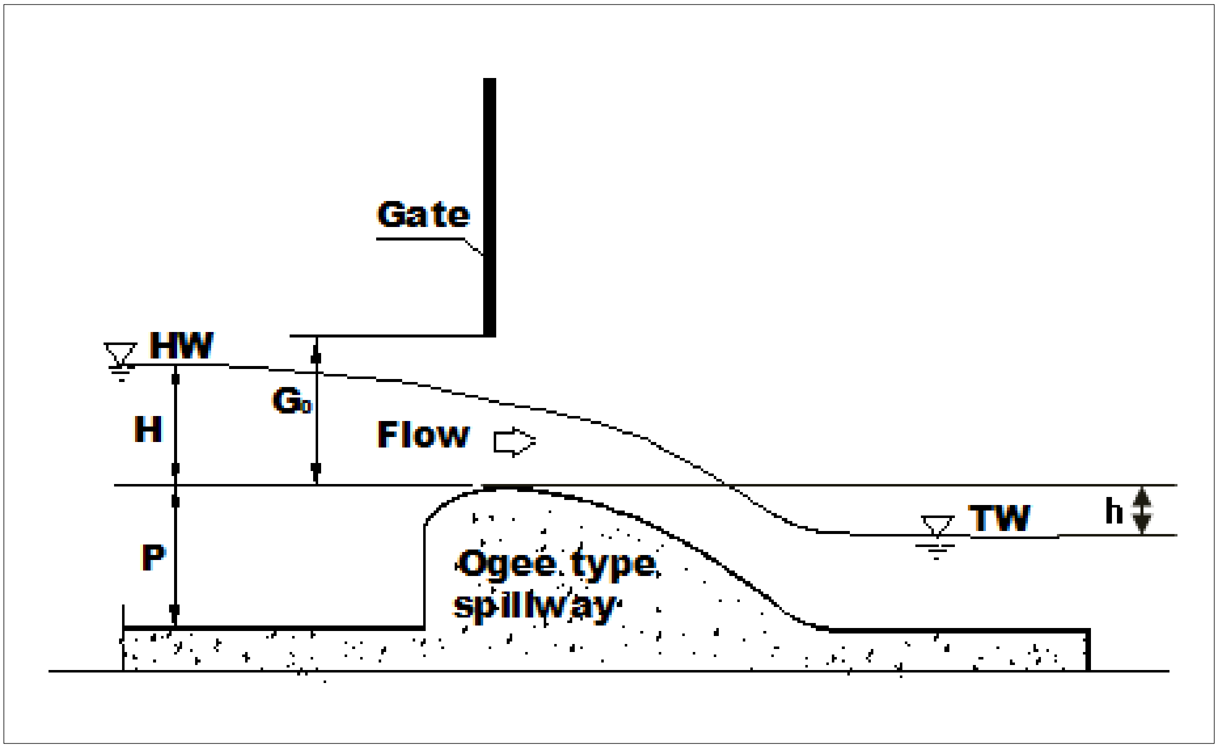


Figure 4. Uncontrolled-free flow

2.1.2.5 Transitional Flows

Sections 2.1.2.1 through **2.1.2.4** describe the four primary flow conditions at spillways. As indicated, there are instances where the flow is in a transition between controlled flow and uncontrolled flow. This transition zone is defined in the NEXFLOW program as a condition where H/G_0 is between 1.0 and 1.7, as indicated by the USACE criteria. When this situation occurs, the flow is taken as the minimum flow between the two flow conditions. **Table 1** provides a summary of the USACE flow equation for each primary flow condition.

Table 1. Summary of the USACE flow equations

Flow Condition	Equation	Restriction	Remarks
Controlled submerged	$Q = C_d L G_o \sqrt{2g(H-h)}$	$\frac{H}{G_o} > 1.7$ and $\frac{h}{G_o} \geq 0.5$	Also known as submerged orifice
Controlled free	$Q = C_d L G_o \sqrt{2g(H-0.5G_o)}$	$\frac{H}{G_o} > 1.7$ and $\frac{h}{G_o} < 0.5$	Also known as free orifice
Uncontrolled submerged	$Q = C_d L h \sqrt{2g(H-h)}$	$\frac{H}{G_o} < 1.0$ and $\frac{h}{H} \geq 0.5$	Also known as submerged weir
Uncontrolled free	$Q = C_d L \sqrt{H^3}$	$\frac{H}{G_o} < 1.0$ and $\frac{h}{H} < 0.5$	Also known as free weir
Transitional Flow	$Q = \min(Quncontrolled, Qcontrolled)$	$1.0 \leq \frac{H}{Go} \leq 1.7$	

2.1.2.6 Over-the-Top Flow

In addition to the four flow conditions previously described, an over-the-top discharge could occur at a spillway during a flood event, as illustrated in **Figure 5**. The discharge over the top of the gate is given by:

$$Q = C_d L \sqrt{2g H_g{}^3}$$ *Equation 6*

where H_g is the head of the approach flow with respect to the top the gate.

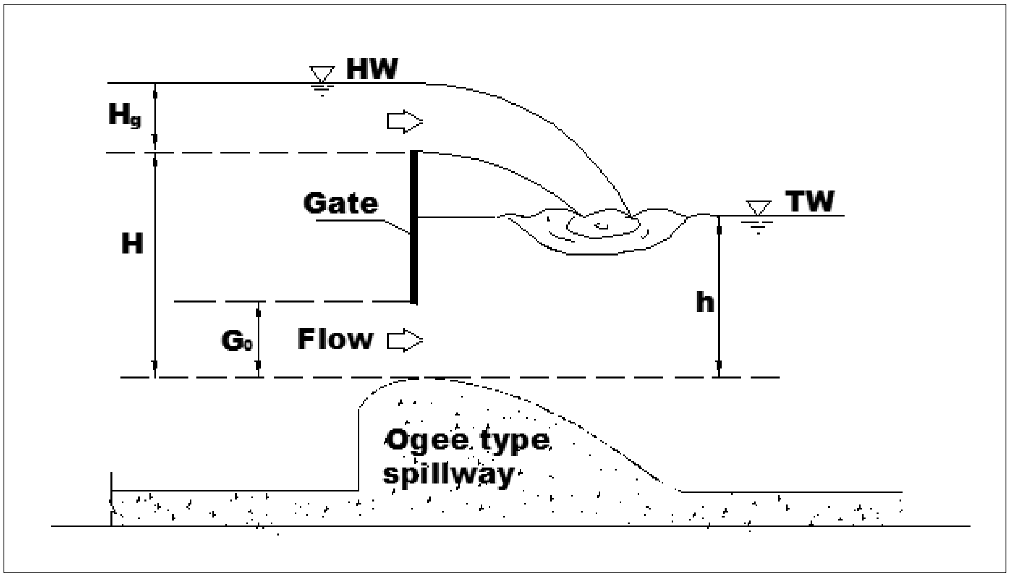


Figure 5. Over-the-top flow

2.1.3 Equations Based on Dimensional Analysis

2.1.3.1 Controlled Submerged Flow

For controlled submerged flow, the flow equation developed by Ansar et al. (2002) is:

$$\frac{y_c}{G_0} = a\left(\frac{H-h}{G_0}\right)^b \qquad \textit{Equation 7}$$

Criteria: $\frac{h}{G_0} \geq 1.0$

$$y_c = \frac{Q^{2/3}}{L^{2/3}g^{1/3}}$$

where:

y_c is the critical depth

a and *b* are dimensionless parameters, typically determined through regression.

The parameters *a* and *b* in Equation 7 (along with the spillway flow equations described in the following sections) account for the effects of piers and abutments. In the controlled-submerged flow condition, the headwater depth, tailwater depth, and gate opening all influence the flow.

2.1.3.2 Uncontrolled Submerged Flow

Chen et al. (2006b) proposed a new flow equation to estimate uncontrolled-submerged flow based on dimensional analysis. The proposed flow equation is:

$$\frac{y_c}{H} = a(1-\frac{h}{H})^b \qquad \textit{Equation 8}$$

Criteria: $\frac{h}{G_0} < 1.0,\ \frac{H}{G_0} < \frac{1}{K},\ \frac{h}{H} \geq K,\ K = \frac{2}{3}$

The parameters *a* and *b* in Equation 8 are as defined previously. Equation 8 first considers the free flow discharge at the given head water depths, as expressed in the left side of the equation. The obtained free flow discharge is then modified for the effects of the tail submergence, as expressed in the right side of the equation. Because the gate opening does not affect the flow, G_0 does not appear in Equation 8.

For uncontrolled-submerged flow, the Villemonte equation (1947) is widely used. This involves a reduction factor (S_c) applied to the free weir flow equation as follows:

$$Q = \frac{2}{3} C_{dfw} L \sqrt{2/3g} H^{3/2} S_c \qquad \textit{Equation 9}$$

where C_{dfw} is the free-weir discharge coefficient. Using the results of Villemonte (1947), the reduction factor can be stated as:

$$S_c = k \left[1 - (\frac{h}{H})^{1.5} \right]^m \qquad \textit{Equation 10}$$

where k and m are dimensionless parameters. Given this expression, Equation 8 can be rewritten as:

$$\frac{y_c}{H} = c \left[1 - (\frac{h}{H})^{1.5} \right]^d \qquad \textit{Equation 11}$$

Equation 11 is similar in form to Equation 8 except that the term (*h/H*) in Equation 11 is raised to the power of 1.5. The values of the parameters *c* and *d* obtained through calibration of Equation 11, however, generally will be different from the values of *a* and *b* obtained through calibration of Equation 8. Equation 8 is used in the NEXFLOW program for uncontrolled-submerged spillway flow computations.

2.1.3.3 Controlled Free Flow

At the controlled free flow condition, the flow equation (Ferro, 2000) is:

$$\frac{y_c}{G_0} = a \left(\frac{H}{G_0} \right)^b \qquad \textit{Equation 12}$$

Criteria: $\frac{h}{G_0} < 1.0,\ \frac{H}{G_0} \geq \frac{1}{K},\ K = \frac{2}{3}$

Under the controlled free flow condition, both the headwater depth and the gate opening affect the flow.

2.1.3.4 Uncontrolled Free Flow

The uncontrolled free flow equation was derived from the critical flow equation and can be stated as (Chen et al., 2006b):

$$\frac{y_c}{H} = a \qquad \textit{Equation 13}$$

Criteria: $\frac{h}{G_0} < 1.0,\ \frac{H}{G_0} < \frac{1}{K},\ \frac{h}{H} < K,\ K = \frac{2}{3}$

a is a dimensionless parameter

For uncontrolled-free flow conditions, neither the gate opening nor the tailwater influences the flow over the spillway. As a result, neither variable appears in Equation 13.

The flow equations based on dimensional analysis are summarized in **Table 2**. Values for the dimensionless parameters in the equations of **Section 2.1.3** typically are determined from field flow measurements or flows simulated with computational fluid dynamics (CFD).

Table 2. Summary of flow equations based on dimensional analysis

Flow Condition	Equation	Restriction	Remarks
Controlled submerged	$Q = L\sqrt{gy_c^{\ 3}}$ $y_c = aG_o\left(\frac{H-h}{G_o}\right)^b$	$\frac{h}{G_o} \geq 1.0$	Also known as submerged orifice
Controlled free	$Q = L\sqrt{gy_c^{\ 3}}$ $y_c = aG_o\left(\frac{H}{G_o}\right)^b$	$\frac{h}{G_o} < 1.0\ \&\ \frac{H}{G_o} \geq \frac{1}{K}$ $K = 2/3$	Also known as free orifice
Uncontrolled submerged	$Q = L\sqrt{gy_c^{\ 3}}$ $y_c = aH(1-\frac{h}{H})^b$	$\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{1}{K}, \& \frac{h}{H} \geq K$ $K = 2/3$	Also known as submerged weir
Uncontrolled free	$Q = L\sqrt{gy_c^{\ 3}}$ $y_c = aH$	$\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{1}{K}, \& \frac{h}{H} < K$ $K = 2/3$	Also known as free weir
Transitional Flow	No transition region		

y_c denotes Critical depth (ft) while other symbols are the same as defined previously.

2.1.3.5 All Flow Regimes

A model that is applicable to all flow regimes along with the transition zones between them (Ansar and Chen, 2009) can be stated as:

$$\frac{y_c}{D^{2/3}\,H^{1/3}} \quad = \quad (c_1 + c_2\frac{D}{H})(1-\frac{h}{H})^{c_3} \qquad \textit{Equation 14}$$

where D = min (G_o, H) while c_1, c_2 and c_3 are parameters to be determined through flow measurements. Gonzalez-Castro and Mohamed (2009) demonstrated that Equation 14 can be enhanced by reformulating it as

$$Q^{2/3} = (gL^2D^2H)^{1/3}\left(c_1 + c_2\frac{D}{H}\right)\left(1-\frac{h}{H}\right)^{c_3} \qquad \textit{Equation 15}$$

where D = min (G_o, y_s) and y_s is the flow depth on the spillway crest. Gonzalez-Castro and Mohamed (2009) indicate that y_s depends on the spillway geometry as well as the approach and tail water conditions. More specifically, they stated that y_s is a function of the spillway design head (H_d), the total upstream energy head (H_e), the tail water stage (T_w), and the head loss across the spillway (h_d) – defined as the vertical distance between the upstream energy grade line elevation and the tail water stage. Furthermore, they found that y_s can be estimated empirically from

$$\frac{y_s}{H_e} = 0.7927\left(\frac{H_e}{H_d}\right)^{0.0488}\left(\frac{h_d}{H_e}\right)^{-0.045} \qquad \textit{Equation 16}$$

Equations 15 and 16 cannot be evaluated independently because H_e depends on the upstream velocity head and, consequently, the discharge rate Q. According to Equation 15, Q in turn depends on H_e, H_d, and h_d because D = min (G_o, y_s). As a result, an iterative procedure is needed to determine the discharge with Equations 15 and 16. An iterative procedure developed by Gonzalez-Castro and Mohamed (2009) currently is used to compute spillway discharges with Equations 15 and 16 (e.g., Dessalegne, 2011b). This procedure is illustrated in **Figure 6** and requires that the channel hydraulic areas at the head water and tail water monitoring sites be determined as functions of the respective stages at these locations.

2.2 Categories of Flow Computation

For flow computation purposes, spillways are classified into six cases, where each case differs in the equations used to compute flow. In Case 1, the flow rate is computed from the standard USACE spillway equations, with the discharge coefficient set equal to a constant for each flow condition. Case 2 is the same as Case 1 except that a variable discharge coefficient is employed in at least one flow condition. Unlike Cases 1 and 2, Case 3 discharges are obtained from non-standard equations derived primarily from regression analyses of flow measurements. Case 4 is essentially the same as Case 1 except that it was customized specifically for S-78 in order to address its variable sill crest elevations. Case 5 contains equations for each flow condition that are based on the dimensional analysis studies described in **Section 2.1.3**. Finally, Case 6 flows are computed with Equations 15. General guidelines for the calibration and implementation of spillway flow computation equations are provided by Zeng and Wilsnack (2009).

The spillways classified in each of the six cases are listed in **Appendices D1** through **D6**. Included in each appendix are the structure dimensions and model parameters needed to compute spillway discharges.

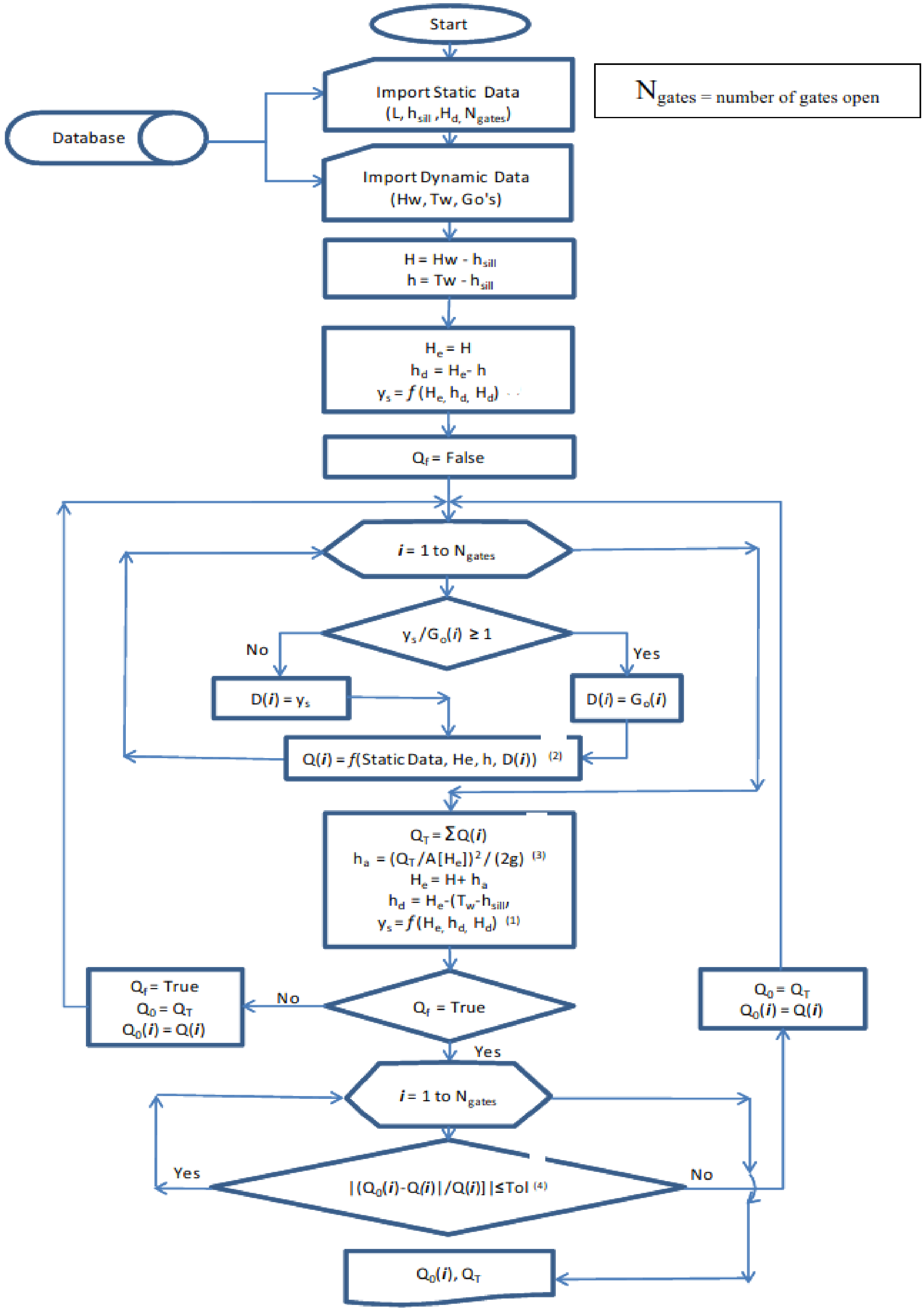


Figure 6. Iterative procedure for evaluating Equations 15 and 16 (Gonzalez-Castro and Mohamed, 2009)

2.3 Spillways with Customized or Special Flow Equations

Certain spillways have unique design features that prevent the direct application of the flow computation procedures presented in the previous sections. The spillways and their customized flow computation procedures are discussed in this section.

2.3.1 Effective Gate Openings at S70, S71, S72, S75, and S99

Before computing discharge with the Case 2 model at structures S70, S71, S72, S75, and S99, the NEXFLOW program computes an effective gate opening termed G_{oe}. The effective gate opening is needed because the structures are equipped with gates that have mudseals. While the actual flow computations at these spillways are based on the Case 2 model, the effective gate openings are computed with the formulas given below.

2.3.1.1 Structures S71 and S72

$$GAP = 0.125$$
$$Goe = \sqrt{(Go - 0.5)^2 + GAP^2}$$
$$Goe = 0.125 \text{ if } 0.125 \le \text{Go} < 0.5$$
$$\text{Goe} = \text{Go} \text{ if } \text{Go} < 0.125$$

2.3.1.2 Structures S70 and S75

$$GAP = 0.125$$
$$\theta = 15 \deg rees = 0.2618 \;\; radians$$
$$Goe = \sqrt{(Go - 0.5)^2 + (GAP + 0.5 * \tan\theta)^2}$$
$$TRANS = 0.5 + 0.125 \tan\theta + 0.5(\tan\theta)^2$$
$$Goe = MIN[Go, (GAP\cos\theta + Go\sin\theta)] \text{ if } \text{Go} < \text{TRANS}$$

2.3.1.3 Structure S99

$$Goe = \sqrt{(Go - 0.56)^2 + 0.04}$$
$$Goe = 0.20 \text{ if } 0.2 \le \text{Go} < 0.56$$
$$\text{Goe} = \text{Go} \text{ if } \text{Go} < 0.20$$

2.3.2 Flow Equations at S97, S49, and S99

The detailed flow computational algorithms at each of these structures follow.

2.3.2.1 Structure S97

At S97, the USBR (1977) method is used to compute the flow rate for uncontrolled-free and uncontrolled-submerged flow conditions. The procedure is summarized as follows:

Step 1: If the tailwater stage (TW) is missing, estimate it from the following:

$$TW = 8.0 + \left[2.142 MIN\left(0.6H, G_o\right)\right]^{2/3} \qquad \textit{Equation 17}$$

Step 2: Estimate the velocity as:

$$V = \frac{632.0\left(H + SE\right) - 8200}{47 \cdot \left(H + SE - C_1\right) + 2 \cdot \left(H + SE - C_1\right)^2} \qquad \textit{Equation 18}$$

where:

SE is the sill elevation, and

C_1 is a constant, taken as 0.8.

Step 3: Compute the variable H_1 as:

$$H_1 = \frac{C_2}{HE} - 0.8 \qquad \textit{Equation 19}$$

where:

HE = H-V^2/2g+2SE, and

C_2 is a constant, taken as 7.0.

If H_1 > 0, set it equal to zero.

Step 4: Compute the variable H_2 as:

$$H_2 = 0.2 - \frac{TW - SE}{HE} \qquad \textit{Equation 20}$$

If H_2 > 0, set it equal to zero.

Step 5: Compute the variable H_3 as:

$$H_3 = \frac{HE}{C_3} - 1.0 \qquad \textit{Equation 21}$$

where:

C_3 is a constant taken as 10.70.

Step 6: Compute the flow coefficient as:

$$\begin{aligned} COEF = C_4 &\cdot (1.0 - 0.377 H_1{}^2 - 0.048 H_1) \cdot (1.0 - 1.093 H_2{}^2 + 0.219 H_2) \\ &\cdot (1.0 - 0.05565 H_3{}^2 + 0.1379 H_3) \end{aligned} \qquad \textit{Equation 22}$$

where:

C_4 = 3.84.

Step 7: Compute the discharge as:

$$Q = COEF \cdot \left[L - 0.02 \cdot HE\right] \cdot HE^{3/2} \qquad \textit{Equation 23}$$

Step 8: Compute a trial value, TWTR, for the tailwater elevation as:

$$TWTR = 0.0316[2Q]^{0.6103} + 8.0 \qquad \textit{Equation 24}$$

Step 9: If the absolute value of the difference between TW and TWR is less than 0.001, then end the calculations and Q is given by Equation 23 in Step 7. On the other hand, if this difference is greater than 0.001, set TW=TWTR and repeat Steps 2 through 9.

2.3.2.2 Structure S49

At S49, the uncontrolled-free and uncontrolled-submerged flows are computed using a modified USBR (1977) method, as follows:

Step 1: Because there is no downstream recorder, estimate the tailwater elevation as follows:

$$TW = SE + 0.5G_o \qquad \textit{Equation 25}$$

Step 2: Estimate the velocity from:

$$V = \frac{125 \cdot H^{3/2}}{37 \cdot (H + SE) + 2 \cdot (H + SE)^2} \qquad \textit{Equation 26}$$

Step 3: Compute the variable H_1 from:

$$H_1 = \frac{19.0}{HE} - 0.8 \qquad \textit{Equation 27}$$

$$Where: \; HE = H - \frac{V^2}{2g} + 2SE$$

If H_1 is greater than zero, set it equal to zero.

Step 4: Compute the variable H_3 from:

$$H_3 = \frac{HE}{12.16} - 1.0 \qquad \textit{Equation 28}$$

Step 5: Compute the discharge coefficient COEF from:

$$COEF = 3.72 \cdot (1.0 - 0.377H_1^2 - 0.048H_1) \cdot (1.0 - 0.05565H_3^2 + 0.1379H_3) \qquad \textit{Equation 29}$$

Step 6: Compute the discharge as:

$$Q = COEF \cdot [L - 0.02 \cdot HE] \cdot HE^{3/2} \qquad \textit{Equation 30}$$

2.3.2.3 Structure S99

At S99, the uncontrolled-free and uncontrolled-submerged flows are computed using the same method employed at S49. The only exception is that the coefficient of 3.72 in the expression for COEF is replaced with 3.47.

2.3.3 Flow Equations at G300, G301, G302, G308, and G309

The flow equations at spillways G300, G301, G302, G308, and G309 are based on dimensional analysis. This set of equations differs from the set of equations summarized in **Table 2** because the former were developed before the Case 5 equations were established. The new flow equations are presented in **Table 3**. All variables and parameters in these flow equations are as defined previously. Efforts to convert these flow equations to standard Case 5 equations currently are underway and expected to be completed in the near future.

Table 3. Flow equations for spillways: G300, G301, G302, G308, and G309

<table>
<tr><th>Flow Condition</th><th>Equation</th><th>Restriction</th><th>Remarks</th></tr>
<tr><td>Controlled submerged</td><td>$Q = L\sqrt{g{y_c}^3}$
$y_c = aG_o\left(\frac{H-h}{G_o}\right)^b$
$a = 1.102$, $b = 0.324$</td><td>$\frac{h}{G_o} \geq 1.0$</td><td>Also known as submerged orifice</td></tr>
<tr><td>Controlled free</td><td>$Q = C_d LG_o\sqrt{2g(H-0.5G_o)}$</td><td>$\frac{h}{G_o} < 1.0 \; \& \; \frac{H}{G_o} \geq \frac{1}{K}$
$K = 2/3$</td><td>Also known as free orifice</td></tr>
<tr><td>Uncontrolled submerged</td><td>$Q = L\sqrt{g{y_c}^3}$
$y_c = h\sum_{i=0}^{3} a_i \left(\frac{h}{H}\right)^i$
<table>
<tr><th colspan="3">COEFFICIENTS</th></tr>
<tr><td></td><td>K=<h/H<0.95</td><td>h/H>=0.95</td></tr>
<tr><td>a_0</td><td>2.33</td><td>8.50</td></tr>
<tr><td>a_1</td><td>-7.05</td><td>-3.25</td></tr>
<tr><td>a_2</td><td>13.09</td><td>-5.25</td></tr>
<tr><td>a_3</td><td>-8.17</td><td>0</td></tr>
</table></td><td>$\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{1}{K}, \& \frac{h}{H} \geq K$
$K = 2/3$</td><td>Also known as submerged weir</td></tr>
<tr><td>Uncontrolled free</td><td>$Q = C_d L\sqrt{H^3}$
$C_d = 3.053$</td><td>$\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{1}{K}, \& \frac{h}{H} < K$
$K = 2/3$</td><td>Also known as free weir</td></tr>
<tr><td>Over-the-top</td><td>$Q = C_d L\sqrt{2g{H_g}^3}$</td><td>$H > (H_g + G_o)$</td><td>Computed as a free weir</td></tr>
<tr><td>Transitional Flow</td><td>No equation for the transition region</td><td></td><td></td></tr>
</table>

3.0 PUMPS

Symbol	**Definition**
A,B,C	Parameters for the Case 8 rating model
C_p	Flap coefficient
H	Head difference between the upstream & downstream stage (i.e., total static head)
H_{fact}	Maximum expected value of H
H_{lwr}	Lower head difference corresponding to Q_{lwr}
H_{upr}	Upper head difference corresponding to Q_{upr}
HW	Headwater elevation
C_f, n	Regression coefficient and exponent, respectively, for siphoning
N	Pump or engine speed in rpm
N_{fact}	Expected range of N
N_{lwr}	Lower pump engine speed corresponding to the discharge Q_{lwr}
N_{min}	Minimum pump or engine speed
N_{max}	Maximum pump or engine speed
N_o	Design RPM of the Pump
N_{upr}	Upper pump or engine speed corresponding to the discharge Q_{upr}
OCL	Elevation of the discharge pipe centerline
Q	Flow rate
Q_{adj}	Flow rate adjusted to account for losses due to the flap gate
Q_{lwr}	Discharge corresponding to the lower pump or engine speed N_{lwr}
Q_{upr}	Discharge corresponding to the upper pump or engine speed N_{upr}
TW	Tailwater elevation
X	Dimensionless head = H/H_{fact}
Y	Dimensionless pump or engine speed = $(N-N_{min})/N_{fact}$

3.1 Background

The USACE directed the construction of most major pump stations within the District. The USACE also developed and calibrated the initial rating equations for the pumps. For flow computation purposes, the SFWMD pumps were classified in the categories discussed below (Otero, 1995). In each case, the total static head (TSH) across the pump station is taken to be:

$$H = ABS(Max(TW, OCL) - HW) \qquad \textit{Equation 31}$$

where H, HW, TW and OCL are as defined above.

3.1.1 Case 1: Constant Speed Pumps

For a constant speed pump, a third-order polynomial of the TSH is used to model the discharge (Otero, 1995):

$$Q = C_0 + C_1 \cdot H + C_2 \cdot H^2 + C_3 \cdot H^3 \qquad \textit{Equation 32}$$

where Q is the discharge rate in cfs, C_0 through C_3 are empirical regression coefficients, and H is defined by Equation 31. The coefficients for Case 1 pumps stations are tabulated in **Appendix E1**.

In the presence of a flap gate, discharge through the pump is adjusted to account for head losses due to the gate. The adjusted discharge is then given by:

$$Q_{adj} = C_p \cdot Q \qquad \textit{Equation 33}$$

where Q_{adj} is the adjusted discharge rate and C_p is the flap coefficient, usually taken as 0.90.

3.1.2 Case 2: Highly Variable Speed Pumps

A two-variable, third-order polynomial is used to model discharge at stations with highly variable speed pumps. This model is expressed as:

$$\begin{aligned} Q = C_0 + C_1 \cdot X + C_2 \cdot Y + C_3 \cdot X^2 + C_4 \cdot XY + C_5 \cdot Y^2 + C_6 \cdot X^3 + \\ C_7 \cdot YX^2 + C_8 \cdot XY^2 + C_9 \cdot Y^3 \end{aligned} \qquad \textit{Equation 34}$$

where:

C_0 through C_9 are regression coefficients,

H is given by Equation 31,

X = a dimensionless static head = H / H_{fact},

H_{fact} is the maximum expected value of H,

Y = a dimensionless pump or engine speed = (N – N_{min})/N_{fact},

N = the pump or engine speed (RPM),

N_{min} = minimum pump or engine speed (RPM),

N_{fact} = the expected range of n

There currently are no pump stations whose flows are computed with the Case 2 model. This information is provided for legacy purposes.

3.1.3 Case 3: Variable Speed Pumps

The discharge for a pump classified as Case 3 is obtained through interpolation between an upper (Q_{upr}) and lower (Q_{lwr}) discharge given by third-order polynomials, as in Case 1. The details of the procedure are described by Otero (1995). The discharge is given by:

$$Q = Q_{lwr} + \left(Q_{upr} - Q_{lwr}\right)\left(\frac{N - N_{lwr}}{N_{upr} - N_{lwr}}\right) \qquad \textit{Equation 35}$$

where:

Q is the discharge at pump speed N,

Q_{lwr} and Q_{upr} are the lower and upper discharges at pump speeds N_{lwr} and N_{upr}, respectively.

The discharges Q_{lwr} and Q_{upr} are given by:

$$Q_{lwr} = C_{10} + C_{11} \cdot H_{lwr} + C_{12} \cdot H_{lwr}^2 + C_{13} \cdot H_{lwr}^3 \quad \text{Equation 36}$$

$$Q_{upr} = C_{20} + C_{21} \cdot H_{upr} + C_{22} \cdot H_{upr}^2 + C_{23} \cdot H_{upr}^3 \quad \text{Equation 37}$$

where:

C_{10} through C_{13} and C_{20} through C_{23} are empirical regression coefficients,

H_{lwr} and H_{upr} are the total static heads corresponding to Q_{lwr} and Q_{upr}, respectively.

H_{lwr} and H_{upr} are obtained from pump affinity laws as follows (Otero, 1995):

$$H_{lwr} = H\left(\frac{N_{lwr}}{N}\right)^2 \quad \text{Equation 38}$$

$$H_{upr} = H\left(\frac{N_{upr}}{N}\right)^2 \quad \text{Equation 39}$$

In Equations 38 and 39, H is the prevailing total static head at pump speed N. The regression coefficients for pumps classified as Case 3 are given in **Appendix E2**.

3.1.4 Case 4: Highly Variable Speed Pump with Two Versions of Flow Algorithms

Case 4 is merely composed of the Case 2 flow equations (i.e., a two-variable polynomial is used to model the flow) implemented at pump station S-9. It served as the basis for computed flow at S-9 between August 9, 1957 and June 23, 2004. Since June 23, 2004, flows have been computed with the Case 8 rating equation (discussed in **Section 3.1.8**). Information on this case is provided only for legacy purposes. At a later date, S-9 flows dated on or before June 23, 2004 may be recomputed with an updated Case 8 rating equation and reloaded into DBHYDRO.

3.1.5 Case 5: Constant Speed Pump with the Possibility of an Unsubmerged Outlet

In Case 5, the pump has a constant speed and an outlet that may be at least partially unsubmerged if the downstream stage is below the outlet crown. There are three possible scenarios associated with the downstream stage in this case (Otero, 1995):

<u>Unsubmerged Outlet</u>: The downstream stage is below the invert of the outlet pipe. The TSH is then the difference between the elevation of the upstream stage and the centerline of the outlet pipe.

<u>Submerged Outlet</u>: The downstream stage is above the crown of the outlet pipe. The TSH is the difference between the upstream and downstream stages.

<u>Partially Submerged Outlet</u>: The downstream stage is between the invert and the crown of the outlet pipe. Under this condition, the TSH is computed with Equation 31.

In Case 5, a second-order polynomial is used to compute the discharge:

$$Q = C_0 + C_1 \cdot H + C_2 \cdot H^2 \quad \text{Equation 40}$$

where C_0 through C_2 are empirical regression coefficients. The coefficients for pumps in Case 5 (S332, G250 and G251) are given in **Appendix E3**. In Equation 40, if the headwater elevation is less than the minimum upstream operating stage, the discharge is taken as zero. If the tailwater elevation is less than the minimum downstream operating stage, the static head is taken as the difference between the headwater elevation and the minimum downstream operating stage. The minimum downstream operating stage is the invert elevation of the discharge pipes for S332, and the elevation of the centerline of the discharge pipes for G250 and G251.

3.1.6 Case 6: Variable Speed Pumps at G600I and ACME2

Case 6 was developed for the variable speed pumps. In this case the flow is computed by:

$$Q = 0.00223 \cdot C_2 \cdot \frac{N}{C_0} \cdot \left\{ C_1 - \left[\frac{\left(\frac{C_0}{N}\right)^2 \cdot H - C_3}{\left| \left(\frac{C_0}{N}\right)^2 \cdot H - C_3 \right|} \right] \left[\left| \left(\frac{C_0}{N}\right)^2 \cdot H - C_3 \right| \right]^{1/3} \right\} \qquad \textit{Equation 41}$$

where C_0 through C_3 are empirical regression coefficients. Flow coefficients for the Case 6 pumps indicated above are listed in **Appendix E4**.

3.1.7 Case 7: Pumps at S13 and S332D

Case 7 was developed for pump stations S13 and S332D. It is currently only implemented at S332D, and is soon to be replaced by a Case 8 rating equation. The flow equations in this case were developed from pump affinity laws (Imru, 1999) and are given by:

$$\begin{aligned} Q &= \frac{N}{N_R}\left[C_1\sqrt{H} + C_3\right] \textit{if} \quad HW \leq TW \\ \textit{and} & \\ Q &= \frac{N}{N_R}\left[C_2\sqrt{H} + C_4\right] \textit{if} \quad HW > TW \end{aligned} \qquad \textit{Equation 42}$$

where N_R is the rated pump or engine speed while C1 through C4 are regression coefficients. The Case 7 parameters for S-332D are listed in **Appendix E5**.

3.1.8 Case 8: Generalized Rating Equation for Pump Stations

Using dimensional analysis, Imru and Wang (2003) demonstrated that:

$$Q = A\left[\frac{N}{N_0}\right] + BH^C\left[\frac{N_0}{N}\right]^{2C-1} \qquad \textit{Equation 43}$$

where A, B and C are parameters that usually are determined through regression analysis. Equation 43 is a physically based model that can be used to estimate flow through variable speed pumps. Equation 43 describes the relationship between discharge, head differential, and pump speed. The equation is considered the standard rating model for pump station rating analyses. Pump stations whose ratings are based on Equation 43 are listed in **Appendix E6** with their associated parameters. General guidelines for the calibration and implementation of the Case 8 flow equation are provided by Wilsnack (2008).

3.1.9 Rating Equation for Siphoning

When the headwater of a pump station is higher than the tailwater, it may be possible to move water through the structure via siphoning instead of through pump operation. Dimensional analysis shows that the siphoning rate through a pump station can be expressed as

$$Q = C_f H^n \qquad \textit{Equation 44}$$

where H is the TSH across the pump station while C_f and n are parameters that can be used to fit Equation 44 to measured flows. Theoretically, n = ½ while C_f depends on the hydraulic properties of the pump station. Values of C_f and n for pump stations with siphoning capability are listed in **Appendix E6**.

4.0 CULVERTS

Symbol	**Definition**
A	Wetted area of the barrel
Ag or A_G	Gate opening area
Ao	Full-barrel wetted barrel area
B	Box culvert span or weir crest length
C	Discharge coefficient for full-barrel flow
Cdg	Orifice flow Coefficient
Cdw	Weir flow coefficient
D	Rise or Diameter of Culvert
g	Acceleration of gravity
Go	Gate opening in feet
h	Tailwater elevation
H	Headwater elevation
HD	Hydraulic depth;
Heq	Equivalent hydraulic head
h_{ds}	Invert elevation at the downstream end
h_{us}	Invert elevation at the upstream end
HW	Headwater depth above upstream invert
K	Conveyance
Ke	Adjusted entrance loss coefficient;
Kf	Friction loss coefficient
Ko	Full-barrel conveyance
L	Barrel length
n	Manning coefficient
Q	Total structure discharge
Q_c	Culvert discharge
Q_w	Weir discharge
R	Hydraulic radius
Sc	Critical slope
Se	Energy slope
So	Barrel slope
TW	Tailwater depth above downstream invert
V	Flow velocity
WE	Weir crest elevation
Yc or y_c	Critical depth
z	Difference between barrel inlet and outlet inverts

4.1 Two Major Classes of Culvert Flow Algorithms

There are two sets of algorithms used to compute flow through simple culverts. The original set of algorithms, denoted as “Old”, were implemented by Fan (1985) and were used in the conventional FLOW program. More recently, a new set of flow algorithms called NFLOW was developed by Damisse and Fru (2006) and is primarily based on five of the culvert flow types identified by Bodhaine (1968). Each set of algorithms is explained in the following subsections.

4.2 Old Culvert Flow Algorithms for a Simple Culvert

When computing flow with the old culvert flow algorithms, flow at a culvert is classified into three major types (Fan, 1985): full-conduit flow (**Figure 7**), orifice flow (**Figure 10**), and open channel flow (**Figure 14**). Additionally, full flow is subdivided into two subtypes depending on whether the inlet is submerged or unsubmerged. Similarly, orifice flow is subdivided into two subtypes depending on whether or not the tailwater partially submerges the barrel. For open channel flow, the flow is subdivided into three subtypes depending on whether critical flow occurs at the inlet, at the outlet, or nowhere if the barrel is under tailwater control. The seven possible flow conditions identified by Fan (1985) at a culvert are summarized in the following subsections.

4.2.1 Full Pipe Flow

Criteria: TW > D

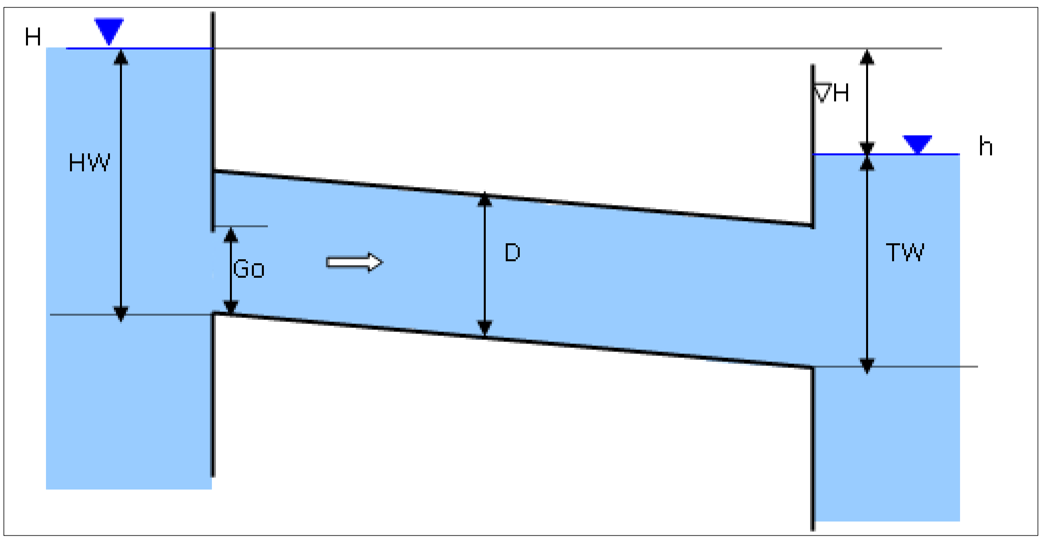


Figure 7. Full pipe flow at a culvert

4.2.1.1 Subtype I: Submerged Inlet. Code: "F1"

Criteria: HW > 1.3*D or HW>2*Go

Comment: Full flow throughout the barrel (**Figure 8**)

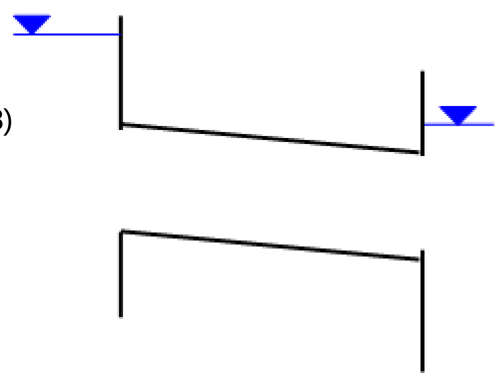


Figure 8. Submerged inlet flow

Equation:
$$Q = A\sqrt{\frac{2g(H-h)}{1+Ke+Kf}}$$ *Equation 45*

where:

A is the barrel area;

g is the acceleration of gravity

H is headwater elevation;

h is tailwater elevation;

Ke is the adjusted entrance loss coefficient;

Kf is the friction loss coefficient given by

$$Kf = \frac{29.1 \cdot n^2 L}{R^{4/3}} \qquad \text{Equation 46}$$

where:

n is the barrel Manning's n;

L is barrel length;

R is barrel hydraulic radius.

4.2.1.2 Subtype II: Unsubmerged Inlet. Code: "F2"

Criteria: HW < 1.3*D or HW<2*Go

Comment: Fan (1985) indicated that entrance loss coefficients given in textbooks are applicable to full flow only and are too large when the inlet is unsubmerged. By assuming the entrance contraction coefficient of a submerged inlet to be 0.6 and applying the continuity equation, the equivalent entrance loss coefficient of an unsubmerged inlet can be shown to be 0.36 times the coefficient for a similar submerged inlet. See **Figure 9**.

Equation: Same as in Subtype I except that the entrance loss coefficient Ke is adjusted by a factor of 0.36.

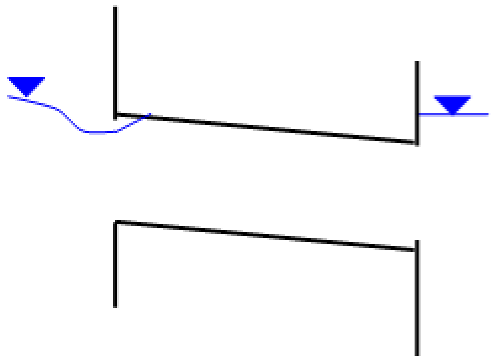


Figure 9. Unsubmerged inlet flow

4.2.2 Orifice Flow

Criteria: TW < D and {HW>1.3*D or HW>2*Go}

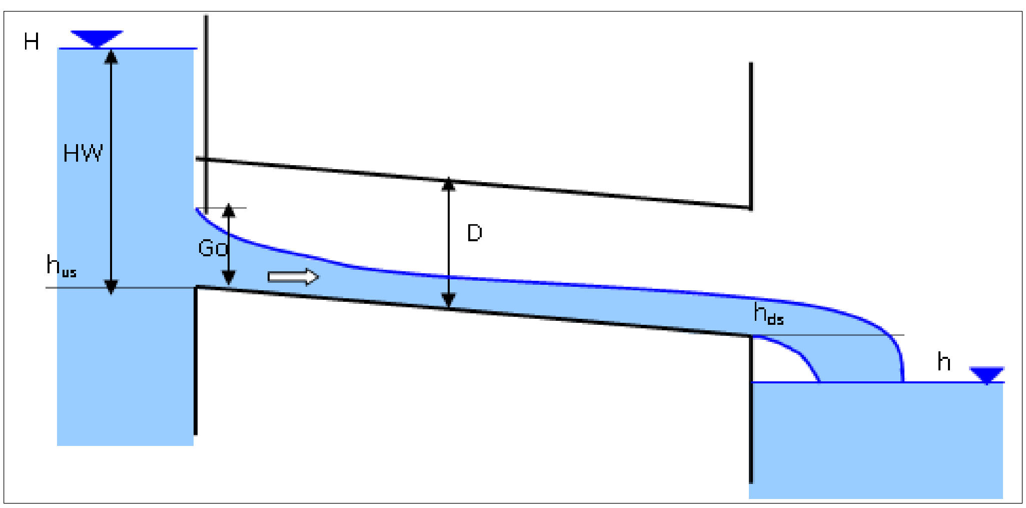


Figure 10. Orifice flow

4.2.2.1 Subtype 1: Free Orifice Flow. Code: "O1"

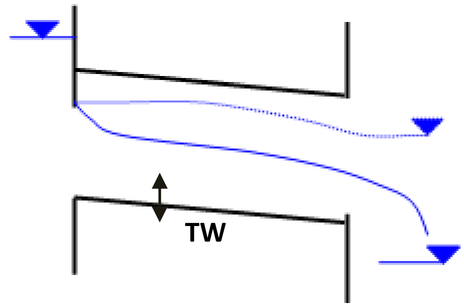


Figure 11. Free orifice flow

Subcriteria: $h_{us} > h_{ds}$

Comment: Inlet control. Barrel is never filled and frictional losses in the barrel do not control the flow (**Figure 11**). The gate can be submerged if the tailwater is higher than the top of the gate opening.

Equation:

Equation 47

$$Q = C_{dg} A_g \sqrt{2g\left[H - h_{us} - \max\{0.6Go, 0.6(h - h_{us})\}\right]}$$

where:

C_{dg} is the orifice flow coefficient, with an average value of 0.6;

A_g is the area of the gate opening in ft^2;

H is the headwater elevation;

h is the tailwater elevation;

h_{us} is the upstream invert elevation;

G_o is the gate opening in ft.

4.2.2.2 Subtype 2: Full or Part Full Pipe Flow. Code: "O2"

Subcriteria: $h_{us} < h_{ds}$

Comment: May occur when the barrel is on an adverse slope under various head water and tail water conditions (**Figures 12** and **13**). Flow is affected by barrel friction and evaluated as full pipe flow with an equivalent hydraulic grade line.

$$Q = A\sqrt{\frac{2gH_{eq}}{1 + Ke + Kf}} \qquad \textit{Equation 48}$$

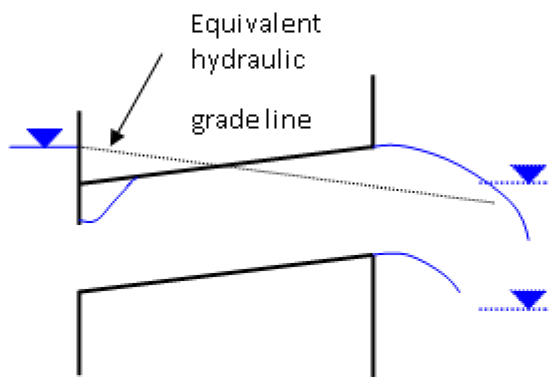


Figure 12. Full pipe flow

where:

A is the area of the barrel;

g is the acceleration of gravity;

Ke is the adjusted entrance loss coefficient;

Kf is the friction loss coefficient, obtained as in Case F1;

H_{eq} is an equivalent hydraulic head given by:

$$H_{eq} = MIN[H-(h_{ds}+0.5D), H-h] \text{ for } \mathrm{H > D + h_{ds}} \quad \textit{Equation 49}$$

or

$$H_{eq} = MIN[0.5(H-h_{ds}), H-h] \text{ for } \mathrm{H < D + h_{ds}} \quad \textit{Equation 50}$$

where:

H is the headwater elevation;

h is the tailwater elevation;

D is the barrel rise; and,

h_{ds} is the downstream invert elevation.

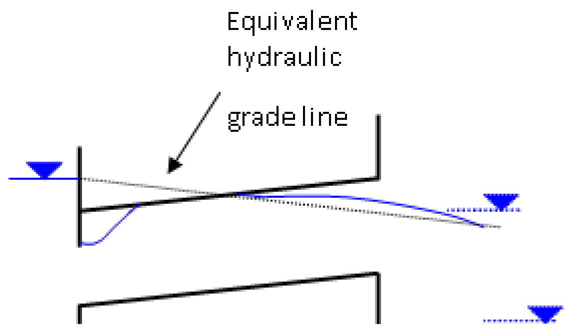


Figure 13. Part-full pipe flow

4.2.3 Open Channel Flow

Criteria: TW < D and {HW<1.3*D or HW<2*Go}

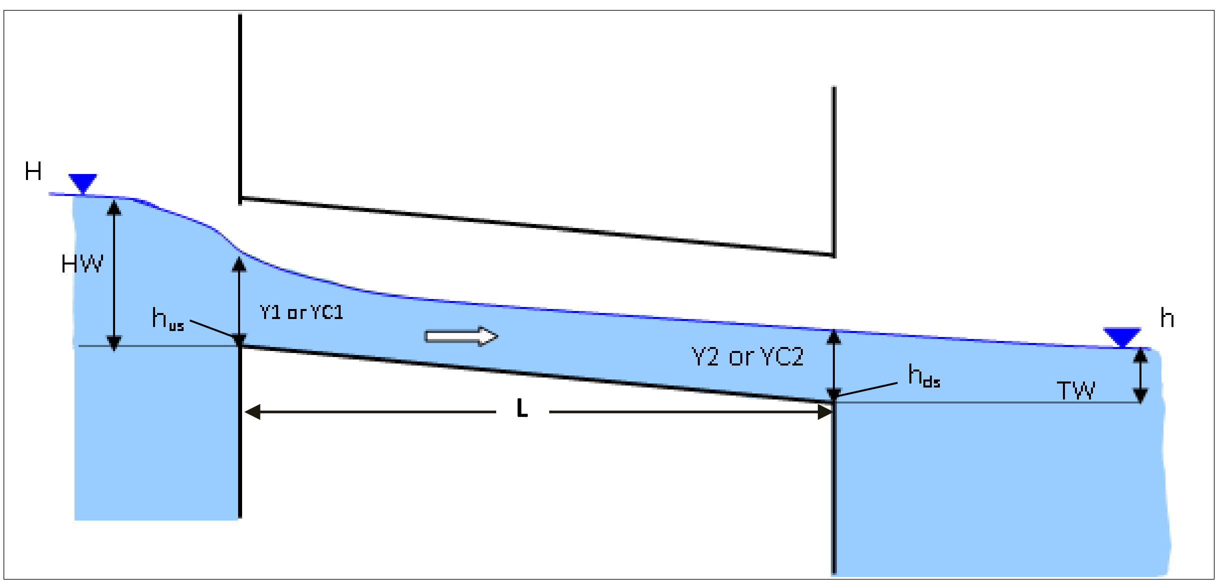


Figure 14. Open channel flow

4.2.3.1 Subtype 1: Inlet Control. Code: "H1"

Comment: Critical flow occurs at the inlet. Hydraulically, the barrel is on a steep slope (**Figure 15**). A hydraulic jump may occur inside the barrel (Q1).

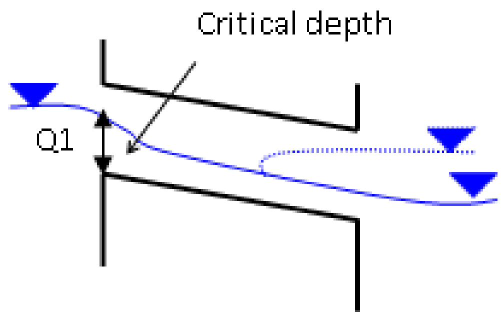


Figure 15. Inlet control

4.2.3.2 Subtype 2: Outlet Control. Code: "H2"

Comment: Critical flow or free fall at outlet (**Figure 16**). The barrel is hydraulically on a mild slope (Q2).

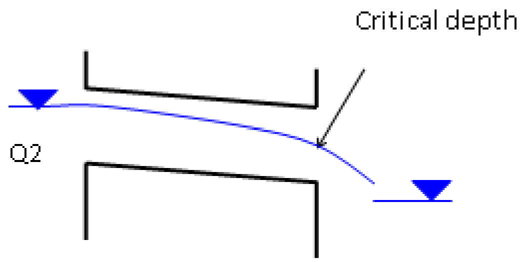


Figure 16. Outlet control

4.2.3.3 Subtype 3: Tailwater Control. Code: "H3"

Comment: Subcritical flow throughout the barrel (**Figure 17**). High tailwater condition (Q3).

Note: The entrance loss coefficient is multiplied by 0.36 because the inlet is unsubmerged (see Case F2).

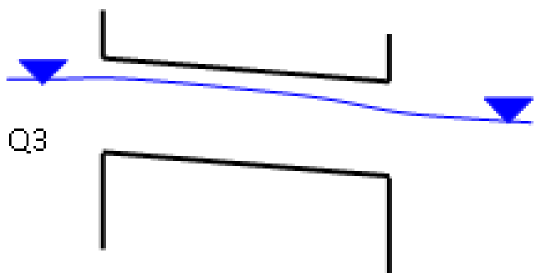


Figure 17. Tailwater control

4.2.3.4 Subtype Criteria

The above subtypes cannot be differentiated by explicit relationships because the criteria depend on the unknown depth of flow, which is implicitly related to the discharge that is to be estimated. The following algorithm is used to differentiate the subtypes:

Step 1 Compute the flow QI assuming inlet control and determine the inlet critical depth YCI.

Step 2 Check if the tailwater elevation h is above the inlet critical depth YCI. If so, compute the flow Q3 by proceeding to Step 5 and compare QI with Q3. The lower of the two is taken to be the actual discharge. If h is below YCI, proceed to Step 3.

Step 3 Compute critical slope SC from QI. Compare the bottom slope SB of the culvert with SC. If SB is greater than SC the flow is under inlet control. Otherwise, proceed to Step 4.

Step 4 Compute the flow Q2 as outlet control and determine the outlet critical depth YC2. Compare tailwater elevation h with YC2. If h is below YC2, compare QI with Q2. The lower of the two is taken to be the actual discharge. Otherwise, if h is above YC2, proceed to Step 5 to compute Q3 under tailwater control.

Step 5 Compute flow Q3 as tailwater controlled and compare QI with Q3. The lower of the two is the actual discharge.

4.2.3.5 Iteration Procedures

Under open channel flow conditions, the unknown flow and depth are related implicitly. Consequently, it is necessary to use an iterative technique to determine the flow and the depth. The iteration is started by estimating an initial depth. The flow and the depth are then computed from the estimated depth. The deviation between the computed and estimated depth is used to revise the estimated depth and iteration continues until a 0.01-foot tolerance level is achieved. Constraints are set in the iteration to assure that critical flow and entrance drawdown conditions are satisfied while the depth is within the limits of the barrel diameter. An iteration adjustment factor, IADJ, is used during iterations to modify the estimated depth as follows:

$$Y1 = Y11 + \frac{0.1 * DEV}{IADJ} \qquad \textit{Equation 51}$$

where:

Y1 is estimated depth;

Y11 is computed depth;

DEV is Y11-Y1;

IADJ is iteration adjustment factor (1 to 11).

Numerical experiments indicate that the choice of IADJ affects the iteration significantly. A large IADJ will assure convergency and stability, but will prolong the iteration. A small IADJ will speed up the iteration, but may lead to infinite oscillation and nonconvergency. For optimum conditions, the NEXFLOW program initializes IADJ at 1 and gradually increases it as the iteration proceeds.

4.2.3.5.1 Inlet Control

For a box culvert, the inlet critical depth, YC1, and discharge, Q, can be determined explicitly from:

$$YC1 = \frac{2 \cdot HW}{3 + Ke} \qquad \text{Equation 52}$$

$$Q = A1\sqrt{g \cdot HD1} \qquad \text{Equation 53}$$

where:

Ke is the entrance loss coefficient;

HD1 is the hydraulic depth at the inlet (= YC1 for a box culvert);

A1 is the flow area at the inlet.

For a circular culvert, YC1 and Q are related implicitly. Thus, YC1 must be determined iteratively until it satisfies the entrance drawdown and critical flow conditions. HD1 can then be determined from YC1. This iterative procedure is as follows:

Step 1: Estimate YC1 initially as 0.75*HW.

Step 2: Estimate HW as HW1 = YC1 + ½ *(1 + Ke)*HD1.

Step 3: If deviation DEV = HW-HW1 is less than 0.01, the entrance drawdown and critical flow conditions are satisfied, so the iteration can be terminated. Otherwise revise YCl by YC1 + DEV*0.1, and return to Step 2.

Step 4: Compute Q from Equation 53.

4.2.3.5.2 Tailwater Control

Under tailwater control, Y2 is known and it is necessary to iterate Y1 until the entrance drawdown condition is satisfied. The iterations are carried out as follows:

Step 1: Estimate Y1 initially as 1.01 *($h-h_{us}$), where h_{us} is the upstream invert elevation of the culvert.

Step 2: Compute the geometric mean conveyance as:

$$K = \frac{1.49}{n\sqrt{A1 \cdot R1^{2/3} \cdot A2 \cdot R2^{2/3}}} \qquad \text{Equation 54}$$

where A1, R1, A2, and R2 are the flow areas and hydraulic radii at the inlet and outlet, respectively.

Step 3: Estimate the energy slope from

$$S_e = \frac{(Y1 + h_{us}) - (Y2 + h_{ds})}{L} \qquad \textit{Equation 55}$$

where:

L is the barrel length;

h_{us}, h_{ds}, Y1, and Y2 are as previously defined (see **Figure 14**).

Step 4: Compute the discharge Q and inlet velocity from

$$Q = K\sqrt{S_e} \qquad \textit{Equation 56}$$

and

$$V1 = \frac{Q}{A1} \qquad \textit{Equation 57}$$

where V1 is the flow velocity at the inlet.

Step 5: Estimate Y11 from

$$Y11 = HW - (1 + Ke) \cdot \frac{V1^2}{2g} \qquad \textit{Equation 58}$$

Step 6: If DEV = Y11-Y1 is less than 0.01, the entrance drawdown condition is satisfied and the iteration can be terminated. Otherwise, revise Y1 using Equation 51 and return to Step 2.

4.2.3.5.3 Outlet Control

Under outlet control, Y1 and Y2 are unknown. Y2 must satisfy the critical flow condition and be designated as YC2. Y1 must satisfy the entrance drawdown condition. Two loops of iteration are needed. First, iterate YC2 until the exit critical flow condition is satisfied. Second, iterate Y1 until the entrance drawdown condition is satisfied. These iterations proceed as follows:

Step 1: Estimate Y1 and YC2 initially as:

$$Y1 = YC1 + h_{ds} - h_{us} \qquad \textit{Equation 59}$$

and

$$YC2 = 0.8 \cdot YC1 \qquad \textit{Equation 60}$$

where YC1 is the inlet critical depth determined from the “Inlet Control” calculations.

Step 2: Compute geometric mean conveyance K, energy slope Se and discharge Q as in Steps 2 through 4 under “Tailwater Control”.

Step 3: Given YC2, compute the hydraulic depth HD2 from channel properties. Compute also the hydraulic depth HD22 from the critical flow relationship

$$HD22 = \frac{V2^2}{g} \qquad \textit{Equation 61}$$

where V2 = Q/A2 is the outlet velocity.

Step 4: If DEV2 = HD22 - HD2 is less than 0.01, outlet critical flow conditions are satisfied; proceed to Step 5. Otherwise, revise YC2 as YC2 + DEV*0.1 / IADJ and return to Step 2.

Step 5: Estimate Y11 as:

$$Y11 = HW - (1 + Ke) \cdot \frac{V1^2}{2g}$$ *Equation 62*

Step 6: If DEV = Y11-Y1 is less than 0.01, the entrance drawdown condition is satisfied and iterations will be terminated. Otherwise, revise using Equation 51 and return to Step 2.

4.2.4 Inlet Control Gate

Three types of inlet control gates (**Figure 18**) are considered: rectangular slide gate, circular slide gate, and flashboard weir. The existence of an inlet gate may affect the flow in two ways:

1) If the restriction is significant, the flow regime will be shifted. For example, open channel flow will be shifted to orifice flow if the gate opening is small; or full pipe flow will be shifted to weir flow if the weir crest is high.

2) If the restriction is minor, the flow regime will remain the same but the entrance loss will be increased. The two conditions can be distinguished by computing the flows under both conditions. The condition with the lower flow is the controlling condition. Numerical experimentation demonstrates that the first condition can be identified by the following criteria:

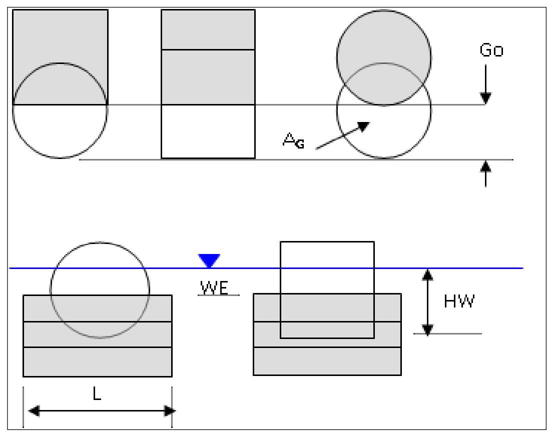


Figure 18. Inlet control gate

$$\text{Orifice control} : \text{H} > 2 * \text{Go}$$ *Equation 63*

$$\text{Weir control} : \text{Aw} < 2\text{A}$$ *Equation 64*

where:

H is the head above the inlet invert;

Go is the gate opening;

Aw is flow area above the weir crest;

A is the flow area in the barrel.

The flow under the second condition can be computed as if the gate did not exist and with the entrance loss coefficient adjusted by one of the following equations:

For a slide gate:

$$Ke = \left[\frac{(\sqrt{K_l} + 1) \cdot A}{A_G} - 1 \right]^2 \qquad \textit{Equation 65}$$

For a weir:

$$Ke = 0.1 \left[\frac{A}{Aw} \right]^2 + K_l \qquad \textit{Equation 66}$$

where:

K_l is the entrance loss coefficient with no gate or weir;

A_G is the area of gate opening area;

Ke is the adjusted entrance loss coefficient due to the gate or weir restriction.

The above adjustment is based on the application of the continuity equation and the assumption that entrance loss is equivalent to a sudden contraction loss (see Fan, 1985 for further explanation). Under gate control conditions, the equations presented in **Section 4.2.2** are used to compute flow. Under weir control conditions, the flow is computed by

Free Weir Flow:

$$Q_{free} = C_{dw} B \sqrt{(H - WE)^3} \qquad \textit{Equation 67}$$

Submerged Flow: Use is made of Villemonte's equation, i.e.

$$Q_{sub} = Q_{free} \left[1 - (h / H)^{3/2} \right]^{0.385} \qquad \textit{Equation 68}$$

where:

Q_{free} is the free weir flow;

Q_{sub} is the submerged weir flow;

C_{dw} is the weir flow coefficient (typical value = 3.3);

B is the weir crest length;

WE is the weir crest elevation;

H = HW - WE

h = MAX(TW – WE,0)

For some weir structures, overflow may occur along the wingwall or riser, which can be treated as a side weir with total length SL and crest elevation SWE. The same equations are used to compute the overflow by substituting SL for B and SWE for WE.

4.2.5 Old Flow Algorithm Summary

The flow parameters pertaining to the old flow algorithms for culverts are listed in **Appendices F1** and **F2**. The equations used for this class of flow computations are summarized in **Table 4**. Additionally, **Figure 19** summarizes the global logic inherent to the old flow algorithms.

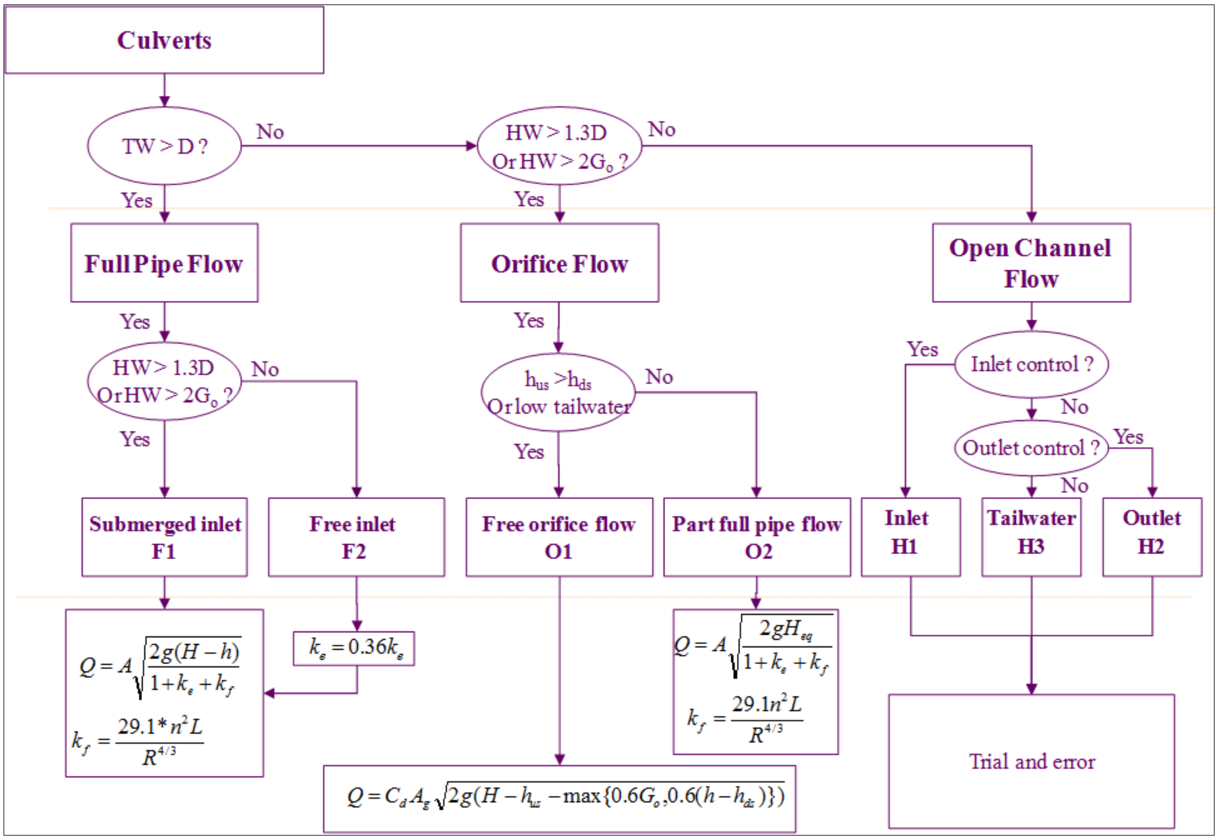
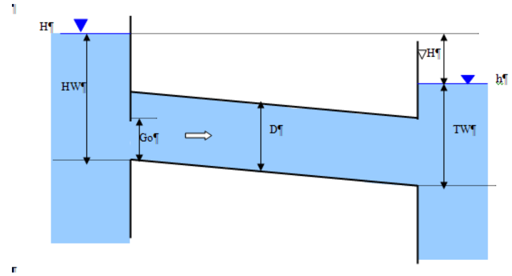
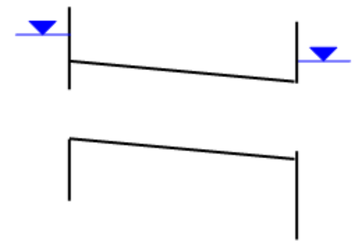
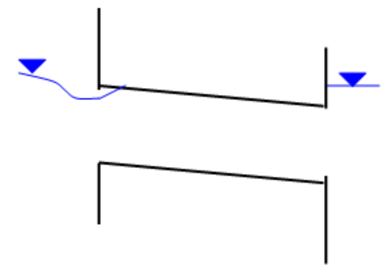
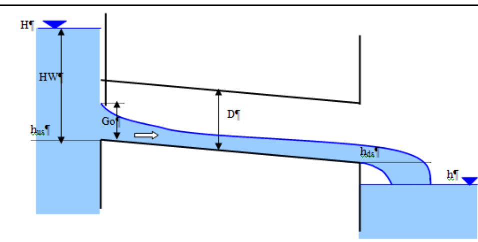
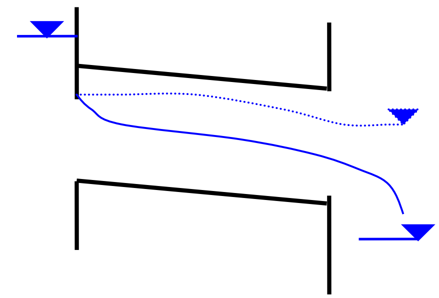
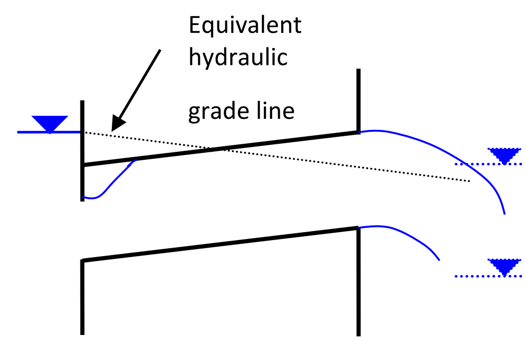
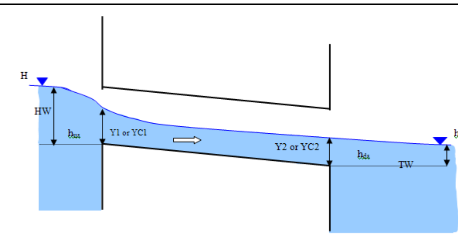


Figure 19. Flow chart depicting the old flow computation procedures for culverts

Table 4. Classification of flow through culverts in the old flow routine

Type	Criteria	Culvert Equations	Illustration
Full flow (two subtypes)	TW>D	$Q = A\sqrt{\frac{2g(H-h)}{1+Ke+Kf_m}}$ A is area of barrel; g is acceleration of gravity; H is headwater elevation; H is tailwater elevation; Ke is adjusted entrance loss coefficient; Kf_m is defined below	
1. Full pipe flow Submerged inlet F1	TW>D and {HW>1.3*D or HW>2*Go	$Kf_1 = \frac{29.1 \cdot n^2 L}{R^{4/3}}$ n is manning coefficient; L is length of barrel; R is hydraulic radius; Go is gate opening in feet; D is depth of culvert	
2.Full flow Unsubmerged inlet F2	TW>D and {HW<1.3*D or HW<2*Go}	$Ke_2 = 0.36 * Ke_1$	
Orifice flow	TW<D and {HW>1.3*D or HW>2*Go}	See below	

Type	Criteria	Culvert Equations	Illustration
1. Free Orifice Flow O1	Orifice flow criteria, plus $h_{us} > h_{ds}$	$Q = C_{dg} A_g \sqrt{2g\left[H - h_{us} - \max\left\{0.6Go, 0.6(h - h_{ds})\right\}\right]}$ C_{dg} is orifice flow coefficient, with an average value of 0.6; A_g is area of gate opening in ft^2; H is headwater elevation; h is tailwater elevation; h_{us} is upstream invert elevation; h_{ds} is downstream invert elevation; G_o is gate opening in ft.	
2. Partial or Full Pipe Flow O2	Orifice flow criteria, plus $h_{us} < h_{ds}$	$Q = A\sqrt{\frac{2gH_{eq}}{1 + Ke + Kf}}$ A is area of barrel; g is acceleration of gravity; Ke is adjusted entrance loss coefficient; Kf is friction loss coefficient, as in Case F1; H_{eq} is equivalent hydraulic head given by $H_{eq} = MIN\left[H - (h_{ds} + 0.5D), H - h\right] \text{for } H > D + h_{ds}$ $H_{eq} = MIN\left[0.5(H - h_{ds}), H - h\right] \text{for } H < D + h_{ds}$ H is headwater elevation; h is tailwater elevation; D is depth of barrel; and, h_{ds} is downstream invert elevation	
Open channel flow	TW < D and {HW<1.3*D or HW<2*Go} Subtype H1, H2 and H3 are based on the result of iteration method	Iteration procedures	

4.3 NFLOW Algorithms for Culverts

In addition to the old algorithms previously presented, more recent flow algorithms (Damisse and Fru, 2006) denoted as NFLOW have been developed using five of the flow types proposed by Bodhaine (1968). The associated five flow computation procedures are discussed in this section along with a recently identified sixth flow type.

4.3.1 Open Channel Flow

Open channel flow is divided into inlet control, outlet control, and tailwater control, depending on whether the critical depth occurs at the inlet, outlet, or nowhere throughout the barrel. Each flow subtype is explained in the following subsections.

4.3.1.1 Inlet Control Rating Model

When the critical depth occurs at the culvert inlet, the flow is occurring under inlet control. This is designated as Type 1 flow.

Criteria: (h1-z)/Go < 1.5, h4/(z+Yc)<1, and Sc<So

Flow Equations:

Circular Culvert:

$$Q = 0.7093 \frac{(\theta_c - \frac{1}{2}\sin 2\theta_c)^{1.5}}{(\sin\theta_c)^{0.5}} D^{2.5} \qquad \textit{Equation 69}$$

where:

h_1 is headwater elevation above the barrel outlet;

h_4 is tailwater elevation above the barrel outlet;

z is the elevation difference between the barrel inlet and outlet inverts;

D is the diameter of the circular culvert or the rise of the box culvert.

$$\theta_c = ar\cos(1 - \frac{2Y_c}{D})$$

Y_c is the critical water depth

So is the culvert bottom slope

Sc is the critical slope, $S_c = \frac{(Q/A_c)^2 n^2}{2.22 R_c^{4/3}}$

A_c is the water area at critical depth, $A_c = \frac{D^2}{4}(\theta_C - \frac{1}{2}\sin 2\theta c)$

R is the hydraulic radius at critical depth, $R_c = A_c / (\theta_c D)$

n is Manning's roughness coefficient

Iteratively calculate the critical angle θ_c to derive the critical depth, Y_c and flow, Q, until the following energy balance equation is satisfied:

$$h_1 - \frac{Q^2}{2gA_c^{\,2}} - (Y_c + z) = 0$$ *Equation 70*

Box Culvert:

$$Q = \sqrt{g} * B * Y_c^{1.5}$$ *Equation 71*

where B is the width of the barrel and $Y_c = 2/3\ (h_1\text{-}Z)$

The final calculated discharge is $Q_c = Cd_1 * Q$, where Cd_1 is an empirical discharge coefficient for Type 1 flow.

4.3.1.2 Outlet Control Rating Model

When the critical depth occurs at the culvert outlet, the flow is under outlet control. This is *designated as Type 2 flow in the NFLOW routines.*

Criteria: $(h_1\text{-}z)/Go < 1.5$, $h_4/Yc \leq 1$, and $Sc \geq So$

Flow Equations:

Equations 69 and 71 are applied to calculate Type 2 flow for a circular culvert and a box culvert, respectively.

Procedure:

Iteratively calculate the critical water depth and flow until the following energy balance equation is satisfied:

$$h_1 - \frac{Q^2}{2gA_3^{\,2}}\left(1 + \frac{2gLA_3^2}{K_2 K_3}\right) - Y_c = 0$$ *Equation 72*

In Equation 72, L is the length of the barrel while K_2 and K_3 are barrel conveyances computed from:

$$K_2 = \frac{1.486}{n} R_2^{2/3} A_2$$ *Equation 73*

$$K_3 = \frac{1.486}{n} R_3^{2/3} A_3 = \frac{1.486}{n} R_c^{2/3} A_c$$ *Equation 74*

where:

R_2 and A_2 are the hydraulic radius and water area based on the water depth Y_2;

R_3 and A_3 are the hydraulic radius and water area based on the outlet depth Y_c;

n is Manning's roughness coefficient.

For a circular barrel, the following equations are used:

$$A_2 = \frac{D^2}{4}\left(\theta_2 - \frac{1}{2}\sin 2\theta_2\right) \qquad R_2 = \frac{A_2}{P_2} \qquad \theta_2 = \cos^{-1}\left(1 - 2 * \frac{Y_2}{D}\right)$$

$$A_c = \frac{D^2}{4}\left(\theta_c - \frac{1}{2}\sin 2\theta_c\right) \qquad R_c = \frac{A_c}{P_c} \qquad \theta_c = \cos^{-1}\left(1 - 2 * \frac{Y_c}{D}\right)$$

For a box culvert, the following equations apply:

$$A_3 = B * Y_c\,,\ P_3 = B + 2Y_c\,,\ R_3 = \frac{A_3}{P_3}$$

$$A_2 = B * Y_2\,,\ P_2 = B + 2Y_2\,,\ Y_2 = 0.9\left(h_1 - z\right),\ R_2 = \frac{A_2}{P_2}$$

The initial guess of Y_2 is 0.90*(h_1-z) with Y_2=h_2-z, This is subsequently compared to $h_2 = h_1 - \frac{u_2^2}{2g}$. An iteration process is performed with a convergence criterion: $h_{2i+1} - h_{2i} \leq 0.01$.

4.3.1.3 Tranquil Flow Rating Model

When flow does not pass through critical depth and subcritical flow occurs throughout the barrel, flow within the culvert is tranquil and is controlled by the tail water. This is designated as Type 3 flow in the NFLOW routines.

Criteria: (h1-z)/Go < 1.5, h4/Yc>1, and h4/D≤1

Flow Equation:

$$Q = C_3 A_3 \sqrt{\frac{2g(h_1 - h_4)}{1 + \frac{2gA_3^2 L C_3^2}{K_2 K_3}}} \qquad \textit{Equation 75}$$

where C_3 is the discharge coefficient (the default value is currently 1.0) and L is the length of the barrel. K_2 and K_3 are conveyances given by

$$K_2 = \frac{1.486}{n} R_2^{2/3} A_2$$

$$K_3 = \frac{1.486}{n} R_3^{2/3} A_3$$

where:

R_2 and A_2 are the hydraulic radius and water area based on the water depth Y_2;

R_3 and A_3 are the hydraulic radius and water area based on the tailwater depth Y_4.

For a circular culvert:

$$\theta_3 = \arccos\left(1 - 2\frac{Y_4}{D}\right); A_3 = \frac{D^2}{4}\left(\theta_3 - \frac{1}{2}\sin 2\theta_3\right); R_3 = \frac{A_3}{P_3}$$

$$\theta_2 = \arccos\left(1 - 2\frac{Y_2}{D}\right); A_2 = \frac{D^2}{4}\left(\theta_2 - \frac{1}{2}\sin 2\theta_2\right); R_2 = \frac{A_2}{P_2}$$

For a box culvert:

$$A_3 = B * Y_4,\ P_3 = B + 2Y_4,\ R_3 = \frac{A_3}{P_3}$$

$$A_2 = B * Y_2,\ P_2 = B + 2Y_2,\ h_2 = 0.9(h_1 - z),\ R_2 = \frac{A_2}{P_2}$$

<u>Procedure</u>:

Iteratively calculate the critical water depth and flow rate until the following energy balance equation is satisfied (neglecting the entrance loss):

$$h_2 = h_1 - \frac{u_2^2}{2g} \qquad \textit{Equation 76}$$

The initial guess of h_2 is $0.90(h_1 - z)$ with Y_2=h_2-z. An iteration process with 1% tolerance is performed using the convergence criterion $h_{2i+1} - h_{2i} \le 0.01$.

4.3.2 Full Pipe Flow

Full pipe flow occurs when a culvert is submerged at both its upstream and downstream ends. This is designated as Type 4 flow in NFLOW.

<u>Criteria</u>: h_1>Go and h_4>D

Equation:

$$Q = CA_0 \sqrt{\frac{2g(h_1 - h_4)}{(\frac{A_0}{A_G})^2 + 2C^2(1 - \frac{A_0}{A_G} + \frac{gA_0^2 L}{K_0^2})}} \qquad \textit{Equation 77}$$

where:

C is the discharge coefficient (default value = 0.75);

A_0 is the full flow area;

A_G is the area under the gate opening;

K_0 is the conveyance under the full flow condition.

4.3.3 Orifice Flow

Orifice flow occurs when a culvert is fully submerged at the upstream end and unsubmerged at the downstream end. This is designated as Type 5 flow in the NFLOW routines.

Criteria: $h_1 > 1.5 * Go$, and $h_4 < D$

Comment: The friction and local head losses are ignored for this flow type.

Flow Equation: From the dimensional analysis of this flow type, the critical water depth can be estimated with the following equation:

$$Y_c = G_o * a\left[\frac{(h_1 - h_4)}{G_o}\right]^b \qquad \textit{Equation 78}$$

where a and b are parameters based on dimensional analysis.

Circular Culvert:

The discharge equation can be expressed as:

$$Q = \sqrt{gD^5 \frac{(\theta - \sin\theta\cos\theta)^3}{64\sin\theta}}$$

where:

$$\theta = \cos^{-1}\left[1 - 2\left(\frac{Y_c}{D}\right)\right]$$

Box Culvert:

$$Q = \left[y_c B^{2/3} g^{1/3}\right]^{\frac{3}{2}}$$

4.3.4 Orifice Flow with Partial Barrel Control

This flow condition, denoted as Type 6, was identified by Damisse et al. (2009). In Type 6 flow, the barrel flows full over part of its length even though the inlet conditions resemble those of Type 5. This is because the flow depth downstream of the hydraulic jump expands to the point where it equals or exceeds the limiting depth of 0.8D (Damisse et al., 2009) When this occurs, Damisse et al. (2009) determined that the Type 4 flow equation can be used to determine the discharge. However, an effective barrel length should be used in Equation 77 to account for the portion of the total length that is flowing full. Determining this effective length is a topic that is currently under investigation.

4.3.5 Summary of NFLOW routines

Table 5 summarizes the rating equations for the five flow types. The culverts utilizing these new routines are listed in **Appendices F3** and **F4**. The global logic implemented in NFLOW is depicted in **Figure 20**. General guidelines for the calibration and implementation of the flow computation equations for standard culverts are provided by Wilsnack and Zhang (2009).

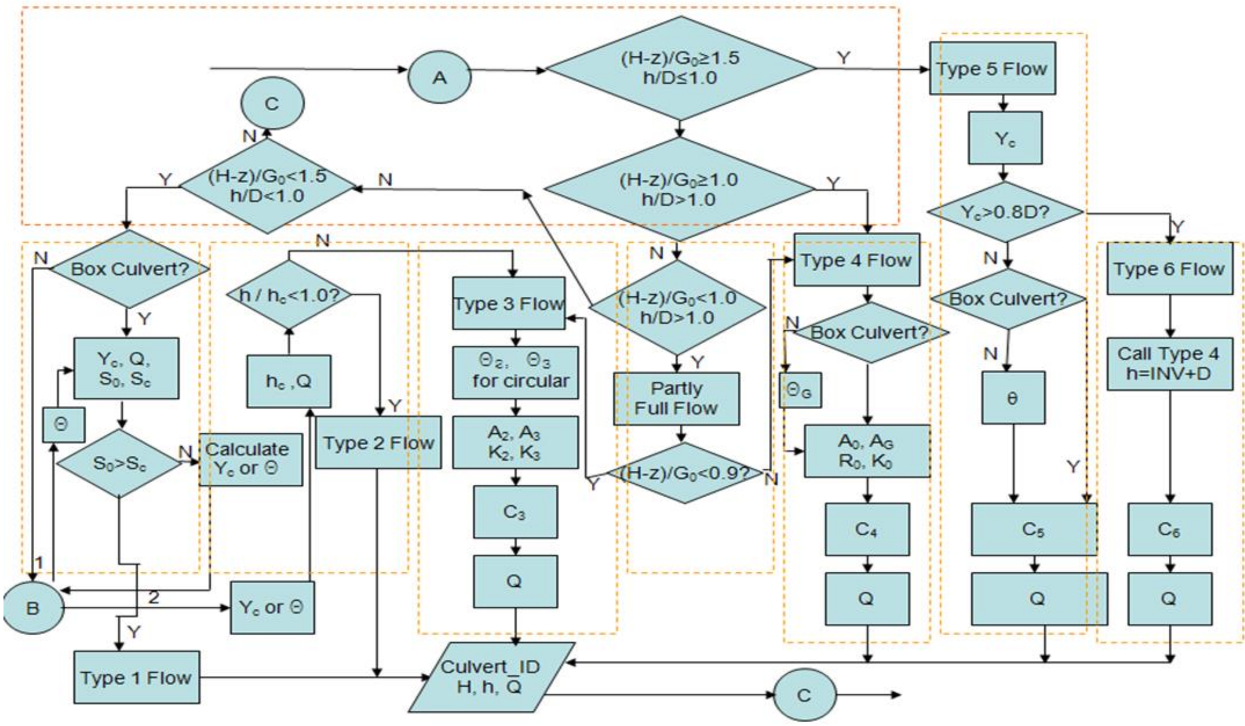
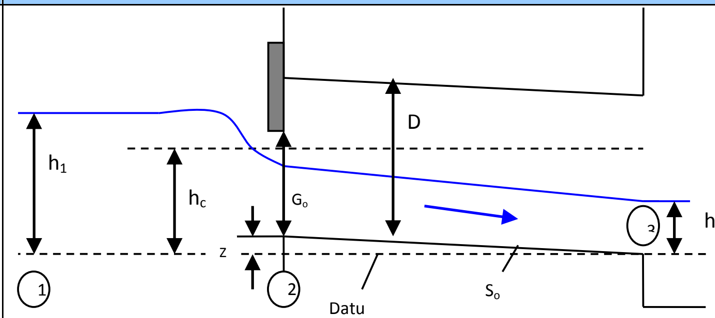
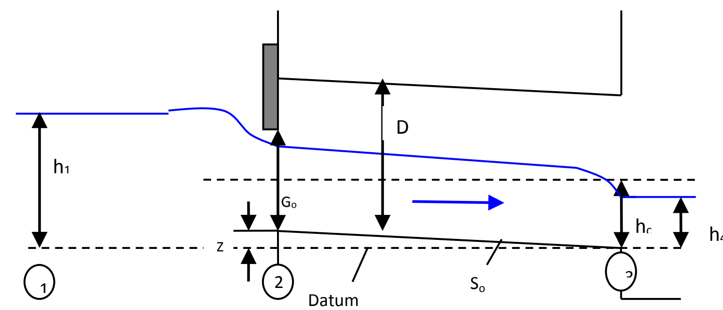
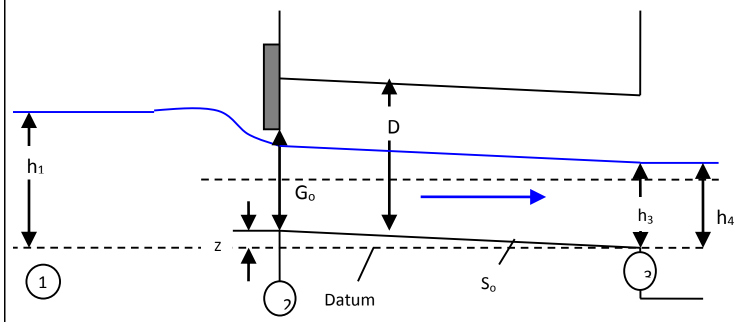


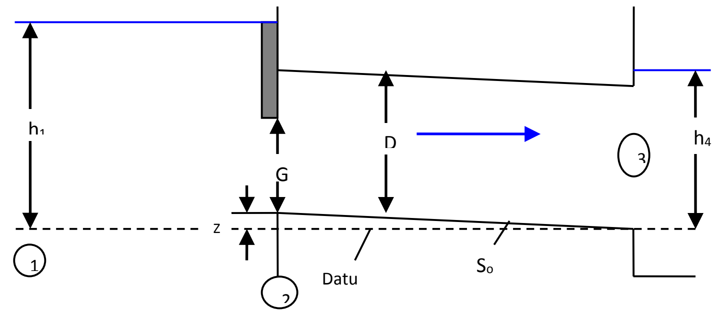
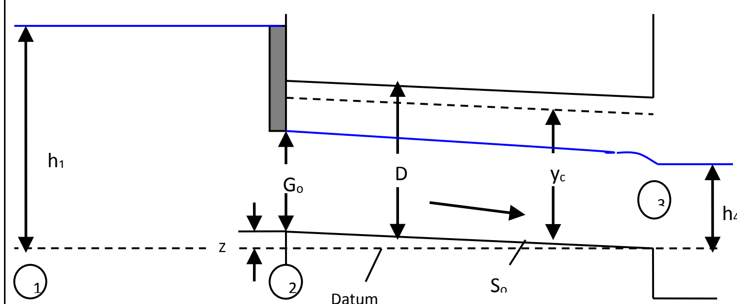
Figure 20. Flow chart depicting the new flow computation procedures for culverts

Table 5. Classification of flow through culverts in the NFLOW routine

Type	Circular Culvert Equations	Box Culvert Equations	Illustration
Type-1 Open Channel Flow INLET CONTROL WITH CRITICAL DEPTH AT INLET $\frac{h_1 - z}{G_o} < 1.5$ $\frac{h_4}{h_c} < 1.0$ $S_o \ge S_c$	$Q = 0.7093 \frac{\left(\theta_c - \frac{1}{2}\sin 2\theta_c\right)^{1.5}}{(\sin\theta_c)^{0.5}} D^{2.5}$ Solve for θ_c; $F(\theta) = h_1 - \frac{Q^2}{2gA^2} - (Y_c + z) = 0$ where: $A = \frac{D^2}{4}\left(\theta_c - \frac{1}{2}\sin 2\theta_c\right),$ $Y_c = \frac{D}{2}(1 - \cos\theta_c)$	$Q = \sqrt{g} * B * Y_c^{1.5}$ $Y_c = \frac{2}{3}(h_1 - z)$	
Type-2 Open Channel Flow OUTLET CONTROL WITH CRITICAL DEPTH AT OUTLET $\frac{h_1 - z}{G_o} < 1.5$ $\frac{h_4}{h_c} < 1.0$ $S_o < S_c$	$Q = 0.7093 \frac{\left(\theta_c - \frac{1}{2}\sin 2\theta_c\right)^{1.5}}{(\sin\theta_c)^{0.5}} D^{2.5}$ Solve for θ_c; $F(\theta_c) = h_1 - \frac{Q^2}{2gA^2}\left(1 + \frac{2gLA^2}{K_2 K_3}\right) - Y_c = 0$ where: $A = \frac{D^2}{4}\left(\theta_c - \frac{1}{2}\sin 2\theta_c\right),$ $Y_c = \frac{D}{2}(1 - \cos\theta_c)$ $P_c = \theta_c * D,\ R_c = \frac{A}{P}$	$Q = \sqrt{g} * B * Y_c^{1.5}$ $Y_{c,initial} = 0.64(h_1 - z)$ Solve for Y_c $F(\theta) = h_1 - \frac{Q^2}{2gA^2}\left(1 + \frac{2gL}{K_2 K_3}\right) - (Y_c + z) = 0$ where: $A_3 = B * Y_c,\ P_3 = B + 2Y_c,$ $R_3 = \frac{A_3}{P_3}$ $A_2 = B * Y_2,\ P_2 = B + 2Y_2,$ $Y_2 = 0.9(h_1 - z),\ R_2 = \frac{A_2}{P_2}$	 **Type 2 – Outlet Control**

Type	Circular Culvert Equations	Box Culvert Equations	Illustration
	$K_2 = \frac{1.486}{n} R_2^{2/3} A_2$ $A_2 = \frac{D^2}{4}\left(\theta_2 - \frac{1}{2}\sin 2\theta_2\right)$ $R_2 = \frac{A_2}{P_2}$ $\theta_2 = \cos^{-1}\left(1 - 2 * \frac{Y_2}{D}\right)$ Y_2 first guess is 0.90*(h_1-Z), then check the estimation with $h_2 = h_1 - \frac{u_2^2}{2g}$. An iteration process with 1% tolerance can be performed using the convergence $h_{2i+1} - h_{2i} \le 0.01$ $K_3 = \frac{1.486}{n} R_c^{2/3} A_c$	$K_2 = \frac{1.486}{n} R_2^{2/3} A_2$ h_2 first guess is 0.90*(h_1-Z), then check the estimation with $h_2 = h_1 - \frac{u_2^2}{2g}$. An iteration process with 1% tolerance can be performed using the convergence $h_{2i+1} - h_{2i} \le 0.01$ $K_3 = \frac{1.486}{n} R_3^{2/3} A_3$	

Type	Circular Culvert Equations	Box Culvert Equations	Illustration
Type-3 Open Channel Flow TRANQUIL FLOW THROUGHOUT $\frac{h_1 - z}{G_o} < 1.5$ $\frac{h_4}{D} \le 1.0$ $\frac{h_4}{h_c} > 1.0$	$Q = C_3 A_3 \sqrt{\frac{2g(h_1 - h_4)}{1 + \frac{2gA_3^2 L C_3^2}{K_2 K_3}}}$ $\theta_3 = \arccos\left(1 - 2\frac{h_4}{D}\right)$; $A_3 = \frac{D^2}{4}\left(\theta - \frac{1}{2}\sin 2\theta\right)$ $\theta_2 = \arccos\left(1 - 2\frac{Y_2}{D}\right)$; $A_2 = \frac{D^2}{4}\left(\theta - \frac{1}{2}\sin 2\theta\right)$ Y_2 first guess is $0.90(h_1 - z)$ then check the estimation with $h_2 = h_1 - \frac{u_2^2}{2g}$. An iteration process with 1% tolerance can be performed using the convergence $h_{2i+1} - h_{2i} \le 0.01$ $P_x = \theta_x * D$; $R_x = \frac{A_x}{P_x}$; $K_x = \frac{1.486}{n} R_x^{2/3} A_x$ where: *x* = 2 or 3 and C_3 = 1.0	$Q = C_3 A_3 \sqrt{\frac{2g(h_1 - h_4)}{1 + \frac{2gA_3^2 L C_3^2}{K_2 K_3}}}$ $A_3 = B * h_4$ $R_2 = \frac{Y_2 * B}{B + 2Y_2}$; $Y_2 = 0.90(h_1 - z)$ $R_3 = \frac{h_4 * B}{B + 2h_4}$ $K_x = \frac{1.486}{n} R_x^{2/3} A_x$ where: *x* = 2 or 3 and C_3 = 1.0 Y_2 first guess is $0.90(h_1 - z)$ then check the estimation with $h_2 = h_1 - \frac{u_2^2}{2g}$. An iteration process with 1% tolerance can be performed using the convergence $h_{2i+1} - h_{2i} \le 0.01$	 **Type 3 – Tranquil Flow**

Type	Circular Culvert Equations	Box Culvert Equations	Illustration
Type-4 FULL PIPE FLOW OUTLET IS SUBMERGED $\frac{h_1 \quad z}{G_o} > 1.0$ $\frac{h_4}{D} > 1.0$	$Q = CA_0\sqrt{\frac{2g(H-h)}{\left(\frac{A_0}{A_G}\right)^2 + 2C^2\left(1-\frac{A_0}{A_G}+\frac{gn^2L}{(1.49)^2R_0^{4/3}}\right)}}$ C = 0.85 (Default)	$Q = CA_0\sqrt{\frac{2g(H-h)}{\left(\frac{A_0}{A_G}\right)^2 + 2C^2\left(1-\frac{A_0}{A_G}+\frac{gn^2L}{(1.49)^2R_0^{4/3}}\right)}}$ $A_0 = A_G = B*h$; $R_0 = \frac{h*B}{2(B+h)}$	 **Type 4 – Full Pipe Flow**
Type-5 ORIFICE FLOW RAPID FLOW AT INLET $\frac{h_1 \quad z}{G_0} > 1.5$ $\frac{h_4}{D} < 1.0$	$Q = \sqrt{gD^5\frac{(\theta-\sin\theta\cos\theta)^3}{64\sin\theta}}$ where: $\theta = \cos^{-1}\left[1-2\left(\frac{Y_c}{D}\right)\right]$ and $Y_c = G_o * a\left[\frac{(H-h)}{G_o}\right]^b$	$Q = \left[y_c B^{2/3} g^{1/3}\right]^{\frac{3}{2}}$ where: $Y_c = G_o * a\left[\frac{(H-h)}{G_o}\right]^b$	 **Type 5 – Orifice Flow at**

4.4 Flow Computation Algorithms for Compound Culverts

In contrast to the simple (standard) culverts discussed in the preceding subsections, a compound culvert is a combination of a culvert and an inlet structure (e.g., gated weir). The flow regimes of a compound culvert are complicated by the use of unusual inlet structures. Currently, there are three kinds of compound culverts implemented in the NEXFLOW Program: the double-leaf gated culvert, the weir-box culvert, and the weir-gated culvert. Flow computation algorithms for these types of compound culverts are summarized in the following subsections. More detailed information is provided by Zeng et al. (2008).

4.4.1 Double-Leaf Gated Culvert

Double-leaf gated culverts (**Figure 21**) in south Florida generally have two vertical lift gates operated independently through a telemetry system.

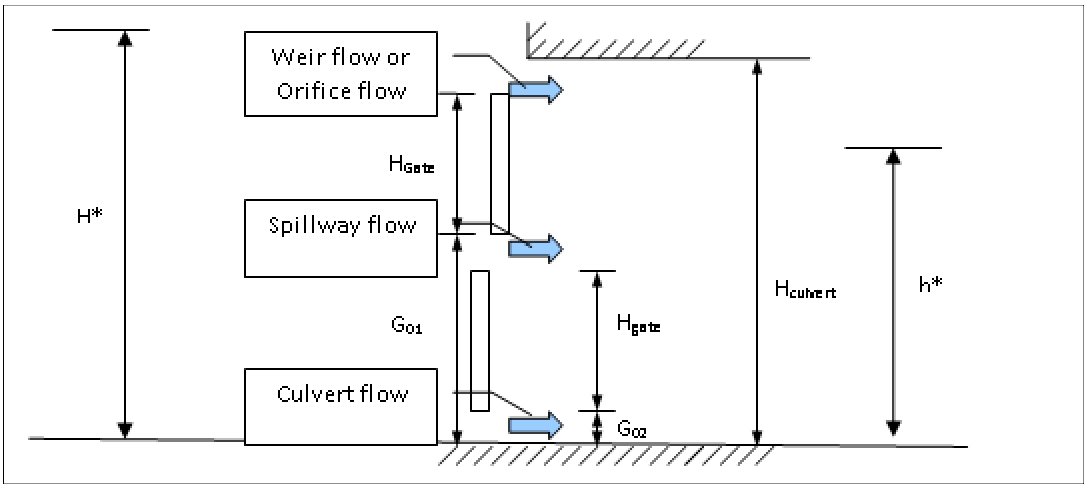


Figure 21. Double-leaf culvert

There are several possible controls for flow through double-leaf gate culverts, including weir flow, spillway flow, and culvert flow. Flow calculations for double-leaf gate culverts are described in the following subsections.

<u>4.4.1.1 Flow Beneath the Bottom Gate</u>

<u>Criteria</u>: $0 < H^* \leq G_{02}+H_{Gate}$ and $G_{02} > 0$

The NFLOW algorithms for box culvert flow calculations are used to compute flow through the opening of the bottom gate. H* and h* are the head water and tail water depths, respectively.

<u>4.4.1.2 Flow Between the Top and Bottom Gates</u>

<u>Criteria</u>: $G_{02}+H_{Gate} < H^* \leq G_{01}+H_{Gate}$, and $G_{01} > G_{02}+H_{Gate}$

The flow through the opening between lower and upper gate is considered spillway flow and uses the following dimensional analysis equations:

$$Q = B\sqrt{gy_c^{\,3}}$$ *Equation 79*

where:

$y_c = aG_o\left(\frac{H-h}{G_o}\right)^b$ for controlled submerged flow ($\frac{h}{G_o} \geq 1.0$)

$y_c = aG_o\left(\frac{H}{G_o}\right)^b$ for controlled free flow ($\frac{h}{G_o} < 1.0, \frac{H}{G_o} \geq \frac{3}{2}$)

$y_c = aH\left(1-\frac{h}{H}\right)^b$ for uncontrolled submerged flow ($\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{3}{2}, \frac{h}{H} \geq \frac{2}{3}$)

$y_c = aH$ for uncontrolled free flow ($\frac{h}{G_o} < 1.0, \frac{H}{G_o} < \frac{3}{2}, \frac{h}{H} < \frac{2}{3}$)

$H = H^* - (G_{02} + H_{Gate})$;

$h = h^* - (G_{02} + H_{Gate})$;

B is the gate width;

y_c is the critical depth;

G_0 is Max (G_{01}-(G_{02}+ H_{Gate}), 0.0);

a and b are parameters determined from measured flows.

4.4.1.3 Flow over the Top Gate

Criteria: $G_{01} + H_{Gate} < H^* < H_{culvert}$

The flow over the top gate opening is calculated as weir flow:

$$Q = B\sqrt{g{y_c}^3} \qquad \textit{Equation 80}$$

where:

$y_c = aH$ For free weir flow (h < 2H/3);

$y_c = aH(1-h/H)^b$ For submerged weir flow (h ≥ 2H/3);

$H = H^* - (G_{01} + H_{Gate})$;

$h = h^* - (G_{01} + H_{Gate})$;

a and b are parameters determined from measured flows.

The flow regime that is defined by the tail water range (0.95*(2/3)*H< h < 1.05*(2/3)*H) is considered to be transitional flow. Within this transition flow regime, the average of the free and submerged flow values is used to estimate the flow.

4.4.1.4 Total Flow through the Double-Leaf Gate Culvert

The sum of discharges through the bottom, middle, and top gate openings is calculated as the total flow through a double-leaf gate culvert. Inherent to this is the assumption is that there is no interference between the flows through the different openings. It is also assumed that the culvert barrels will not control the flow. This latter assumption is consistent with the design and operation of the double-leaf gated culvert structures constructed as of date. The double-leaf culverts and their static parameters are listed in **Appendix F5**.

4.4.2 Weir-Box Culverts

In south Florida, there are at least four types of weir-box culverts with different configurations of inlet structures. The flow through a weir-box culvert can be controlled by the weir, the barrel, or both. Four types of weir-box culverts are considered in the NEXFLOW Program. They are:

- Open weir-box with a gated spillway inlet;
- Closed weir-box with a sluice gate at the barrel entrance;
- Open weir-box with a slide gate at the side wall of the inlet; and
- Closed weir-box with a slide gate at the inlet tower.

Flow computations through each of these designs are discussed in the following subsections.

4.4.2.1 Type 1: Open Weir-Box with a Gated Spillway at the Inlet

The open weir-box with a gated spillway inlet is depicted in **Figure 22**. The inlet structure's upstream end wall includes a sluice gate.

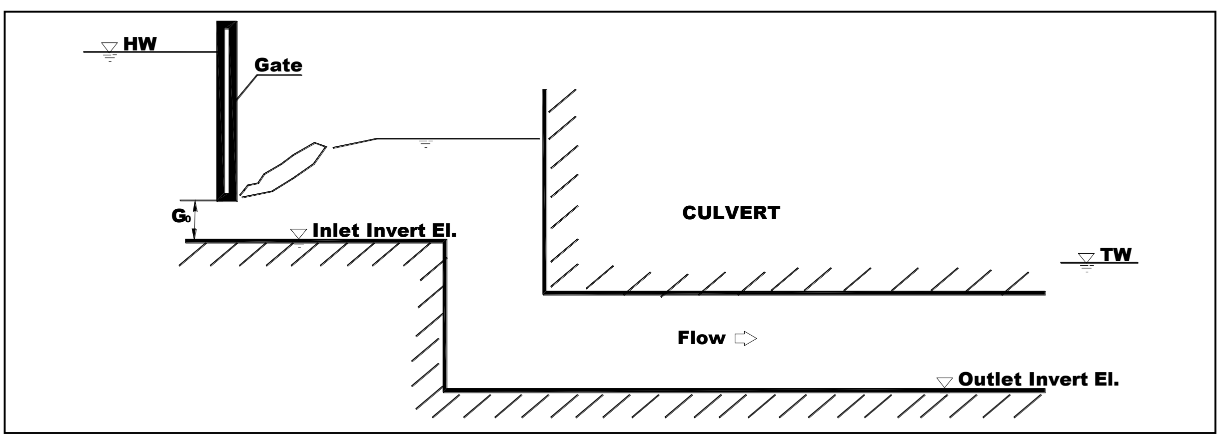


Figure 22. Illustration sketch of a weir-box culvert with a gated spillway at the inlet

Flow through the Inlet

Flow through the inlet is considered spillway flow. The appropriate equations from **Table 2** are applied in the calculation of flow over the sill.

Flow through the Culvert Barrel

Flow Equation 77 for full pipe flow is used to calculate the flow through culvert barrel when the flow becomes full pipe flow condition.

Actual Flow through the Type 1 Culvert Structure

The minimum value of the flows through the inlet and culvert barrel is designated as the actual flow. Parameter values for the rating equations are provided in **Appendix F6**.

4.4.2.2 Type 2: Closed Weir-Box with a Sluice Gate at the Barrel Entrance

A closed weir-box with sluice gate design can be found at G304A-I and G306A-I in STA-1W (**Figure 23**). In this structure, water can flow over the inlet weir crest, then pass through the gated culvert. Flow can be controlled by the weir or the gated culvert.

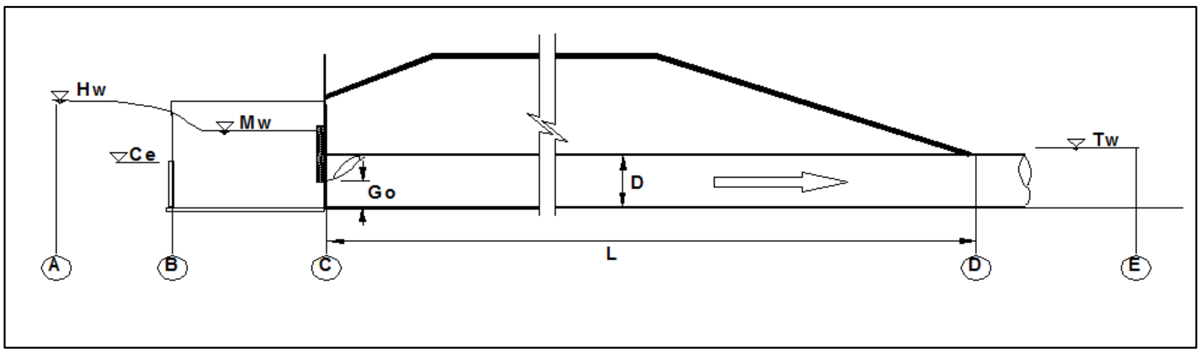


Figure 23. Illustration of a closed weir-box culvert with a sluice gate at the barrel entrance

In the report "Ratings for Pressured Flow in Gated Culverts with Weir-Box Inlet G304A-J and G306A-J" (Gonzalez, 2005), the rating algorithms for weir-box culverts G304 and G306 were developed using a lumped approach to estimate the discharge coefficient at the inlet. The effects of form and surface resistances were included in the coefficient. Furthermore, it was found that the discharge coefficient is a function of the ratio of the gate opening to the hydraulic area of the flow in the barrel (A_G/A_o), and that it can be approximated by a cubic polynomial. The resultant rating equations described below have been used to rate flows at the G304 and G306 culverts.

Flow over the Weir

The flow over the weir, Q_w, is calculated by Equation 81 (Gonzalez, 2005). Possible flow regimes include uncontrolled free and submerged weir flow.

$$Q_{inlet} = C_d C_v B\sqrt{2gH_1^{\ 3}} \qquad \textit{Equation 81}$$

where:

$$C_d = C_{d0}\frac{1}{1-\Phi}\left(1-\frac{\Phi}{1+\xi_w^4}\right)$$

$$C_v = c_1 x^3 + c_2 x^2 + c_3 x + c_4$$

$$x = \sqrt{\alpha_1} C_{dw} \frac{H_1}{H_1 + P}$$

C_{d0} =0.326

Φ =2/9

$$\xi_w = H_1 / w_l$$

H_1 is the head water depth above the weir elevation; B is the weir width; C_d is the discharge coefficient; C_v is the approach velocity coefficient; P is the distance from the weir sill to the channel bed; w_l is the weir crest length; c_1 =0.4256; c_2 =-0.0806; c_3 =0.0599; c_4 =0.993; $C_{dw} = \sqrt{27} C_d / 2$; and α_1 =1.04.

Flow through the Gated Culvert

The culvert controlled flow is calculated with a simplified form of the full pipe flow equation as follows:

$$Q_c = C_{dc} A_0 \sqrt{2g(HW - TW)} \qquad \text{Equation 82}$$

where:

$$C_{dc} = C_1 (A_r)^3 + C_2 (A_r)^2 + C_3 A_r$$

$$A_r = A_G / A_0$$

A_G is the area under the gate opening while A_0 is the full flow area;

C_1 (default = -0.0327), C_2 (default = -0.4472) and C_3 (default = 0.988) are coefficients.

Actual Flow through the Type 2 Culvert Structure

The actual flow through the structure is given by Equation 83. Parameter values for the rating equations are provided in **Appendix F7**.

$$Q = \min(Q_w, Q_c) \qquad \text{Equation 83}$$

4.4.2.3 Type 3: Open Weir-Box with an Auxiliary Gate on the Side Wall of the Inlet and a Sluice Gate at the Barrel Entrance

This type of gated culvert structure has an open weir-box with a sluice gate installed on its sidewall as an inlet (**Figure 24**). The flow can be controlled by the weir or the gated culvert.

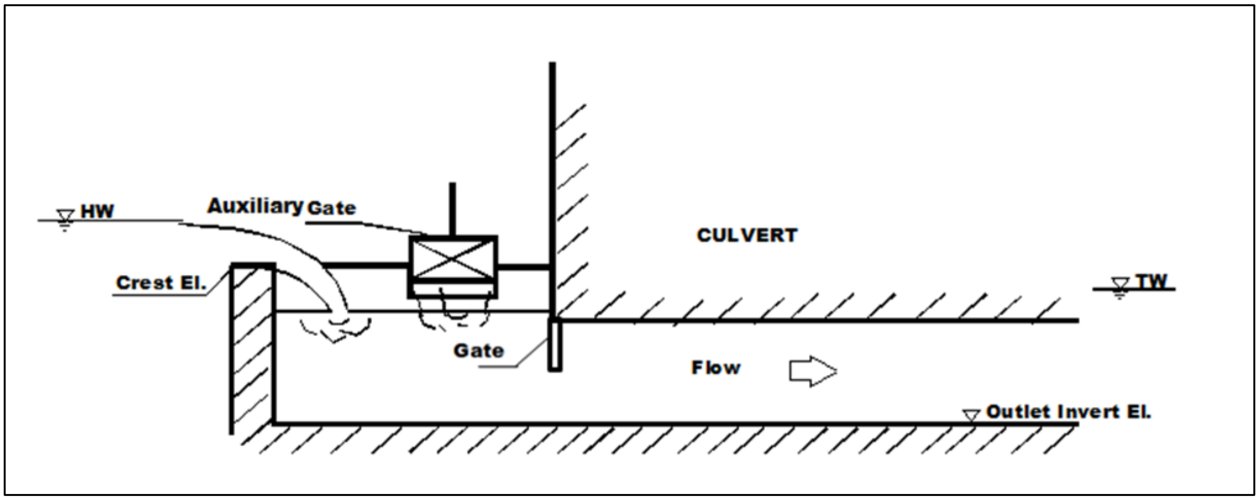


Figure 24. A weir-box culvert with a sluice gate on its sidewall, followed by a gated culvert

Flow over the Weir

Refer to **Section 5.0** for the appropriate weir equation that can be used to calculate the flow over the weir crest, Q_{weir}.

Flow through the Auxiliary Gate

The auxiliary gate is used primarily for maintenance purposes and rarely opened. Therefore, the flow underneath the auxiliary gate is not considered in the flow computation.

Flow through the Gated Culvert

The culvert controlled flow is calculated with Equation 82, where the discharge coefficient is determined through calibration to measured flow rates. As explained in the preceding subsection, the discharge coefficient must account for all of the energy losses instead of just the local head losses.

Actual Flow through the Type 3 Culvert Structure

The actual discharge, Q, through the structure is given by Equation 83. Parameter values for the flow computation equations are provided in **Appendix F8**.

4.4.2.4 Type 4: Closed Weir-Box with a Slide Gate at the Inlet Tower

Discharge through this type of weir-box culvert is depicted in **Figure 25**. When the upstream water stage is lower than the crown elevation and higher than the weir crest elevation, weir flow occurs. Flow is considered to be orifice flow when the upstream water stage is higher than the crown elevation. Flow can also be controlled by the barrel if the pipe is fully submerged.

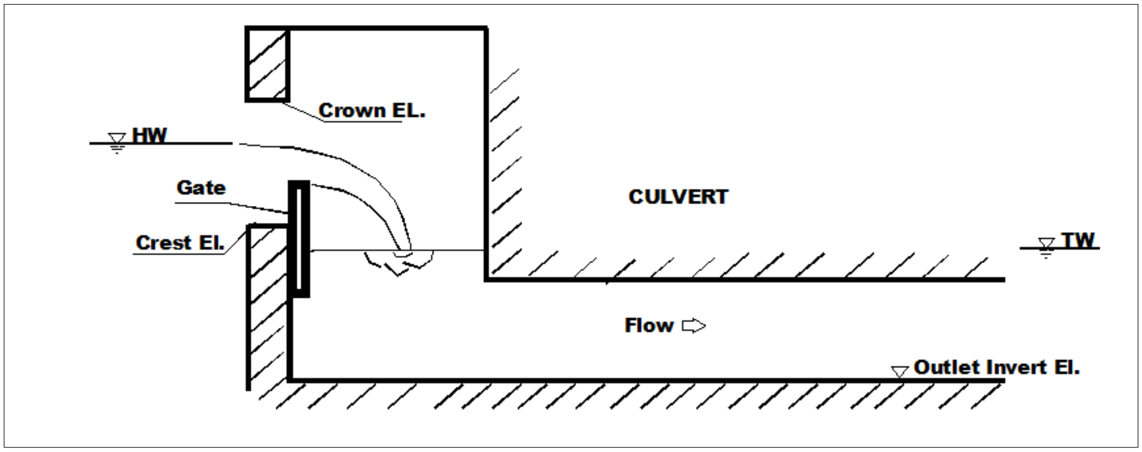


Figure 25. Illustration of a weir-box culvert with a slide gate installed in the inlet tower

Orifice Flow between Crown and Top Edge of Gate

Criteria: HW > Crown EL.

The orifice flow algorithm discussed in the previous subsection is used to calculate the flow between top edge of slide gate and crown elevation of inlet tower. In this case, G_o is the opening height between the crown and top edge of gate.

Weir Flow over the Top Edge of the Gate

Criteria: Crown EL. > HW > WB_{crest} (top edge of the gate)

The appropriate equation discussed in the previous subsection applied to calculate the flow over the top of the gate.

Flow through the Barrel Culvert

Equation 77 for full pipe flow is used to compute the barrel controlled flow.

Actual Flow through the Type 4 Culvert Structure

The minimum value of the computed flows through the inlet structure and culvert barrel is taken to be the actual flow through the weir-box culvert. Parameter values for the rating equations are provided in **Appendix F9**.

4.4.2.5 Type 5: Open Weir-Box with an Auxiliary Gate on the Side Wall of the Inlet and Multiple Culvert Barrels

This type of culvert structure has the same inlet structure design that is inherent to the Type 3 structure discussed above. Unlike the Type 3 structure, however, the Type 5 culvert structure can include multiple barrels. Additionally, none of the barrels have a sluice gate installed at its entrance.

The discharge through the inlet structure is computed in the same manner outlined for the Type 3 culvert structure. Additionally, flow through each of the culvert barrels is calculated with Equation 77, where $A_G = A_o$ because no gates are present.

Parameter values for the Type 5 structure rating equations are provided in **Appendix F10**.

4.4.3 Weir-Gated Culvert

A weir-gated culvert structure is illustrated in **Figure 26**. The variables used in the following equations are defined in **Table 6** and **Figure 26**.

Table 6. Weir-gated culvert variables

Variable	Variable Description
$H_{a,g}$	Approach head over the gate
B_e	Effective width of the weir
$B_{e,g}$	Effective width of the gate
D	Diameter or height of barrel
G_o	Gate Opening
H_{ce}	Approach head of the weir
H_{tot}	Height of head water above gate bottom
WG_{crest}	Weir crest elevation
WG_{gate}	Top elevation of the gate
WG_{wc}	Weir coefficient
WG_{ww}	Width of weir

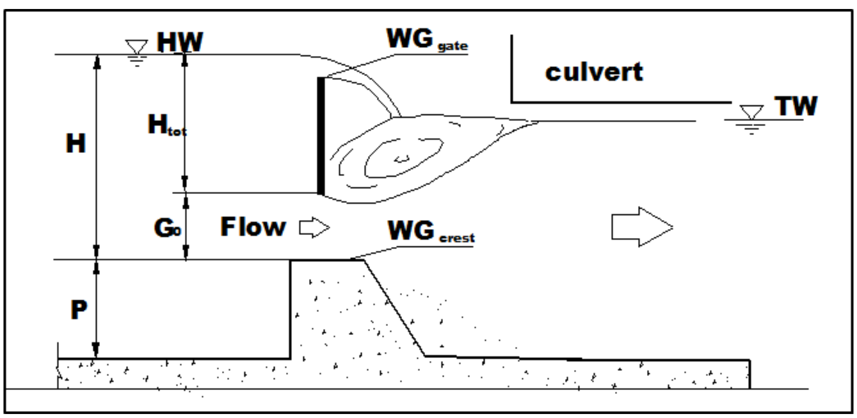


Figure 26. Illustration of a weir-gated culvert

<u>Flow over the Top of the Gate (Overtopping)</u>

Criteria: $H > H_{tot} + G_o$

Equation:

$$Q_{OT} = WG_{wc} * B_{e,g} * H_{a,g}^{\ 1.5} \quad \textit{Equation 84}$$

where:

$H_{tot} = HW - WG_{crest} - G_o$;
$H_{a,g} = HW - WG_{gate}$;
$B_{e,g} = WG_{ww} - 0.2 * H_{a,g}$.

Flow over the Weir

Criteria: $WG_{crest} + G_o > HW > WG_{crest}$

Free flow ($TW \leq WG_{crest}$)

$$Q_W = \mathrm{WG}_{\mathrm{wc}} * B_e * H_{ce}^{1.5} \qquad \textit{Equation 85}$$

Submerged flow ($TW > WG_{crest}$):

$$Q_W = WG_{wc} * B_e * H_{ce}^{1.5} * (1 - (\frac{h_{ce}}{H_{ce}})^{1.5})^{0.385} \qquad \textit{Equation 86}$$

where:

$H_{ce} = HW - WG_{crest}$

$h_{ce} = TW - WG_{crest}$

$B_e = WG_{ww} - 0.2 * H_{ce}$

Flow through the Culvert Barrel (Full Pipe Flow)

Criteria*:* TW $\geq$ culvert crown elevation

$$Q_D = C_d * A_0 \sqrt{\frac{2g(H-h)}{1+K_e+K_f}} \qquad \textit{Equation 87}$$

where: C_d=1.0.

Weir-gated culverts belong to the class of culverts whose flows are estimated with the old culvert routine discussed previously. This is why the full pipe flow is calculated with Equation 87.

Actual Flow through the Weir-Gated Culvert Structure

The actual discharge, Q, through the structure is given by

$$Q = Q_{OT} + \min(Q_D, Q_w) \qquad \textit{Equation 88}$$

Parameter values for the rating equations are provided in **Appendix F11**. Currently, if $H > G_o$, flow through the gate opening is still computed using Equation 88. In reality, an orifice equation should be used. This should be corrected in future versions of NEXFLOW. Fortunately, orifice flow through the gate opening does not occur frequently.

4.4.4 Flashboard Culverts

Flashboards and risers are included in the intake structure of weir-gated culverts to allow for operational flexibility. The flow computation routine for flashboard culverts is briefly described in the following subsections.

4.4.4.1 Flow Algorithms for the Case 1 Flashboard Culvert Structures

Flow over the Weir

Criteria: H>WE, and T≤WE

$$Q_w = Cd_w * WB_e * H_w^{1.5} \quad \text{Equation 89}$$

where:

H and T are headwater and tailwater stages, respectively;

WE is the crest elevation of the flashboard;

H_w is the water depth above the flashboard, H_w = H- WE;

WB_e is the effective width of the flashboard, with WB_e = WB-0.2H_w and WB = the physical width of the flashboard;

Cd_w is the weir discharge coefficient.

If the weir flow is submerged (T>WE), the Villemonte (1947) equation is used to adjust the flow calculated with Equation 89.

Flow over the Surrounding Riser

Criteria: H>SWE

Equation:

$$Q_{sw} = Cd_w * (SWB - WB) * (H - SWE)^{1.5} \quad \text{Equation 90}$$

where SWE is the crest elevation of the riser while SWB is its perimeter.

Flow through the Culvert Barrel

The flow through the barrel, Qc, is determined using the equations and associated criteria of the old culvert routine (**Section 4.2**).

Actual Flow through the Case 1 Flashboard Culvert Structure

The actual discharge, Q, through the structure is given by

$$Q = \min(Q_{sw} + Q_w, Q_c) \quad \text{Equation 91}$$

4.4.4.2 Flow Algorithms for the Case 2 Flashboard Culvert Structures

Flow over the Weir

For Case 2 Flashboard Culvert structures, Equation 89 and the same corresponding criteria are used to estimate the flow over the weir. However, the effective width of the flashboard, WB_e, is taken to be WB_e = WB-0.2H_w.

Flow over the Surrounding Risers

Equation 90 and the same criteria are used to estimate the flow over the surrounding risers. However, in this case SWB is replaced by an effective riser perimeter equal to SWB-0.2(H-SWE).

Flow through the Culvert Barrel

In this case the discharge through the barrel, Q_c, is estimated with the NFLOW culvert routine described in **Section 4.3**. The related flow equations and associated criteria for five flow types are used to estimate the barrel-controlled flow.

Actual Flow through the Case 2 Flashboard Culvert Structure

Equation 91 and the same criteria are used to estimate the actual discharge through the flashboard culvert.

Parameter values for the flashboard culvert structure rating equations are provided in **Appendices F12** and **F13** for the Case 1 and Case 2 structures, respectively.

4.4.5 Two-End Gated Culverts

This type of structure depicted in **Figure 27** has a special two-end gated configuration: one sluice gate installed at the upstream end of the barrel and another located at the downstream end. This allows for flow control in either direction. The flow through this compound culvert can be controlled by the inlet gate, the outlet gate, or the barrel itself, depending on the stages and operational settings.

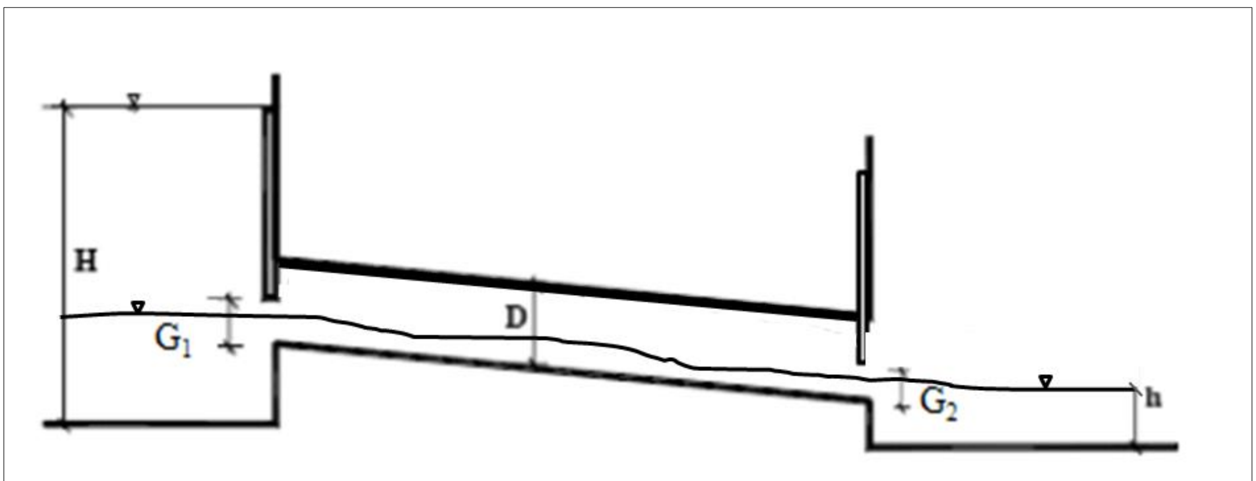


Figure 27. Illustration of a two-end gated culvert

Zeng et al. (2009) proposed that the equations given in **Table 2** for controlled, submerged spillway flows can be applied to culvert flow Types 4 and 5 of the NFLOW procedure while the uncontrolled, submerged flow equations can be used to compute Types 1 to 3 flows through a gated culvert. The primary assumption here is that gated culvert flow can be conceptualized as spillway flow by neglecting the friction losses incurred within the barrel. At gated culverts owned and operated by the SFWMD, barrel friction loss typically accounts for 10% or less of total head loss (Zeng et al., 2009). Consequently, the non-dimensional equations for computing spillway flows can be used to estimate discharges through most gated culverts.

By conceptualizing a two-end gated culvert as two standard gated culverts linked in series, non-dimensional flow equations can be applied to calculate the flows through both gated culverts. From continuity, the discharges through the two fictitious culverts installed in series should be equal. Therefore, an iterative method (e.g., Newton-Raphson) is needed to determine the pressure head at the downstream end of the first barrel along with the critical depth. This procedure is outlined in **Figure 28**. The pressure head at the downstream end of the first barrel (H_{mid}) initially is estimated to be the average of H and h. Flows through both gated culverts are then calculated and compared. If the two computed discharge rates do not agree within a specified tolerance, the stage at the downstream end of the first barrel is systematically adjusted and the flow computations repeated until an acceptable agreement between the computed discharges is obtained.

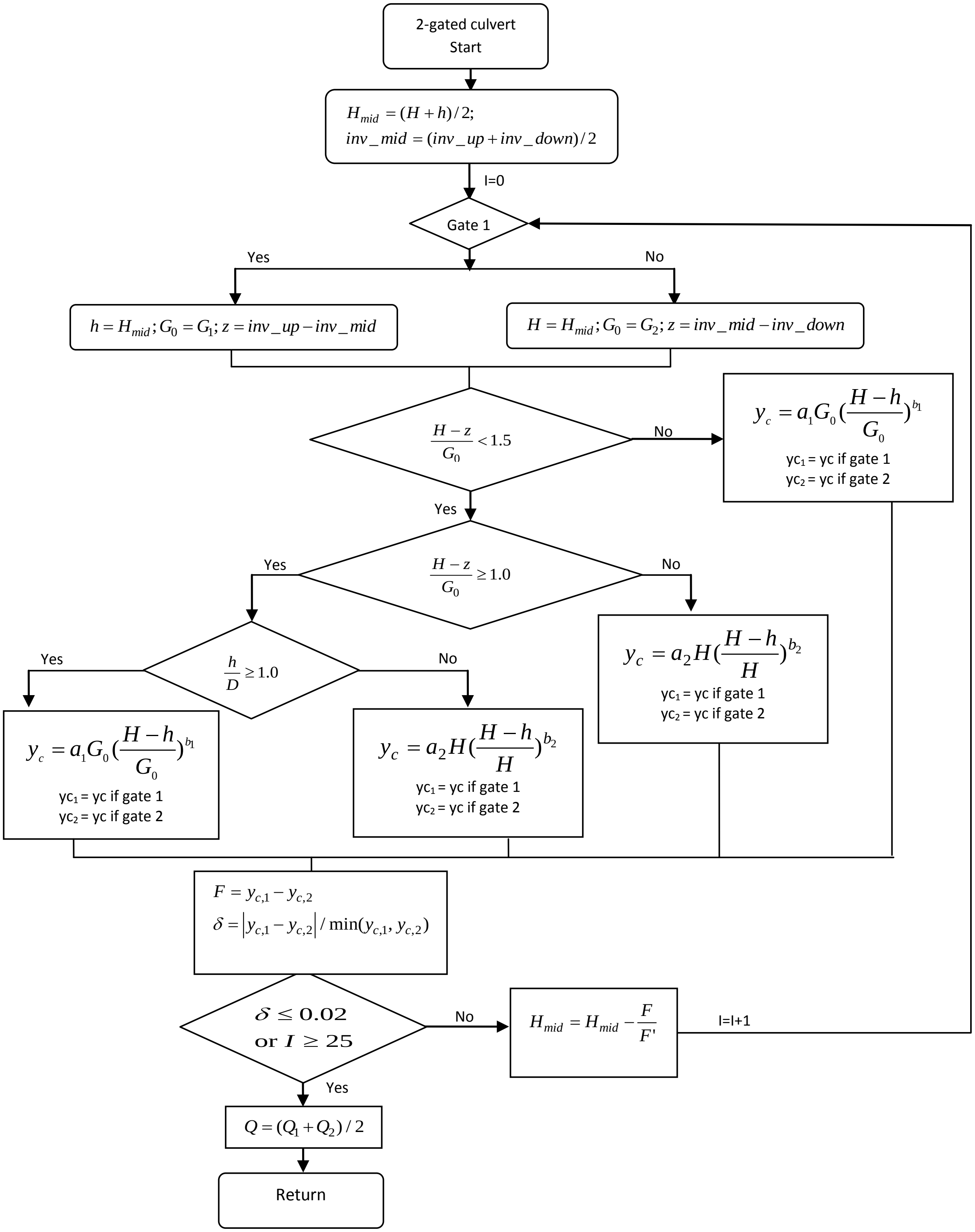


Figure 28. Flow chart depicting the flow computation procedure for a two-gated culvert

4.4.6 Culverts G-509N and G-509S

Culverts G-509N and G-509S connect the discharge chamber of pump station G-509 to the spreader canals for STA-5/6 cells 4B and 5B, respectively. The total flow through these culverts must therefore be equal to the discharge from G-509. The following iterative procedure is used to compute flow through both culvert barrels:

1) Obtain G509_P flow from the Database
2) Initialize current stage, lower bound and upper bound of stage in chamber
3) Initialize G509N_C and G509S_C flows
4) Calculate Total Flow = G509N_C + G509S_C
5) If Total Flow < G509_P flow then lower bound of stage in chamber is equal to current stage in chamber
6) Otherwise, upper bound of stage in chamber is equal to current stage in chamber
7) Current stage in the chamber is equal to the middle point between lower bound and upper bound of stage in chamber
8) Calculate G509N_C and G509S_C using the FLOW program
9) Calculate Total Flow = G509N_C + G509S_C
10) If the difference of G509_P and G509N_C + G509S_C is less than a given tolerance level (currently set to 0.01) then populate the current stage as final stage in chamber in the Database and stop the process.
11) Otherwise repeat the process starting from step 5.

4.4.7 Culvert G372HL

The design of culvert structure G372HL is unusual in that it is composed of a single barrel with two slide gates installed at its upstream end. These gates were placed in series and at right angles to each other. Flow through this structure is computed with the appropriate NFLOW routine, where the minimum gate opening is used in the flow computations.

5.0 WEIRS

Symbol	Definition
Cd	Coefficient of discharge
Ce	Effective length coefficient
CW	Channel width
H	Head water depth above sill crest
h	Tail water depth above sill crest
L	Measured crest length
Le	Effective crest length
n	Exponent taken as 1.5
ND	Notch depth
Q_{free}	Free weir flow
TWD	Top width of the weir
Wc	Crest width in the direction of the flow

Three types of weirs are used for water control within the SFWMD: ogee, trapezoidal, and variable. Otero (1995) first described flow computation procedures for District weirs. Since Otero's report there have been substantial changes to these procedures. A summary of Otero's work is presented below followed by discussions on the new and improved flow computation procedures that have been developed for selected weir types.

5.1 Ogee Weirs

An ogee weir has a parabolic crest and essentially functions as an ogee spillway. Currently, flow is computed at only two ogee weirs: S50 and S48. Only free weir flow conditions are expected at these weirs. Therefore, the flow Q_{free} is computed using the free weir equation:

$$Q_{free} = C_d L_e H^n \quad \text{Equation 92}$$

where:

C_d is the ogee coefficient of discharge;

H is the headwater depth above the sill crest;

n is an exponent taken as 1.5;

L_e is the effective crest length, given by:

$$L_e = L - C_e H \quad \text{Equation 93}$$

where L is the measured crest length and C_e is the effective length coefficient. The ogee weirs and their respective flow parameters are listed in **Appendix G1**.

5.2 Trapezoidal Weirs

A trapezoidal weir has a fixed crest with a trapezoidal cross-section or notch (**Figure 29**). Free flow at trapezoidal weirs is computed using a modified free weir equation. Submerged flow is computed using Villemonte's (1947) equation. V-notch and rectangular weirs are special cases of the trapezoidal weirs. Flow at these structures is computed using the flow computation procedures described in the following subsections for each of the flow conditions indicated.

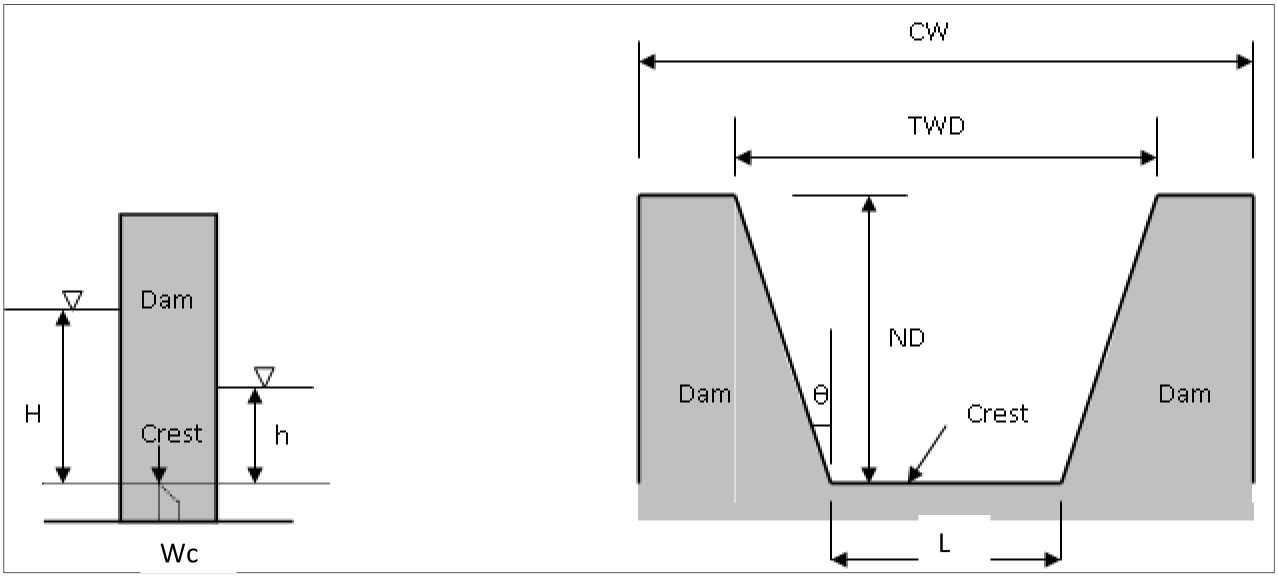


Figure 29. Trapezoidal Weir

5.2.1 *Free Flow over the Crest Only*

Criteria: $0 < H \le ND$ and $\mathrm{h} \le 0$

Flow Equation (Horton, 1907):

$$Q_{free\,crest} = C_d L H^{3/2} + 2.5 H^{5/2} \tan\theta \qquad \text{Equation 94}$$

where:

ND is the notch depth (**Figure 29**);

C_d is the discharge coefficient;

H, L and tan θ are shown in **Figure 29**.

5.2.2 *Submerged Flow over the Crest Only*

Criteria: $0 < H \le ND$ and $\mathrm{h} > 0$

Flow Equation:

$$Q_{subm\,crest} = Q_{free\,crest}\left[1 - \left(\frac{h}{H}\right)^{3/2}\right]^{0.385} \qquad \text{Equation 95}$$

Note that flow over the weir is assumed submerged once the tailwater depth is above the weir crest (h > 0). This is different from the submergence criteria used for uncontrolled flow at gated spillways, where submergence is assumed to take place when h/H > 2/3.

5.2.3 Free Flow over the Crest and Free Flow over the Structure Top

Criteria: $H > ND$ and $\mathrm{h} < 0$

Flow Equation:

$$Q_{free\,crest+free\,dam} = C_d\left[(L + ND\tan\theta)\cdot ND \cdot H^{0.5} + CW(H\text{-}ND)^{3/2}\right] \quad \text{Equation 96}$$

5.2.4 Submerged Flow over the Crest and Free Flow over the Structure Top

Criteria: $H > ND$ and $0 < \mathrm{h} \leq \mathrm{ND}$

Flow Equation:

$$Q_{subm\,crest+free\,dam} = C_d\,(L + ND\tan\theta)\cdot ND \cdot H^{0.5}\left[1\text{-}\left(\frac{h}{H}\right)^{3/2}\right]^{0.385} + C_d CW(H\text{-}ND)^{3/2} \quad \text{Equation 97}$$

5.2.5 Submerged Flow over the Crest and Submerged Flow over the Structure Top

Criteria: $H > ND$ and $\mathrm{h} > \mathrm{ND}$

Flow Equation:

$$Q_{submcrest+submdam} = C_d\,(L + ND\tan\theta)\cdot ND \cdot H^{0.5}\left[1-\left(\frac{h}{H}\right)^{3/2}\right]^{0.385} + C_d \cdot CW \cdot (H - ND)^{3/2} \cdot \left[1-\left(\frac{h-ND}{H-ND}\right)^{3/2}\right]^{0.385} \quad \text{Equation 98}$$

Rating parameters for trapezoidal weirs are provided in **Appendix G2**.

5.2.6 Special Equations for Lainhart Dam

Flow computations at Lainhart Dam have been subject to frequent revisions due to the aging and deterioration of the structure. According to Dessalegne and Damisse (2012), discharges across Lainhart Dam are computed using four algorithms implemented in the NEXFLOW program (Damisse 2000; Gonzalez, 2004; Hansing and Zeng, 2010; Dessalegne and Damisse, 2012). The algorithms account for seepage, free flow, and submerged flow components. The submerged flow algorithm (the standard Villemonte equation) was incorporated after the installation of a tailwater sensor in March 2008. The flow algorithms are as follows:

Prior to April 1, 2001 (Rating #1)

Weir Crest Elevation = 10.5

When H < 0, From Leakage and Seepage flow was computed by:

$$Q = \frac{2}{3}(HW - 6)^{2.5}$$

When H ≥ 0,

$$Q = 28.62 + 77.93H^{1.5}$$

Between April 1, 2001 and March 14, 2008 (Rating #2)

Weir Crest Elevation = 10.5

When H < 0

$$Q = 1.5(HW - 6)^{1.5}$$

When H ≥ 0,

$$Q_{free} = 14.3 + 88.8H^{1.5}$$

Between March 15, 2008 and December 22, 2009 (Rating #3)

Weir Crest Elevation = 10.43

When H < 0

$$Q = 1.5(HW - 6)^{1.5}$$

When h/H ≤ 0.8

$$Q_{free} = 13.97 + 88.8H^{1.5}$$

When h/H > 0.8

$$Q_{sub} = 13.97 + 88.8H^{1.5} \bullet \left[1 - \left(\frac{h}{H}\right)^{1.5}\right]^{0.385}$$

Between December 22, 2009 and May 2, 2013 (Rating #4)

Weir Crest Elevation = 10.25

When H < 0

$$Q = 1.5(HW - 6)^{1.5}$$

When h/H ≤ 0.7

$$Q_{free} = 13.14 + 88.8H^{1.5}$$

When h/H > 0.7

$$Q_{sub} = 13.14 + 1.4086 \times 88.8H^{1.5} \bullet \left[1 - \left(\frac{h}{H}\right)^{1.5}\right]^{0.385}$$

In the above equations, *HW* is the headwater elevation, *H* is headwater depth above the weir crest and *h* is the tailwater depth above the weir crest.

As of May 2, 2013, the NEXFLOW program no longer computes flow at Lainhart Dam because the responsibility for flow computations at the site were transferred to the U.S. Geological Survey.

5.2.7 Special Equations for the Faka Union Weir

Flow across the Faka Union Weir was previous computed with trapezoidal weir equations. New rating equations based on the Case 5 uncontrolled spillway flow model were recently developed by Dessalegne (2011a) for this weir. The equations have been included in the weir flow computation section of the NEXFLOW program.

5.3 Variable Crest Weirs

A variable crest weir is a weir in which the depth of the notch can be regulated by raising or lowering the crest. For variable crest weirs, the discharge coefficient depends on whether the weir is sharp-crested, broad-crested, or somewhere in between. The ratio of the headwater above the sill (H) to the crest width (W_c) in the direction of the flow (H/W_c) dictates whether a weir is broad- or sharp-crested. **Table 7** lists the discharge coefficients for variable weirs. The variable weirs and their respective flow parameters are listed in **Appendix G3**.

Table 7. Discharge coefficients for variable crest weirs

Crest Type	Flow Condition	Coefficient of Discharge, Cd
Broad	$H<0.4W_c$	2.62
Transition	$0.4 \le H \le 1.5W_c$	$2.62+0.64(H/W_c-0.4)$
Sharp	H>1.5Wc	3.32

During flow computations, the sill elevation and the crest width for variable crest weirs are treated as dynamic parameters. The variable crest weir discharge coefficient is determined using the criteria given in **Table 7** along with the crest lengths, widths, and elevations provided in **Appendix G3**. The flow computation procedure can be summarized as follows:

(1) $H \le 0$:

Q = 0

(2) H > 0 and $h \le 0$:

$$Q = C_d\left(L - 0.2H\right)H^{1.5}$$

(3) $H > 0 \; and \; h > 0$:

$$Q = C_d\left(L - 0.2H\right)H^{1.5}\left[1 - \left(\frac{h}{H}\right)^{1.5}\right]^{0.385}$$

(4) $HW \ge ND$ +Minimum Crest Elevation

When water over-tops the structure and flows over the embankment, the weir crest length depends on the topography of the embankment. Because Q depends on this length, it cannot be easily calculated under such circumstances. Furthermore, the Villemonte (1947) correction factor for submergence shown in Step 3 above becomes less accurate as flow conditions deviate from those of a sharp-crested weir.

6.0 USE OF CFD IN CALIBRATING FLOW RATING EQUATIONS

As mentioned previously, the generalized flow rating equations presented in the previous sections are typically calibrated to field flow measurements prior to their being used to compute flow through specific structures. Currently, field flow measurements at hydraulic structures are acquired through hydroacoustic-based flow meters, including acoustic Doppler flow meters (ADFMs), acoustic Doppler current profilers (ADCPs), and other state-of-the-art flow meters. The measured flow data are reviewed and evaluated for compliance with accepted quality standards. Measured flows that are of acceptable quality are then used to calibrate and verify the flow rating equations for the structure where the flows were measured. Field flow measurements can be expensive and time consuming. Furthermore, at a given structure, flow measurements usually cannot be carried out over the desired range of static heads and flows due to meteorological and operational constraints. This can make the calibrated rating equation less reliable over the ranges of static heads and flows that lack measured data.

Due to the availability of high-performance computers and general purpose computational fluid dynamics (CFD) software, it is possible to numerically simulate flows through hydraulic structures under conditions for which measured data are lacking or nonexistent. The CFD simulations used to compute these flows are based on the Reynolds-Averaged Navier-Stockes equations, the κ-ε turbulence closure model, and resolution of the free-surface through use of the Volume of Fluid (VOF) method. In recent years, the SFWMD has successfully developed and applied new approaches (Zeng et al., 2010, 2011) to generate CFD-simulated flow data that can be used to improve culvert, spillway, weir, and pump station flow ratings.

More recently, Zeng et al. (2014a,b) developed a framework for selecting boundary conditions for CFD simulations, assessing numerically generated flows, and evaluating flow rating improvements achieved through calibration to a set of measured and simulated flows. This has helped increase the number of flow rating equations that can be improved by increasing the amount and variety of flow data available for calibration.

7.0 LIMITATIONS OF THE NEXFLOW PROGRAM

The NEXFLOW program accurately computes flow at most structures. However, the program has limitations that can introduce errors into the computed flows. This section describes the current limitations of the NEXFLOW program and the need for further research.

7.1 Spillways

7.1.1 Transitional Flows

In the NEXFLOW program, the transitions between submerged and unsubmerged flows and between controlled and uncontrolled flows are not well defined in the Case 1 model. The break point between submerged and unsubmerged flow is taken to be at a tailwater depth to headwater depth ratio of 0.5 (h/H = 0.5) for uncontrolled flows. For controlled flows, a ratio of tailwater depth to gate opening equal to 0.5 (h/Go = 0.5) is the assumed break point. No engineering bases for these limits are given. Furthermore, it is expected that the transition point will vary from one structure to another. Similarly, the flow is assumed in transition between controlled and uncontrolled flows whenever the ratio of the headwater depth to the gate opening is between 1 and 1.7 (1 < H/Go < 1.7). There is not a strong physical basis for these demarcations. Moreover, in this transition region it is not clear which flow model (controlled or uncontrolled) is more accurate. Currently, the NEXFLOW program sets the discharge equal to the minimum of the two flows. The selection of the minimum of these two flows has little, if any, physical basis. A somewhat more realistic approach would be to use the average flow between the two computed discharges. Better still, the Case 1 transition regions should be defined with a solid hydraulic basis and flow equations that are applicable to these regions should be developed. The process used to determine transitional flows can be depicted by **Figure 30**.

Likewise, in the Case 5 flow model, the demarcation between submerged and unsubmerged flows occurs at h/H = 2/3 for uncontrolled flow, and h/Go > 1.0 for controlled flow. The basis for these thresholds is not clear, and no transitional zone is defined. Additionally, controlled and uncontrolled flow is differentiated by the criterion H/Go = 3/2. While this has some physical basis, no transition zone is defined. These issues require additional investigation.

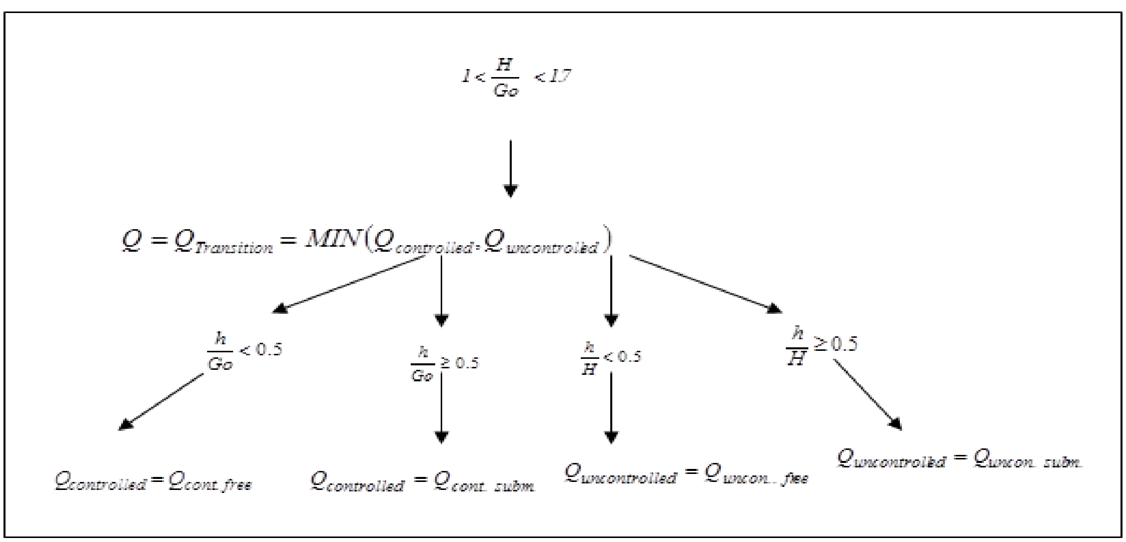


Figure 30. Procedures used by NEXFLOW to compute transitional flows

7.1.2 Reverse Flows

When the headwater elevation is less than the tailwater elevation, the NEXFLOW program interchanges the headwater and tailwater elevations, and computes the discharge with the same equation as forward flow, and assigns a negative value to it. There are two primary issues associated with this practice. First, if there is an actual reverse flow, the equation used to compute forward flow (positive discharge) is not necessarily applicable to flow in the opposite direction. This is particularly true at ogee-type spillways where the shapes of the opposite sides of the spillway are entirely different. Flow equations that are applicable to reverse flow through spillways need to be developed.

Second, a measured negative head difference at a coastal spillway presents a unique problem. It can be produced by tidal effects on the downstream side of the structure. Under these circumstances, a flow driven by tidal effects is, in reality, superimposed on the familiar gravity-driven flow. The flow computation algorithms needed to accurately compute flow under these conditions have been developed (Ma et al., 2014) and are currently being reviewed and tested.

7.2 Pumps

Certain improvements are needed to better handle flow computations under unusual conditions that sometimes occur at pump stations such as the following:

- Multiple pumps discharging into a common header that is connected to a single transmission pipe. In this instance, allowances need to be made for entering multiple rating equations per pumping unit, where the rating equation applied to a given pump depends on the number of pumps in operation.
- Modifications to the case 8 rating equation are needed so that it can directly compute pumped flows under a negative static head. This subject requires further research.
- The procedure used to account for head losses through flap gates needs improvement and more experimental data.

7.3 Culverts

The limitations of the current flow program in computing flows through culverts are discussed in the following subsections. The latter two limitations have little impact on computed daily flows because the hydraulic conditions associated with the limitations do not occur frequently.

7.3.1 Full-Barrel Flows

The NFLOW equation for full-barrel flow (Equation 77) was derived under the assumption that the coefficient C is a constant. In reality, it can be shown that C varies with the gate opening (Gonzalez, 2005; Wilsnack, 2010). The NEXFLOW program should be modified accordingly. Additionally, the measured flow data or CFD-simulated flows needed to quantify the relationship between C and Go at each culvert should be acquired. However, this effort likely would require considerable resources.

7.3.2 Unaddressed Flow Scenarios

NEXFLOW can handle up to six flow scenarios at a standard culvert. According to Franz and Melching (1997), this number can be substantially higher. Some of the uncovered scenarios, although unlikely in south Florida, include the following:

Critical flow in the approach section (few feet upstream of the culvert entrance) with a supercritical flow throughout the culvert including the entrance section.

Supercritical flow throughout the culvert barrel with a hydraulic jump occurring near its downstream end.

7.3.3 Transitional Flows

The transitions between the different flow conditions (open channel flow, orifice flow, and full pipe flow) at a culvert are not well defined and are not considered in the flow computations. These transitions warrant further investigations.

7.3.4 Reverse Flows

There are limitations of NEXFLOW in computing reverse flows through culverts. The same equations used to compute forward flow are applied to flow in the reverse direction. The only difference in the computed reverse flow is that its sign is negative. The primary issue associated with this practice is that the equations used to compute forward flows (positive discharge) are not necessarily applicable to flows in the opposite direction. This is especially true at culverts where (1) the invert elevations at the two barrel ends are substantially different, or (2) inlet and outlet conditions lead to significantly different entrance loss coefficients. Flow equations that are applicable to reverse flows need to be developed for asymmetrical culverts.

7.4 Weirs

For most weirs, the NEXFLOW program assumes that free weir flow becomes submerged weir flow once the tailwater elevation rises above the weir crest ($h > 0$). This is a commonly used assumption for sharp-crested weirs (Wu and Rajaratnam, 1996; Villemonte, 1947; Abou-Seida and Quarashi, 1976). Flow at a weir becomes submerged when the following condition is satisfied: the downstream flow depth is increased to the extent that the velocity at every point through the weir is less than the critical value (Walker and Skogerboe, 1987). Therefore, the transition between free and submerged weir flow will not necessarily take place once the tailwater is above the weir crest. The transition range for the submergence of sharp-crested weirs should be better defined and accounted for in flow computations.

Similarly, Hulsing (1967) reported that submergence has minimal effect on the discharge of a broad-crested weir if the submergence ratio is less than 0.85. However, some improvement to the accuracy of flow computations at broad-crested weirs may be realized if the transition range for downstream submergence is better defined.

8.0 SUMMARY AND CONCLUSIONS

The SFWMD maintains and operates more than 500 hydraulic structures, including spillways, pump stations, culverts, and weirs. Using instantaneous stage and control information, instantaneous flow values at these structures are calculated using an in-house computer program called NEXFLOW. The NEXFLOW program, written in the Java programming language with embedded SQL scripts, is a reengineered version of the previous FLOW program that was written in Fortran Pro/E.

The NEXFLOW program currently is used for the following purposes:

- Computing flows through water control structures;
- Verifying the validity of stream-gauging records using physically based equations;
- Calibrating discharge coefficients of the control structures under various flow conditions and structure operations;
- Testing and developing new and more robust computational algorithms for the purpose of improving existing flow records; and
- Performing quality assurance of existing data.
- Flows computed by the NEXFLOW program are used for water budget analyses, water quality analyses, flood plain studies, flood frequency analyses, hydrologic modeling, and design of new water management facilities.

This Flow Atlas is a compilation and exposition of the flow equations currently used to compute flow through all District structures. Most of the equations provided herein are physically based, derived from the fundamental principles of hydraulics and fluid mechanics. Some of the equations, however, are empirical in nature, obtained from regression analyses. Additionally, this report tabulates the associated flow parameters for each structure. One new flow computation procedure introduced in this report pertains to Case 6 spillway flows. These flows are computed by a single equation that is applicable to all spillway flow regimes along with the transition regions between them. This flow rating model was first developed and introduced by Ansar and Chen (2009) and later enhanced by Gonzalez-Castro and Mohamed (2009).

Current limitations of the flow computational procedures, possible improvements, and areas requiring further research were addressed.

9.0 ACKNOWLEDGEMENTS

This version of the Flow Atlas was preceded by several earlier versions, including Ansar and Alexis (2003) and SFWMD (2007). Much of the information, including figures, contained herein was carried over from these earlier versions and modified. The authors of this version of the Flow Atlas would like to acknowledge the contributions of the previous authors.

10.0 APPENDICES

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Appendix B – Examples of SFWMD Water Control Structures

Figure B-1. Diesel Pump Station

Figure B-2. Diesel and Electric Pump Station

Figure B-3. Vertical Lift Gate

Figure B-4. Sluice/Slide Gate

Figure B-5. Tainter Gate

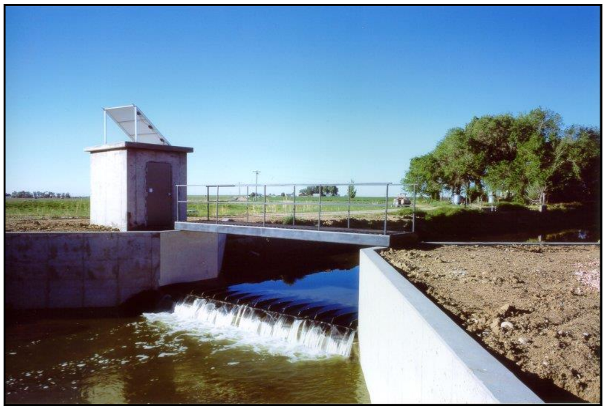

Figure B-6. Bladder Gate

Figure B-7. Fixed-Crest Weir

Figure B-8. Flashboard Bays

Figure B-9. Sector Gate Navigational Lock

Figure B-10. Vertical Lift Navigational Lock

Appendix C – Typical SFWMD Water Control Structure Designs

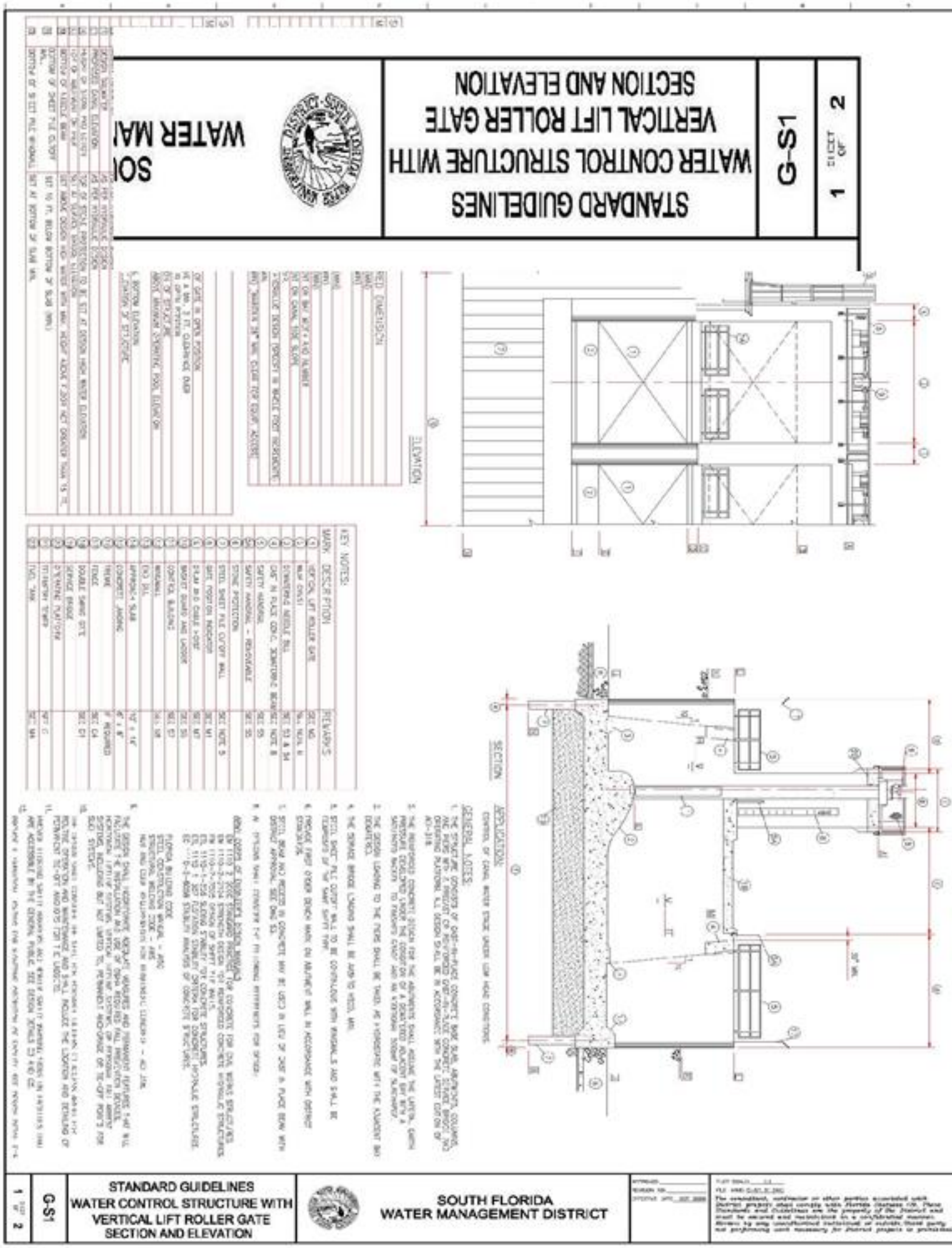

Figure C-1. Standard Guidelines: Section View of a Water Control Structure with a Vertical Gate

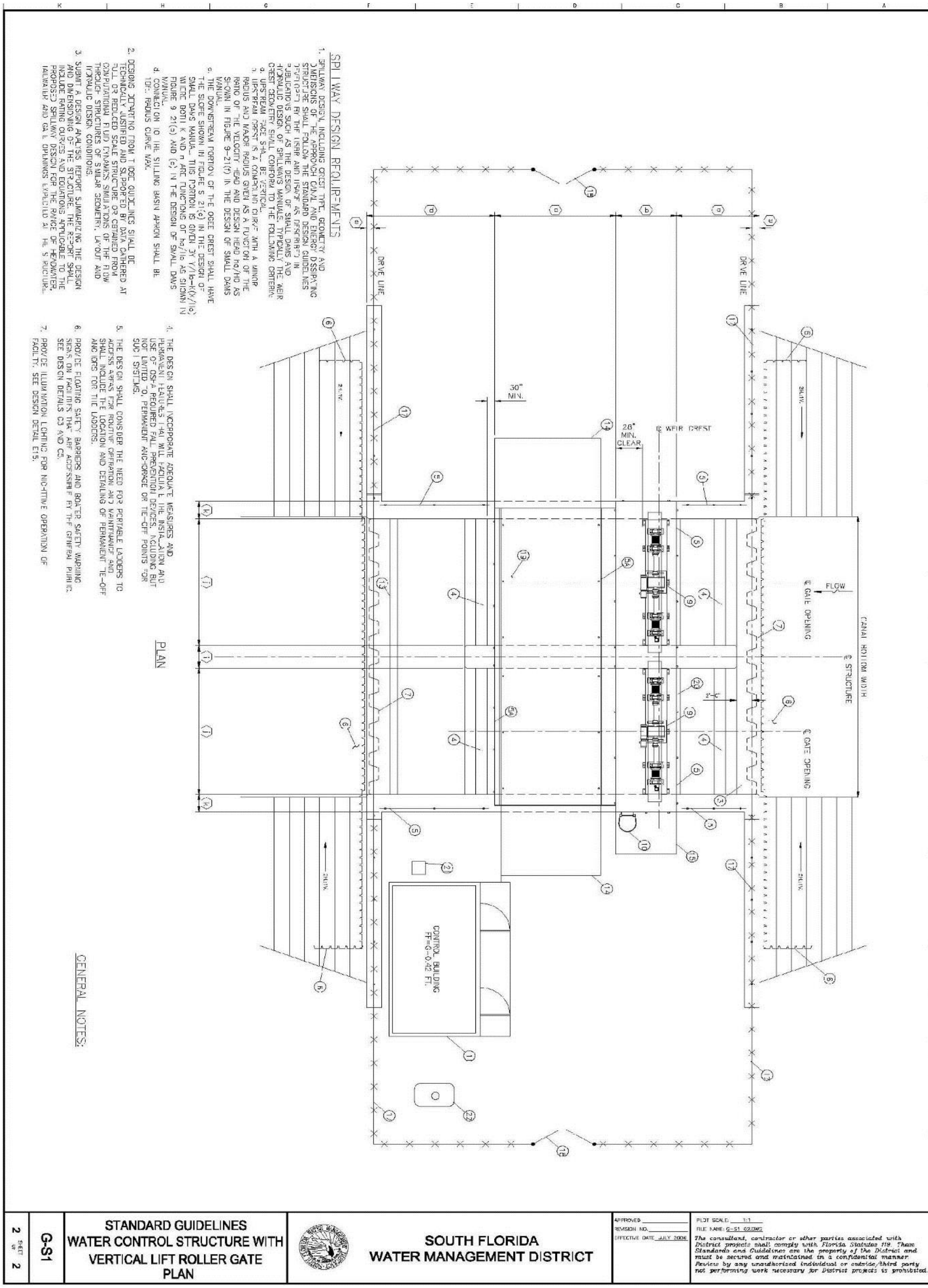

Figure C-2. Standard Guilelines: Plan View of a Water Control Structure with a Vertical Gate

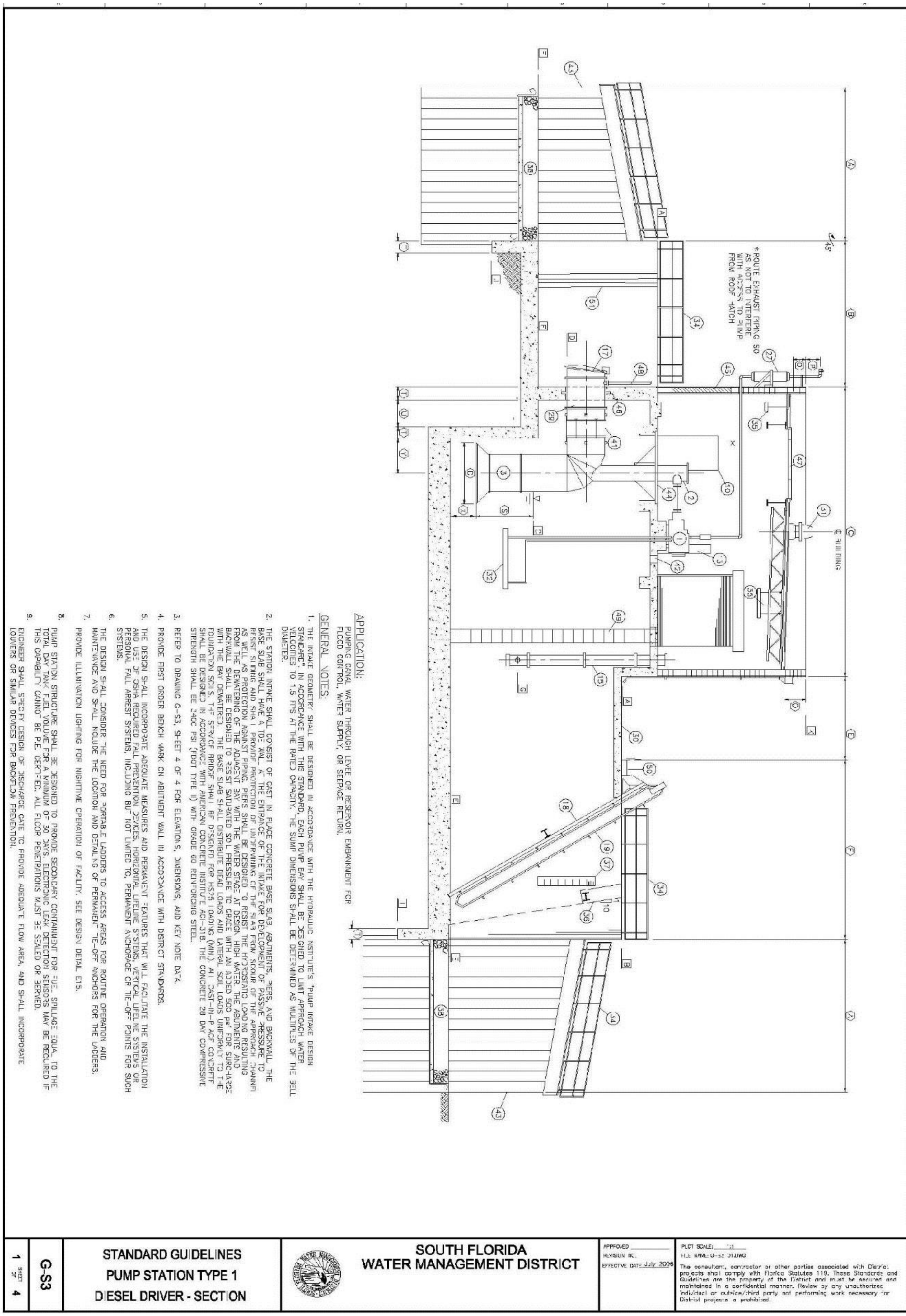

Figure C-3. Standard Guidelines: Elevation View of a Pump Station with a Type 1 Diesel Driver

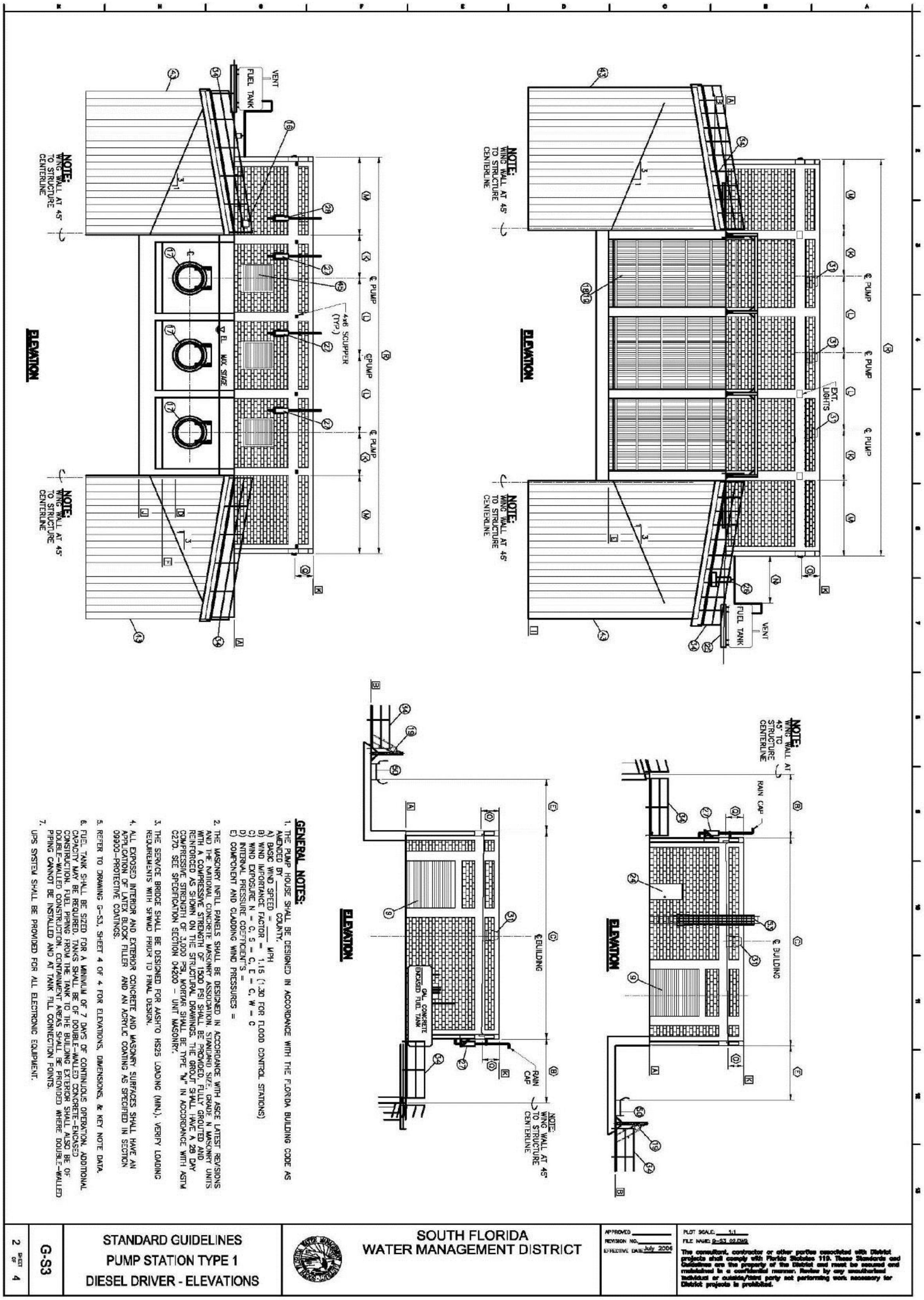

Figure C-4. Standard Guidelines: Plan View of a Pump Station with a Type 1 Diesel Driver

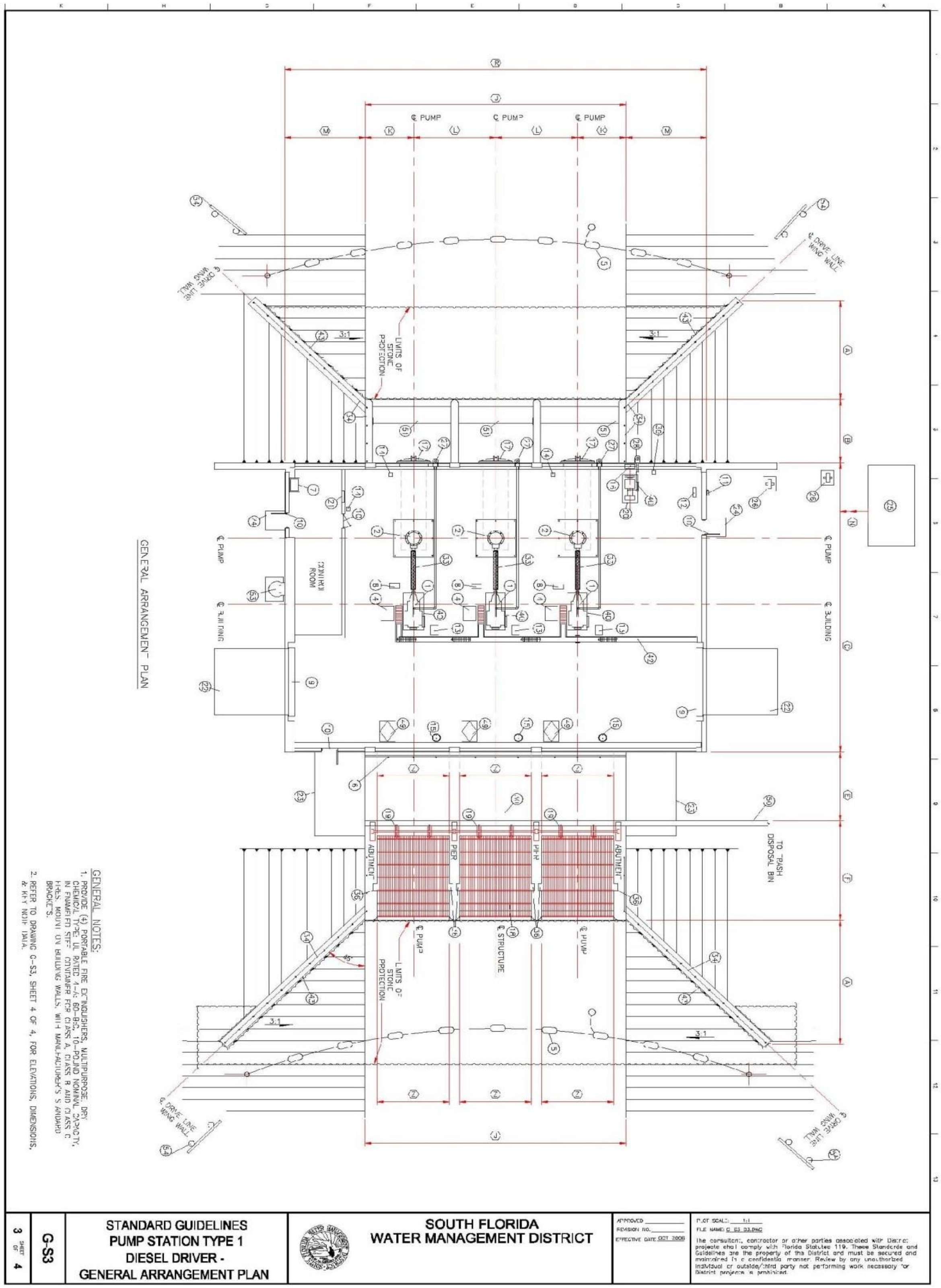

Figure C-5. Standard Guidelines: General Arrangement Plan for a Pump Station with a Type 1 Diesel Diver

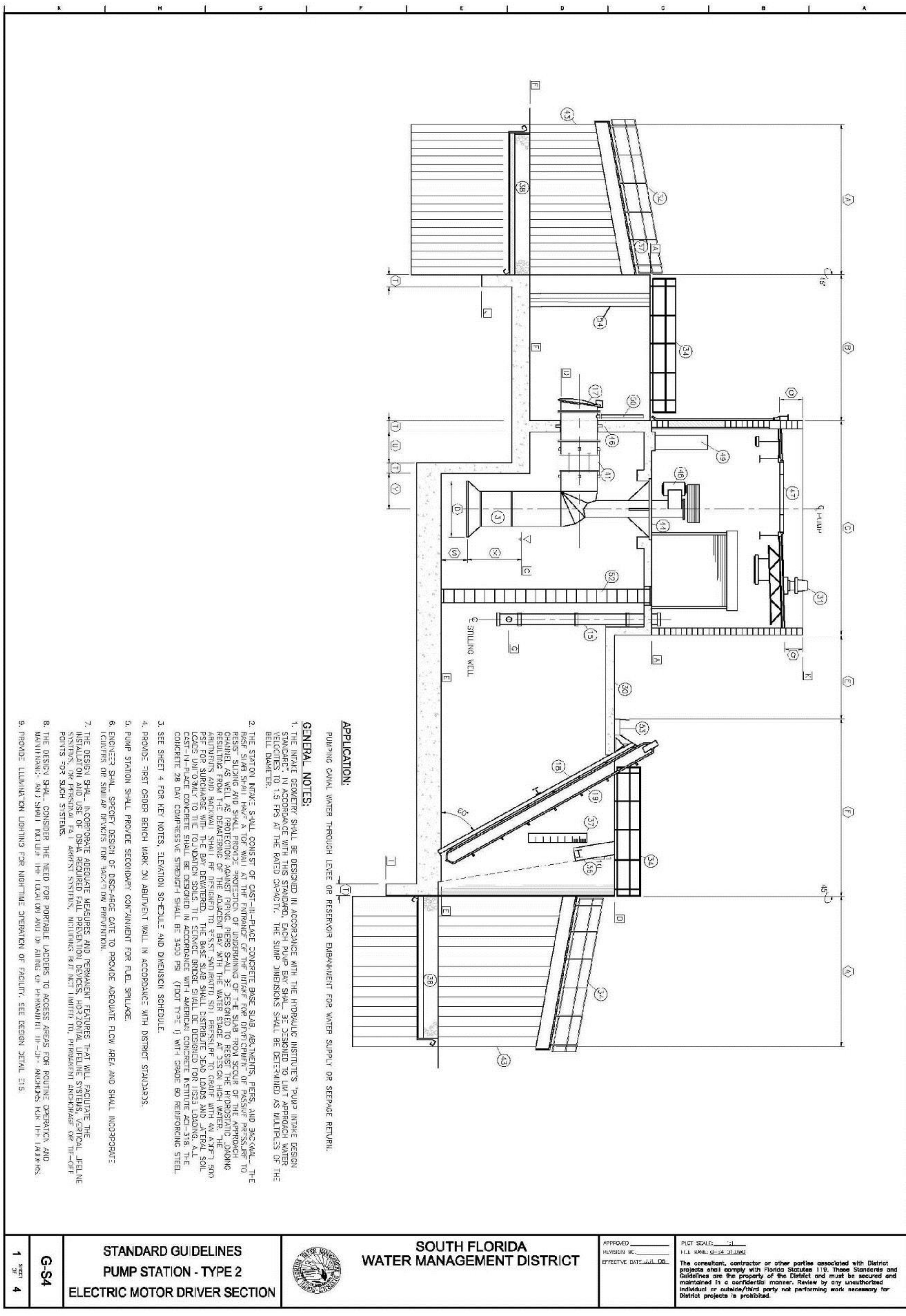

Figure C-6. Standard Guidelines: Type 2 Electric Motor Driver Section

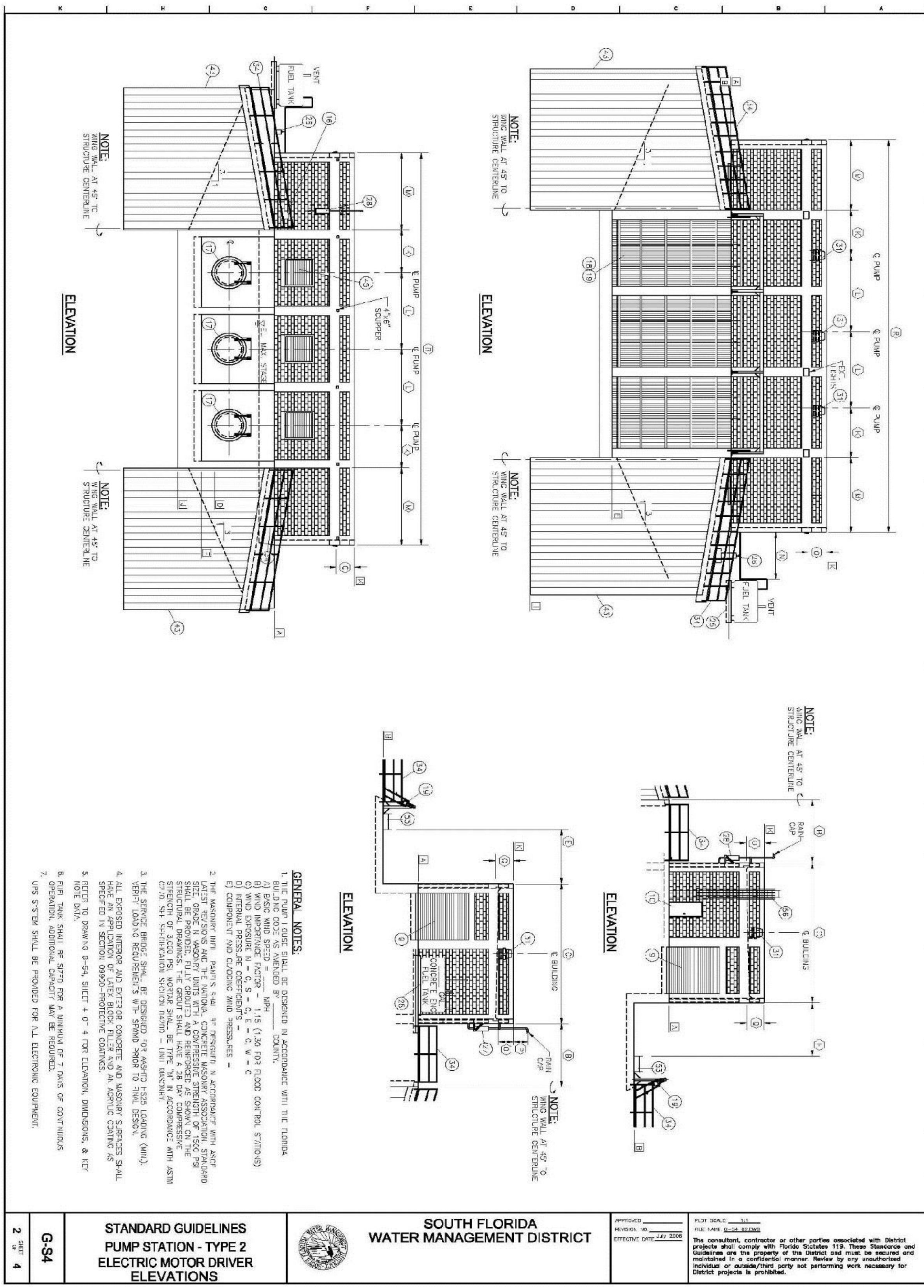

Figure C-7. Standard Guidelines: Type 2 Electric Motor Driver Elevation

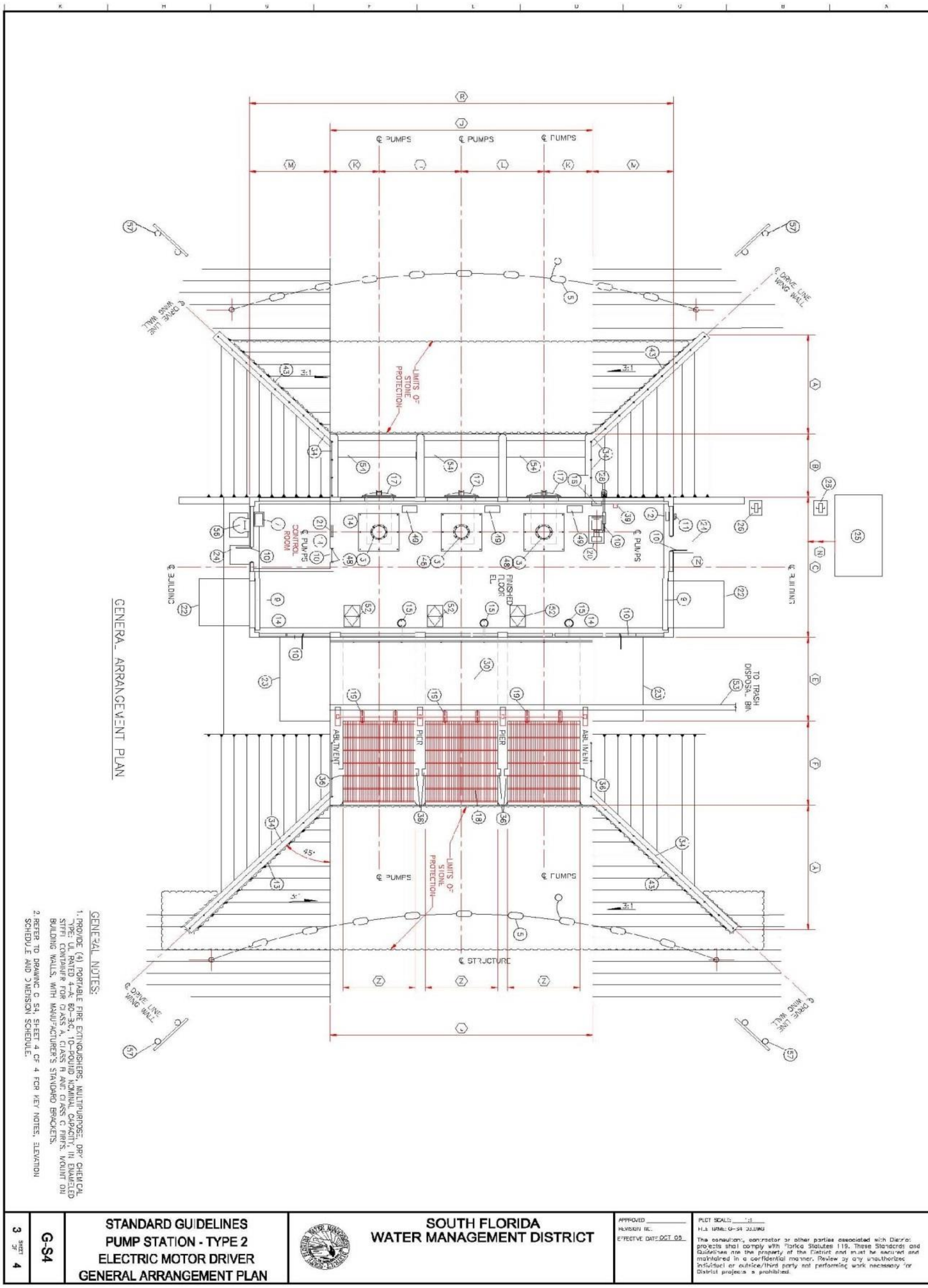

Figure C-8. Standard Guidelines: Type 2 Electric Motor Driver, General Arrangement Plan

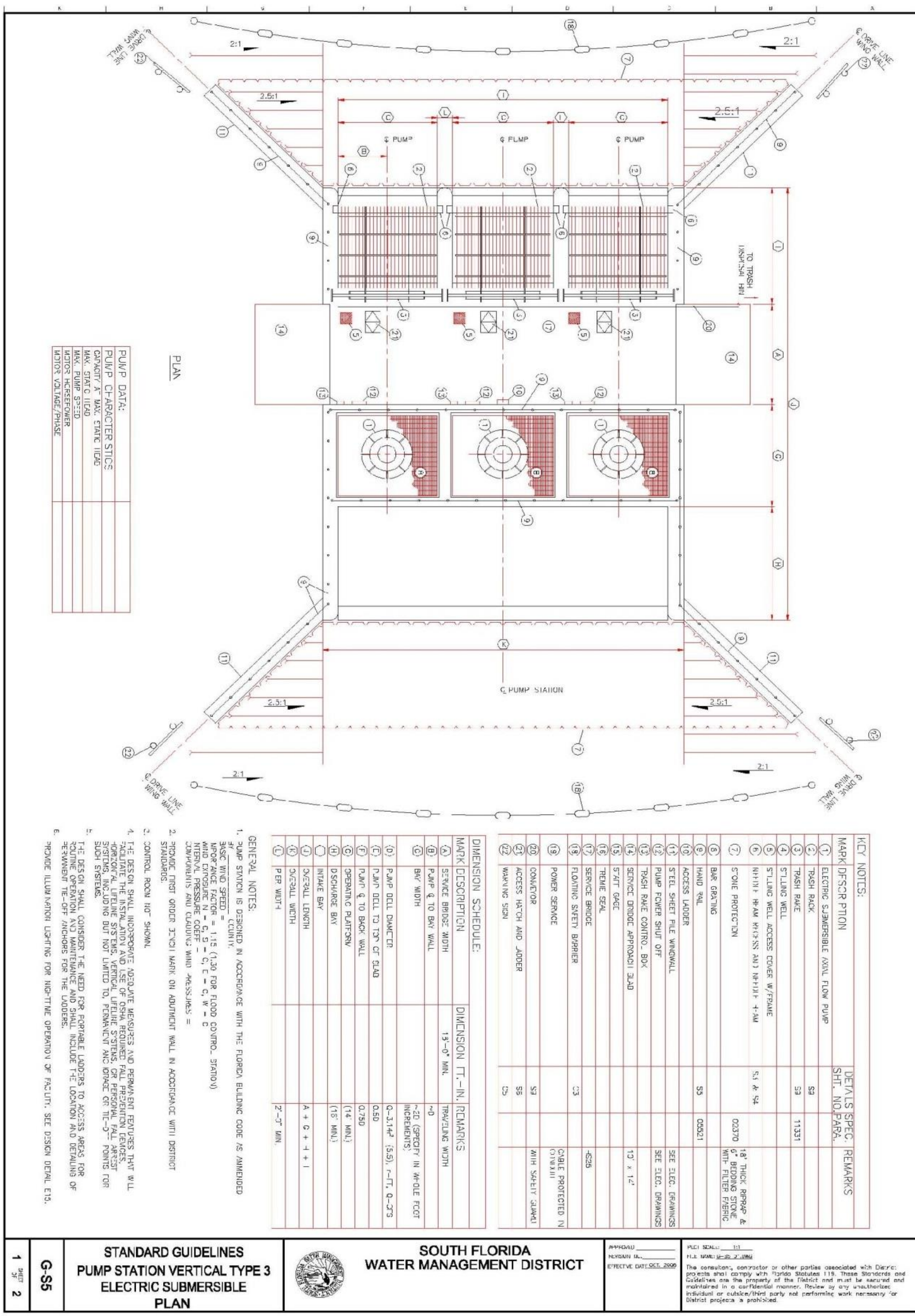

Figure C-9. Standard Guidelines: Electric Pump Station, Vertical Type 3 Submersible Plan

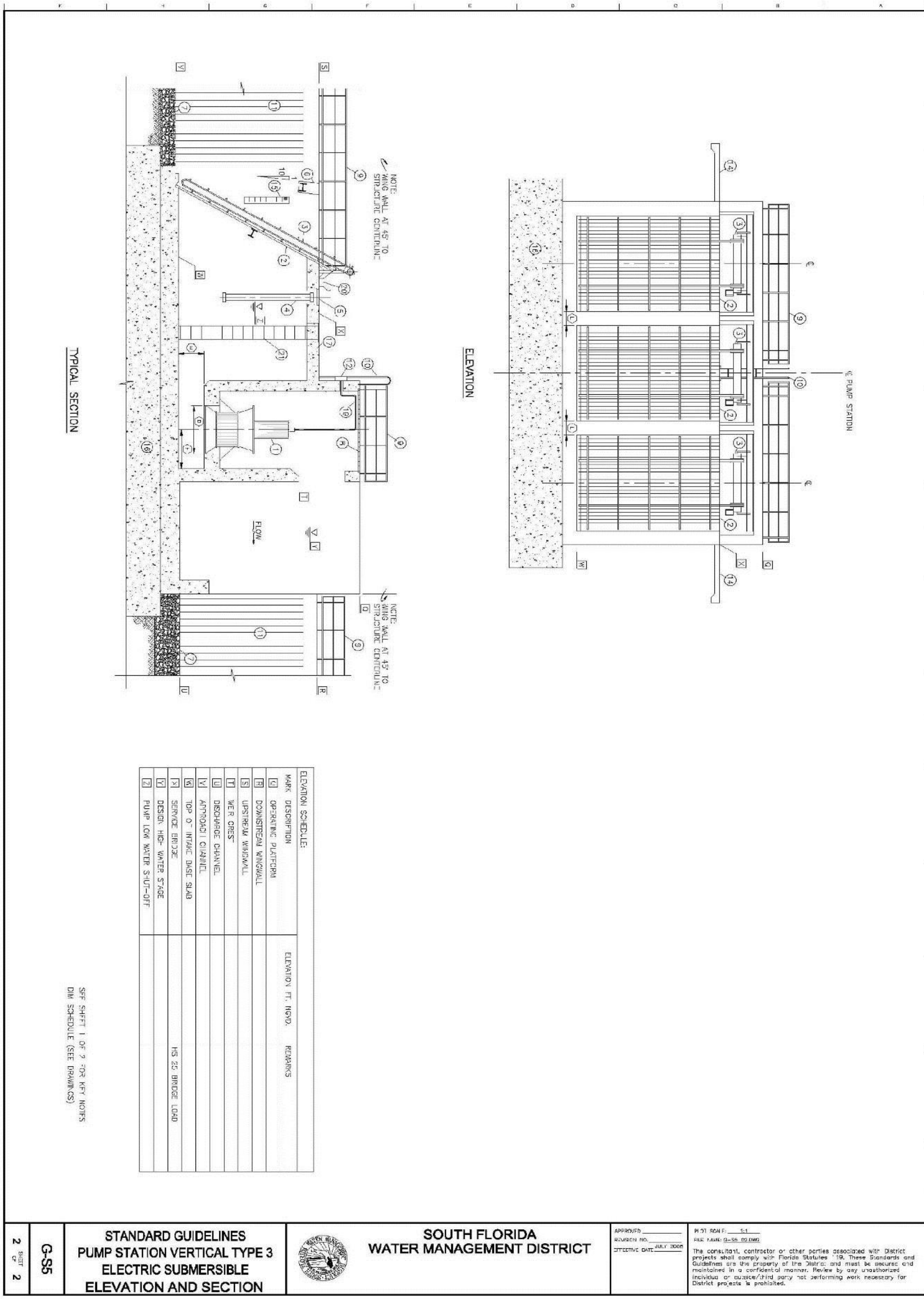

Figure C-10. Standard Guidelines: Electric Pump Station, Vertical Type 3 Submersible Elevation and Section

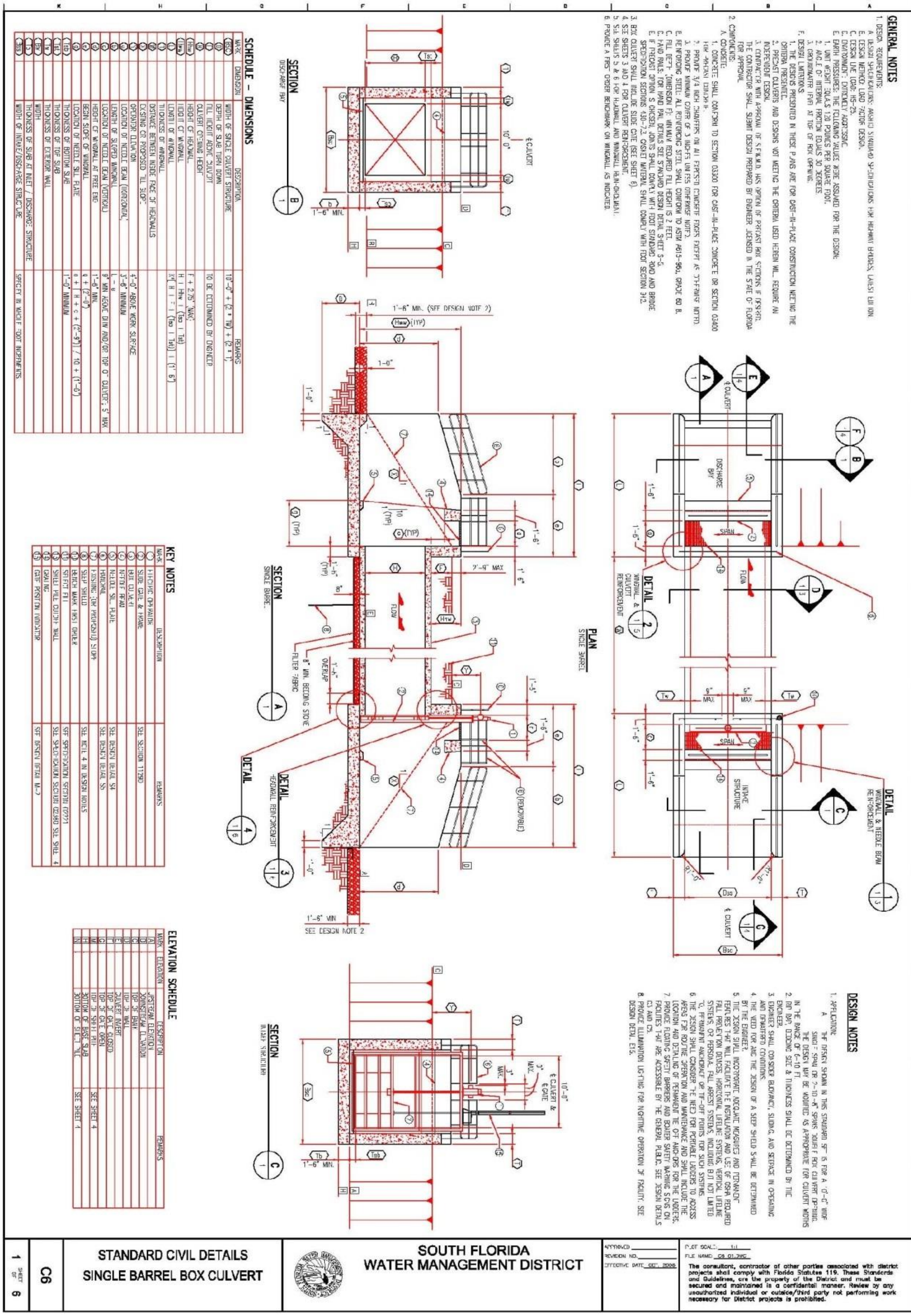

Figure C-11. Standard Civil Details for a Single-Barrel Box Culvert

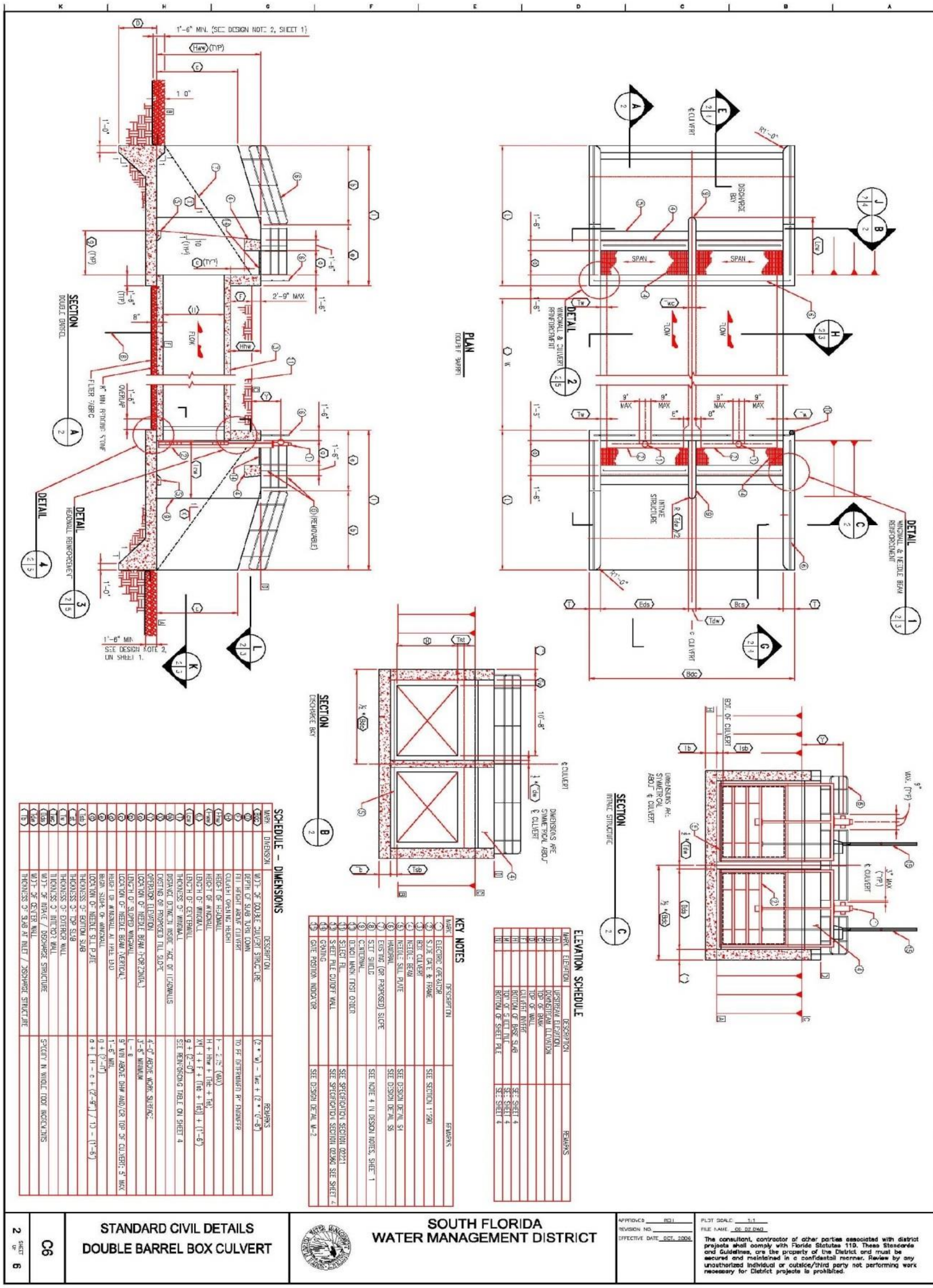

Figure C-12. Standard Civil Details for a Double-Barrel Box Culvert

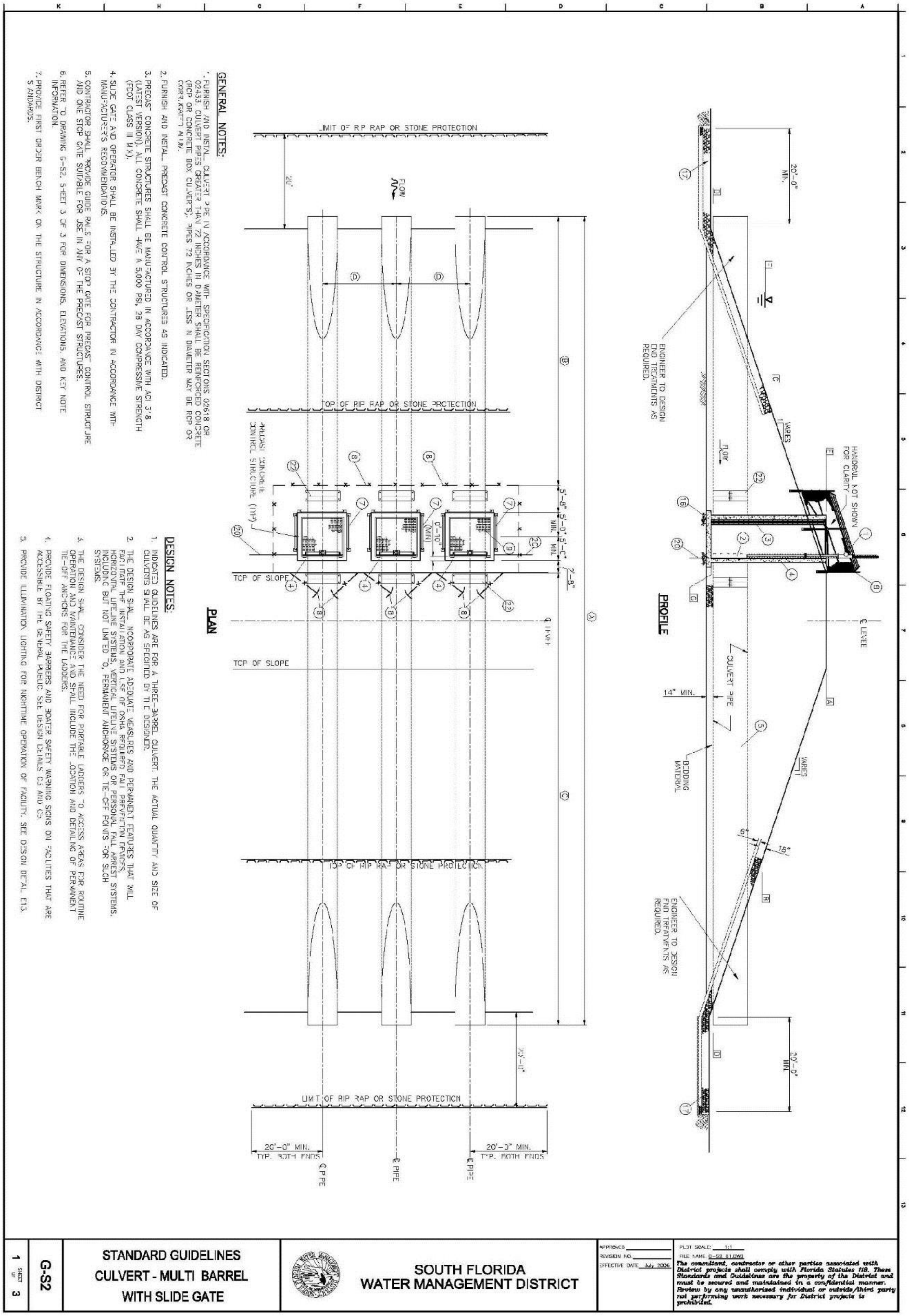

Figure C-13. Standard Civil Details for a Multi-Barrel Box Culvert

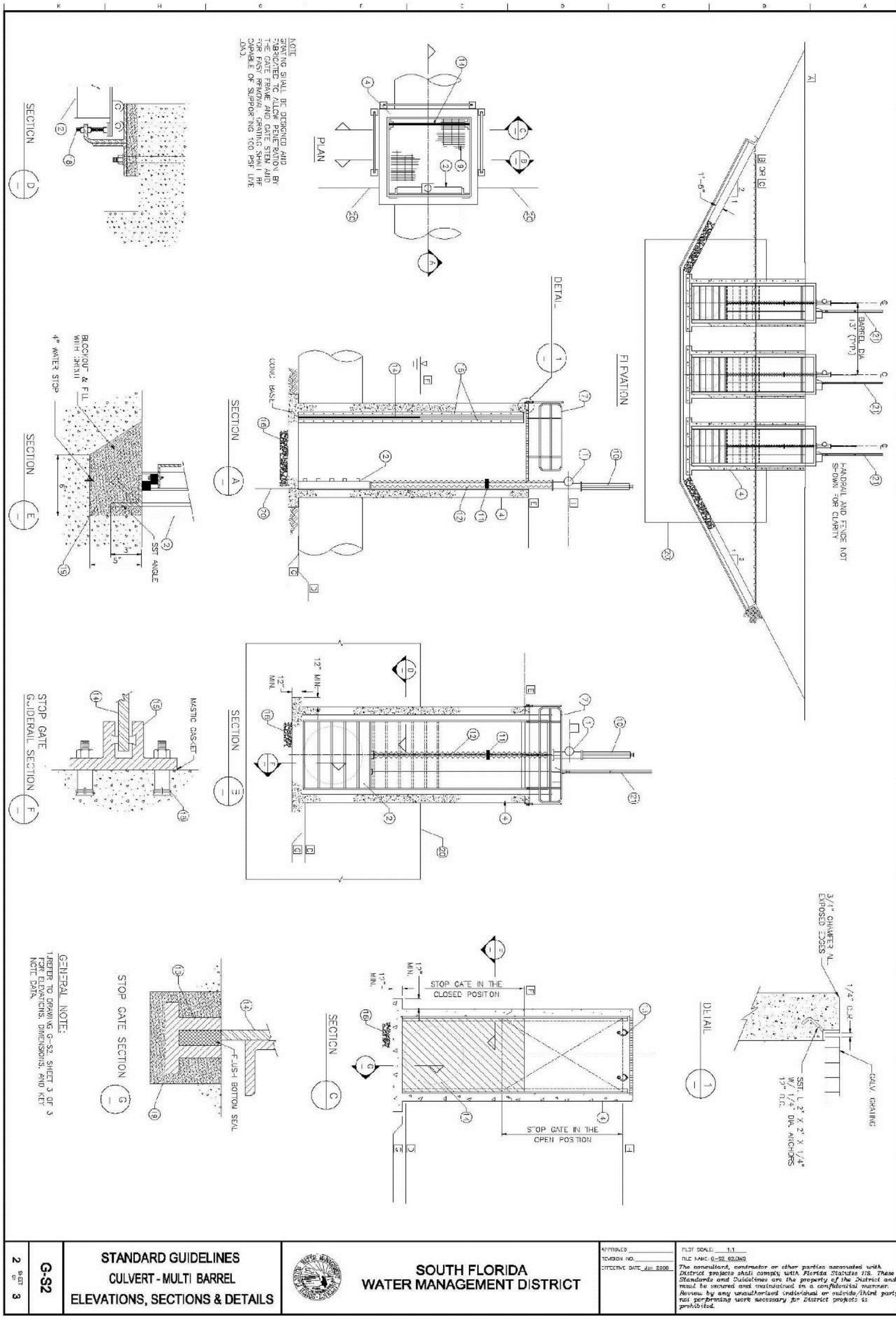

Figure C-14. Elevations, Sections and Details of a Multi-Barrel Box Culvert

Appendix D – Spillways

Appendix D1 – Flow Parameters for Spillways in Case 1

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elevation (ft)	Sill Length (ft)	Sill	Bypass Stage	CSFC	CFFC	USFC	UFFC	OTFC
S148_S	12/14/1965	1	12	20.8	-7	20	O	9	0.75	0.75	0.9	2.9	0.41
S148_S	12/14/1965	2	12	20.8	-7	20	O	9	0.75	0.75	0.9	2.9	0.41
S167_S	12/31/1799	1	7	12.8	-0.5	12	O	6.5	0.75	0.75	1	3.2	0.41
S174_S	06/19/1970	1	8	16.8	-1.5	16	O	11	0.75	0.75	0.9	2.9	0.41
S177_S	01/01/1967	1	12.6	22.8	-7.1	22	O	9	0.75	0.75	0.9	2.9	0.41
S179_S	12/31/1799	1	12	25.8	-7.5	25	O	6	0.75	0.75	0.9	2.9	0.41
S179_S	12/31/1799	2	12	25.8	-7.5	25	O	6	0.75	0.75	0.9	2.9	0.41
S20A_S	12/31/1799	1	11.4	16.75	-9.3	16	O	7	0.75	0.75	0.9	2.9	0.41
S20F_S	12/31/1799	1	13	25	-9	25	O	7	0.75	0.75	0.947	2.9	0.41
S20F_S	12/31/1799	2	13	25	-9	25	O	7	0.75	0.75	0.947	2.9	0.41
S20F_S	12/31/1799	3	13	25	-9	25	O	7	0.75	0.75	0.947	2.9	0.41
S20G_S	12/31/1799	1	12.3	25.8	-8.3	26	O	7	0.75	0.75	0.9	2.9	0.41
S20_S	12/31/1799	1	11.4	16.75	-7.4	16	O	7	0.75	0.75	0.9	2.9	0.41
S21A_S	12/31/1799	1	11.8	20.8	-7.8	20	O	8	0.75	0.75	1.1	3.19	0.41
S21A_S	12/31/1799	2	11.8	20.8	-7.8	20	O	9	0.75	0.75	1.1	3.19	0.41
S21_S	03/25/1963	1	10.7	27.8	-6.5	27	O	8	0.75	0.75	0.9	2.9	0.41
S21_S	03/25/1963	2	10.7	27.8	-6.5	27	O	8	0.75	0.75	0.9	2.9	0.41
S21_S	03/25/1963	3	10.7	27.8	-6.5	27	O	8	0.75	0.75	0.9	2.9	0.41
S25B_S	12/31/1799	1	11.9	22	-7.9	22	O	5.7	0.75	0.75	0.9	2.9	0.41
S25B_S	12/31/1799	2	11.9	22	-7.9	22	O	5.7	0.75	0.75	0.9	2.9	0.41
S26_S	12/31/1799	1	14.1	26	-10.1	26	O	5.5	0.75	0.75	0.9	2.9	0.41
S26_S	12/31/1799	2	14.1	26	-10.1	26	O	5.5	0.75	0.75	0.9	2.9	0.41
S27_S	04/06/1959	1	15	27.7	-11	27	O	4	0.75	0.75	0.9	2.9	0.41
S27_S	04/06/1959	2	15	27.7	-11	27	O	4	0.75	0.75	0.9	2.9	0.41
S28_S	12/14/1965	1	17.5	27.8	-13.5	27	O	4	0.75	0.75	0.9	2.9	0.41
S28_S	12/14/1965	2	17.5	27.8	-13.5	27	O	4	0.75	0.75	0.9	2.9	0.41
S29_S	12/11/1953	1	15	22.8	-11	22	O	6	0.75	0.75	0.9	2.9	0.41
S29_S	12/11/1953	2	15	22.8	-11	22	O	6	0.75	0.75	0.9	2.9	0.41
S29_S	12/11/1953	3	15	22.8	-11	22	O	6	0.75	0.75	0.9	2.9	0.41
S29_S	12/11/1953	4	15	22.8	-11	22	O	6	0.75	0.75	0.9	2.9	0.41

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elevation (ft)	Sill Length (ft)	Sill	Bypass Stage	CSFC	CFFC	USFC	UFFC	OTFC
S333_S	08/09/1978	1	14.6	29	-3.1	29	O	14.5	0.75	0.75	0.9	2.9	0.41
S334_S	01/01/1990	1	34.2	29	-6.9	29	O	27.8	0.75	0.75	0.9	2.9	0.41
S335_S	04/20/1979	1	12.2	20	-4.2	20	O	11.5	0.75	0.75	0.9	2.9	0.41
S339_S	12/31/1799	1	17.8	12	-2.8	12	O	15	0.75	0.75	0.9	2.9	0.41
S339_S	12/31/1799	2	17.8	12	-2.8	12	O	15	0.75	0.75	0.9	2.9	0.41
S339_S	12/31/1799	3	17.8	12	-2.8	12	O	15	0.75	0.75	0.9	2.9	0.41
S33_S	11/01/1954	1	9	20	-2	20	O	10	0.75	0.75	0.9	2.9	0.41
S340_S	12/31/1799	1	17.8	12	-4.3	12	O	13.5	0.75	0.75	0.9	2.9	0.41
S340_S	12/31/1799	2	17.8	12	-4.3	12	O	13.5	0.75	0.75	0.9	2.9	0.41
S340_S	12/31/1799	3	17.8	12	-4.3	12	O	13.5	0.75	0.75	0.9	2.9	0.41
S36_S	11/01/1954	1	14	25	-7	25	O	11.5	0.75	0.75	1.1	3.2	0.41
S308_S	01/01/1800	1	16.9	29	9.1	116	O	32	0.75	0.75	0.9	3.1	0.41
S308_S	01/01/1800	2	16.9	29	9.1	116	O	32	0.75	0.75	0.9	3.1	0.41
S308_S	01/01/1800	3	16.9	29	9.1	116	O	32	0.75	0.75	0.9	3.1	0.41
S308_S	01/01/1800	4	16.9	29	9.1	116	O	32	0.75	0.75	0.9	3.1	0.41
S354_S	01/01/1800	1	34.5	23	3.2	23	O	34	0.75	0.75	0.85	2.9	0.41
S354_S	01/01/1800	2	34.5	23	3.2	23	O	34	0.75	0.75	0.85	2.9	0.41
COCO1_S	01/01/1800	1	8.5	10	0	20	O	8.5	0.7	0.72	1.06	3.3	0.42
COCO1_S	01/01/1800	2	8.5	10	0	20	O	8.5	0.7	0.72	1.06	3.3	0.42
COCO2_S	06/11/1996	1	16	10	0	26	O	16	0.75	0.75	0.9	3.1	0.41
COCO2_S	06/11/1996	2	16	10	0	26	O	16	0.75	0.75	0.9	3.1	0.41
COCO3_S	01/01/1800	1	6.5	10	6.5	20	T	16	0.75	0.75	1.2	3	0.42
COCO3_S	01/01/1800	2	6.5	10	6.5	20	T	16	0.75	0.75	1.2	3	0.42
G339_S	01/01/1800	1	11.5	18	8	36	O	21	0.75	0.75	0.9	3.1	0.41
G339_S	01/01/1800	2	11.5	18	8	36	O	21	0.75	0.75	0.9	3.1	0.41
G421_S	12/31/2004	1	4	20	6	20	O	13.06	0.75	0.75	1.2	3	
G54_S	04/21/1992	1	9.5	16	-4	48	T	9	0.75	0.75	0.9	2.9	0.41
G54_S	04/21/1992	2	9.5	16	-4	48	T	9	0.75	0.75	0.9	2.9	0.41
G54_S	04/21/1992	3	9.5	16	-4	48	T	9	0.75	0.75	0.9	2.9	0.41
G56_S	09/03/1991	1	12.3	20	-3.5	20	O	14	0.72	0.75	0.9	2.9	0.41
G56_S	09/03/1991	2	12.3	20	-3.5	20	O	14	0.72	0.75	0.9	2.9	0.41
G56_S	09/03/1991	3	12.3	20	-3.5	20	O	14	0.72	0.75	0.9	2.9	0.41

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elevation (ft)	Sill Length (ft)	Sill	Bypass Stage	CSFC	CFFC	USFC	UFFC	OTFC
G57_S	01/01/1800	1	6	14	-1	14	O	9	0.75	0.75	0.85	3.28	0.41
G57_S	01/01/1800	2	6	14	-1	14	O	9	0.75	0.75	0.85	3.28	0.41
S155A_S	01/01/2003	1	13.5	14	6.2	14	O	19.2	0.75	0.75	1.2	3	0.41
S155A_S	01/01/2003	2	13.5	14	6.2	14	O	19.2	0.75	0.75	1.2	3	0.41
S77_S	01/01/1800	1	12.4	20	5.6	80	O	35.5	0.75	0.75	0.9	3.1	0.41
S77_S	01/01/1800	2	12.4	20	5.6	80	O	35.5	0.75	0.75	0.9	3.1	0.41
S77_S	01/01/1800	3	12.4	20	5.6	80	O	35.5	0.75	0.75	0.9	3.1	0.41
S77_S	01/01/1800	4	12.4	20	5.6	80	O	35.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	1	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	2	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	3	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	4	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	5	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	6	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	7	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S79_S	01/01/1800	8	19.2	38	-15	304	O	10.5	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	1	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	2	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	3	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	4	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	5	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	6	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
S80_S	01/01/1800	7	20.56	20	0.56	140	O	20.56	0.75	0.75	0.9	3.1	0.41
G338_C	01/01/1800	1	12.5	14	7	14	O	21	0.75	0.75	0.9	3.1	0.41
S10A_C	12/31/1799	1	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10A_C	12/31/1799	2	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10A_C	12/31/1799	3	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10A_C	12/31/1799	4	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10C_C	01/01/1800	1	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10C_C	01/01/1800	2	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10C_C	01/01/1800	3	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10C_C	01/01/1800	4	8	25	10	25	O	23	0.75	0.75	0.9	3.1	

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elevation (ft)	Sill Length (ft)	Sill	Bypass Stage	CSFC	CFFC	USFC	UFFC	OTFC
S10D_C	01/01/1800	1	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10D_C	01/01/1800	2	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10D_C	01/01/1800	3	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
S10D_C	01/01/1800	4	8	25	10	25	O	23	0.75	0.75	0.9	3.1	
G334	01/01/1800	1	8.2	16	6.75	32	O	19.25	0.75	0.75	1.2	3.1	0.41
G334	01/01/1800	2	8.2	16	6.75	32	O	19.25	0.75	0.75	1.2	3.1	0.41
G93	12/31/1799	1	5	10	-1.8	10	O	6	0.75	0.75	0.9	2.9	0.41
G93	12/31/1799	2	5	10	-1.8	10	O	6	0.75	0.75	0.9	2.9	0.41

O = ogee spillway crest; T = trapezoidal spillway crest.

Appendix D2 – Flow Parameters for Spillways in Case 2

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC	CFFC	USFC	UFFC	OTFC
S12A_S	12/31/1799	1	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12A_S	12/31/1799	2	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12A_S	12/31/1799	3	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12A_S	12/31/1799	4	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12A_S	12/31/1799	5	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12A_S	12/31/1799	6	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	1	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	2	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	3	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	4	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	5	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12B_S	12/31/1799	6	10.2	25	0.8	150		12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	1	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	2	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	3	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	4	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	5	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12C_S	12/31/1799	6	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	1	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	2	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	3	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	4	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	5	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S12D_S	12/31/1799	6	10.2	25	0.8	150	O	12	0.75	0.75	0.9	3.1	0.41
S153L_S	12/31/1799	1	8.8	18.8	0	12	O	25	0.75	0.75	0.9	3.1	0.41
S153L_S	12/31/1799	2	8.8	18.8	0	12	O	25	0.75	0.75	0.9	3.1	0.41
S153L_S	12/31/1799	3	8	18.8	0	12	O	25	0.75	0.75	0.9	3.1	0.41
S153L_S	12/31/1799	4	0	18.8	0	12	O	25	0.75	0.75	0.9	3.1	0.41
S153_S	12/31/1799	1	8.8	18.8	12.2	18	O	25	0.75	0.75	0.9	3.1	0.41
S153_S	12/31/1799	2	8.8	18.8	12.2	18	O	25	0.75	0.75	0.9	3.1	0.41

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC	CFFC	USFC	UFFC	OTFC
S176_S	12/31/1799	1	8	20.8	-1	20	O	11	0.85	0.85	1.15	3.3	0.41
S191_S	12/31/1799	1	17.6	27.8	7.4	27	O	24.5	0.75	0.75	0.9	3.1	0.41
S351_S	12/31/1799	1	30	20	4.5	20	O	38	0.75	0.75	0.85	3.1	0.41
S351_S	12/31/1799	2	30	20	4.5	20	O	38	0.75	0.75	0.85	3.1	0.41
S351_S	12/31/1799	3	30	20	4.5	20	O	38	0.75	0.75	0.85	3.1	0.41
S37A_S	08/09/1961	1	12.8	25.8	-7.7	25	O	8	0.75	0.75	0.9	3	0.41
S37A_S	08/09/1961	2	12.8	25.8	-7.7	25	O	8	0.75	0.75	0.9	3	0.41
S40_S	12/14/1965	1	9	25.8	-0.4	25	O	11.5	0.75	0.75	0.9	3	0.41
S40_S	12/14/1965	2	9	25.8	-0.4	25	O	11.5	0.75	0.75	0.9	3	0.41
S41_S	12/31/1799	1	9	25.8	-0.4	25	O	11.5	0.75	0.61	0.9	3.1	0.407
S41_S	12/31/1799	2	9	25.8	-0.4	25	O	11.5	0.75	0.61	0.9	3.1	0.407
S46_S	12/31/1799	1	8	20.7	6.7	20	O	20	0.75	0.75	0.9	3.1	0.41
S46_S	12/31/1799	2	8	20.7	6.7	20	O	20	0.75	0.75	0.9	3.1	0.41
S46_S	12/31/1799	3	8	20.7	6.7	20	O	20	0.75	0.75	0.9	3.1	0.41
S49_S	05/23/1994	1	16.6	17.75	4.4	17	O	26.5	0.75	0.75	0.9	3.1	0.41
S49_S	05/23/1994	2	16.6	17.75	4.4	17	O	26.5	0.75	0.75	0.9	3.1	0.41
S5AS_S	04/15/1954	1	19.33	22.8	1	22	O	29	0.75	0.75	0.9	3.1	0.41
S5AS_S	04/15/1954	2	19.33	22.8	1	22	O	29	0.75	0.75	0.9	3.1	0.41
S60_S	12/31/1799	1	9.1	12.8	55	12	O	71	0.73	0.75	0.9	3.1	0.41
S62_S	12/31/1799	1	6.8	14.8	55.3	14	O	68.6	0.75	0.75	0.9	3.1	0.41
S63A_S	12/31/1799	1	7.7	15.8	49.4	15	O	64	0.75	0.75	0.9	3.1	0.41
S63A_S	12/31/1799	2	7.7	15.8	49.4	15	O	64	0.75	0.75	0.9	3.1	0.41
S63_S	12/31/1799	1	8.1	15.8	54	15	O	68.5	0.748	0.75	0.9	3.1	0.41
S68_S	12/14/1965	1	10.2	21.8	31.2	21	O	41	1.5	1.5	0.9	3.28	0.41
S68_S	12/14/1965	2	10.2	21.8	31.2	21	O	41	1.5	1.5	0.9	3.28	0.41
S68_S	12/14/1965	3	10.2	21.8	31.2	21	O	41	1.5	1.5	0.9	3.28	0.41
S70_S	02/13/1961	1	12	27.8	15	27	O	30	0.9	0.9	0.9	3.28	0.41
S70_S	02/13/1961	2	12	27.8	15	27	O	30	0.9	0.9	0.9	3.28	0.41
S71_S	02/13/1961	1	11.2	25.8	10.2	25	O	27	1	1	0.9	3.28	0.41
S71_S	02/13/1961	2	11.2	25.8	10.2	25	O	27	1	1	0.9	3.28	0.41
S71_S	02/13/1961	3	11.2	25.8	10.2	25	O	27	1	1	0.9	3.28	0.41
S72_S	05/12/1960	1	12	27.8	9.9	27	O	27	1	1	0.9	3.28	0.41

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC	CFFC	USFC	UFFC	OTFC
S72_S	05/12/1960	2	12	27.8	9.9	27	O	27	1	1	0.9	3.28	0.41
S75_S	05/12/1960	1	10	28.8	17	28	O	31.5	1	1	1.1	3.28	0.41
S82_S	12/14/1965	1	7.2	23.7	26.7	23	O	40	1.5	1.5	0.9	3.28	0.41
S82_S	12/14/1965	2	7.2	23.7	26.7	23	O	40	1.5	1.5	0.9	3.28	0.41
S83_S	12/14/1965	1	13.6	25.8	18.4	25	O	40	1.5	1.5	0.9	3.28	0.41
S84_S	12/08/1961	1	11.8	21	13.2	21	O	35	1.5	1.5	0.9	3.28	0.41
S84_S	12/08/1961	2	11.8	21	13.2	21	O	35	1.5	1.5	0.9	3.28	0.41
S49_S	05/23/1994	1	16.6	17.75	4.4	17	O	26.5	0.75	0.75	0.9	3.1	0.41
S49_S	05/23/1994	2	16.6	17.75	4.4	17	O	26.5	0.75	0.75	0.9	3.1	0.41
S97_S	01/01/1990	1	15.2	22.8	7.8	22	O	27	0.75	0.75	0.9	3.1	0.41
S97_S	01/01/1990	2	15.2	22.8	7.8	22	O	27	0.75	0.75	0.9	3.1	0.41
S99_S	01/01/1990	1	16.9	25.8	5.6	25.8	O	28	0.75	0.75	0.7	2.9	0.41
S99_S	01/01/1990	2	16.9	25.8	5.6	25.8	O	28	0.75	0.75	0.7	2.9	0.41

O = ogee spillway crest.

Appendix D3 – Flow Parameters for Spillways in Case 3

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC	CFFC	USFC	UFFC	OTFC
S11B_S	12/31/1799	1	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11B_S	12/31/1799	2	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11B_S	12/31/1799	3	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11B_S	12/31/1799	4	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11C_S	12/31/1799	1	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11C_S	12/31/1799	2	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11C_S	12/31/1799	3	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11C_S	12/31/1799	4	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S118_S	02/10/1966	1	10	20.8	-5	20	O	10	0.75	0.75	0.9	3.1	0.41
S119_S	12/31/1799	1	7.3	12.8	-2.4	12	O	10	0.75	0.75	0.9	3.1	0.41
S165_S	12/31/1799	1	7	12.8	-0.5	12	O	6	0.75	0.75	0.9	3.1	0.41
S39_S	09/15/1952	1	24	16	2.5	15	O	24	0.75	0.75	0.9	3.1	0.41
S47D_S	12/31/1799	1	8.5	22.7	4.5	22	O	18.5	0.75	0.75	0.9	3.1	0.41
S65B_S	01/01/1990	1	15.7	27	26.3	27	O	46.5	0.75	0.75	0.9	3.1	0.41
S65B_S	01/01/1990	2	15.7	27	26.3	27	O	46.5	0.75	0.75	0.9	3.1	0.41
S65B_S	01/01/1990	3	15.7	27	26.3	27	O	46.5	0.75	0.75	0.9	3.1	0.41
G160_S	01/01/1800	1	15	25	3	50	T	21	0.75	0.75	0.9	3.1	0
G160_S	01/01/1800	2	15	25	3	50	T	21	0.75	0.75	0.9	3.1	0
S140_S	01/01/1800	1	9	16	4	16	O	19	0.75	0.75	0.9	3.1	0.41
G300_S	01/01/1800	1	8.4	20	11	44	O	22	0.75	0.75	0.9	3.1	0.41
G300_S	01/01/1800	2	8.4	20	11	44	O	22	0.75	0.75	0.9	3.1	0.41
G301_S	01/01/1800	1	11.7	22	7.6	66	T	22	0.75	0.75	0.9	3.1	0.41
G301_S	01/01/1800	2	11.7	22	7.6	66	T	22	0.75	0.75	0.9	3.1	0.41
G301_S	01/01/1800	3	11.7	22	7.6	66	T	22	0.75	0.75	0.9	3.1	0.41
G302_S	01/01/1800	1	8.2	20	9.4	40	T	23.75	0.75	0.75	0.9	3.1	0
G302_S	01/01/1800	2	8.2	20	9.4	40	T	23.75	0.75	0.75	0.9	3.1	0
G308_S	01/01/1800	1	6.7	14	7.4	14	O	16	0.75	0.75	0.9	3.1	0
G309_S	01/01/1800	1	6.7	14	7.6	14	O	16	0.75	0.75	0.9	3.1	0
G81_S	01/01/1800	1	9.5	5.67	13.5	15	O	21.2	0.75	0.75	0.9	3.1	0.41
G81_S	01/01/1800	2	9.5	5.67	13.5	15	O	21.2	0.75	0.75	0.9	3.1	0.41

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC	CFFC	USFC	UFFC	OTFC
G81_S	01/01/1800	3	9.5	5.67	13.5	15	O	21.2	0.75	0.75	0.9	3.1	0.41
S13_S	01/01/1800	1	11.3	16	-8	16	O	8	0.59	0.75	0.9	3.1	0.41
S7_S	01/15/1965	1	11	15.2	2.8	14.7	O	16	0.75	0.75	0.9	3.1	0.41
S11A_C	01/01/1800	1	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11A_C	01/01/1800	2	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11A_C	01/01/1800	3	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41
S11A_C	01/01/1800	4	9	25	7.5	25	O	20.5	0.75	0.75	0.9	3.1	0.41

O = ogee spillway crest; T = trapezoidal spillway crest.

Appendix D4 – Flow Parameters for Spillways in Case 4

<table>
<tr><th>Station</th><th>Effective Date</th><th>Gate No.</th><th>Gate Height (ft)</th><th>Gate Width (ft)</th><th>Sill Elev. (ft)</th><th>Sill Length (ft)</th><th>Sill Type</th><th>Bypass Stage (ft)</th><th>CSFC</th><th>CFFC</th><th>USFC</th><th>UFFC</th><th>OTFC</th></tr>
<tr><td rowspan="4">S78_S</td><td rowspan="4">05/23/1994</td><td>1</td><td>13</td><td>20</td><td>1.56</td><td>20</td><td>O</td><td>19.6</td><td rowspan="4">See special structure procedures</td><td>0.9</td><td rowspan="4">If H=0, CFFC = 0.75;
If H≠0,
$CFFC = 0.9027 + \frac{0.0049H}{G_0} - \frac{3.7869}{H}$</td><td rowspan="4">CSFC = CFFC</td><td>0.41</td></tr>
<tr><td>2</td><td>13</td><td>20</td><td>1.56</td><td>20</td><td>O</td><td>19.6</td><td>0.9</td><td>0.41</td></tr>
<tr><td>3</td><td>10.4</td><td>25</td><td>-0.03</td><td>25</td><td>O</td><td>19.6</td><td>0.9</td><td>0.41</td></tr>
<tr><td>4</td><td>10.4</td><td>25</td><td>-0.03</td><td>25</td><td>O</td><td>19.6</td><td>0.9</td><td>0.41</td></tr>
</table>

Note: Structure S78 has two vertical and two radial gates. It is registered as a Case 4 spillway to permit extraction of the different sill elevations (-0.03 and 1.56) and the different gate data from DM_tables. However, flow at this structure is computed using constant coefficient equations (Case 1).

Appendix D5 – Flow Parameters for Spillways in Case 5

Station	Effective Date	Number of Gates	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC		USFC		CFFC		UFFC	OTFC
									a	b	a	b	a	b	a	
S65X_S	01/01/2002	1	14.2	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65X_S	01/01/2002	2	14.2	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S123_S	02/10/1966	1	12.7	25	-7.3	25	O	10	1.089	0.31	0.9071	0.2861	0.9	0.33	0.71	0.41
S123_S	02/10/1966	2	12.7	25	-7.3	25	O	11	1.089	0.31	0.9071	0.2861	0.9	0.33	0.71	0.41
S155_S	02/01/1986	1	7.7	25	1.8	75	O	16	1.05	0.3	1.19	0.3	0.844	0.391	0.7421	0.41
S155_S	02/01/1986	2	7.7	25	1.8	75	O	16	1.05	0.3	1.19	0.3	0.844	0.391	0.7421	0.41
S155_S	02/01/1986	3	7.7	25	1.8	75	O	16	1.05	0.3	1.19	0.3	0.844	0.391	0.7421	0.41
S166_S	01/01/1967	1	8.5	12	-2	12	O	6	1.0595	0.36	1.2088	0.3072	0.9	0.33	0.71	0.41
S18C_S	06/22/1992	1	11	22	-7	22	O	8	1.1212	0.31	1.5875	0.3998	0.9	0.33	0.71	0.41
S18C_S	06/22/1992	2	11	22	-7	22	O	8	1.1212	0.31	1.5875	0.3998	0.9	0.33	0.71	0.41
S190_S	03/01/1990	1	13.1	24	3.4	24	O	20.5	1.0162	0.31	1.19	0.3	0.9	0.33	0.71	0.41
S190_S	03/01/1990	2	13.1	24	3.4	24	O	20.5	1.0162	0.31	1.19	0.3	0.9	0.33	0.71	0.41
S22_S	06/25/1956	1	15	17	-11	17	O	7.5	1.0073	0.28	1.19	0.3	0.9	0.3	0.71	0.41
S22_S	06/25/1956	2	15	17	-11	17	O	7.5	1.0073	0.28	1.19	0.3	0.9	0.3	0.71	0.41
S37B_S	01/01/1990	1	7.5	25.8	0	25	O	11.5	1.0954	0.18	1.19	0.3	0.9	0.33	0.71	0.41
S37B_S	01/01/1990	2	7.5	25.8	0	25	O	11.5	1.0954	0.18	1.19	0.3	0.9	0.33	0.71	0.41
S44_S	12/07/1977	1	4.4	20	3.3	20.7	O	12	1.05	0.3	1.19	0.3	1.012	0.352	0.809	0.407
S44_S	12/07/1977	2	4.4	20	3.3	20.7	O	12	1.05	0.3	1.19	0.3	1.012	0.352	0.809	0.407
S59_S	01/01/1963	1	8.9	18	49.1	18	O	65	1.1091	0.24	1.2046	0.3093	0.9	0.33	0.71	0.41
S61_S	10/01/1963	1	18.1	27.8	36.9	27	O	62	0.9958	0.28	1.19	0.3	0.9	0.33	0.71	0.41
S65C_S	02/25/1966	1	15.2	27	20.8	27	O	39.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65C_S	02/25/1966	2	15.2	27	20.8	27	O	39.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65C_S	02/25/1966	3	15.2	27	20.8	27	O	39.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65C_S	02/25/1966	4	15.2	27	20.8	27	O	39.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65D_S	08/01/2009	1	13.8	27	13.1	34.5	O	27	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65D_S	08/01/2009	2	13.8	27	13.1	34.5	O	27	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65D_S	08/01/2009	3	13.8	27	13.1	34.5	O	27	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65D_S	08/01/2009	4	13.8	27	13.1	34.5	O	27	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65E_S	12/14/1965	1	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65E_S	12/14/1965	2	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41

Station	Effective Date	Number of Gates	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC		USFC		CFFC		UFFC	OTFC
									a	b	a	b	a	b	a	
S65E_S	12/14/1965	3	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65E_S	12/14/1965	4	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65E_S	12/14/1965	5	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65E_S	12/14/1965	6	13.8	27	9.7	27	O	32.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S352_S	01/01/1800	1	36	23	5.2	23	O	38	1.1049	0.35	1.19	0.3	0.9	0.33	0.71	0.41
S352_S	01/01/1800	2	36	23	5.2	23	O	38	1.1049	0.35	1.19	0.3	0.9	0.33	0.71	0.41
G311_S	09/01/2005	1	11	20	10	20	O	24	1	0.3	0.77	0.17	0.86	0.35	0.7	0.41
G311_S	09/01/2005	2	11	20	10	20	O	24	1	0.3	0.77	0.17	0.86	0.35	0.7	0.41
G311_S	09/01/2005	3	11	20	10	20	O	24	1	0.3	0.77	0.17	0.86	0.35	0.7	0.41
G341_S	07/07/2005	1	15	25	0	50	T	16	0.9789	0.29	0.838	0.167	0.86	0.35	0.7	
G341_S	07/07/2005	2	15	25	0	50	T	16	0.9789	0.29	0.838	0.167	0.86	0.35	0.7	
G303_S	01/01/1990	1	8	16	9	32	T	19	1.2514	0.42	1.1994	0.323	0.8736	0.44	0.7743	0
G303_S	01/01/1990	2	8	16	9	32	T	19	1.2514	0.42	1.1994	0.323	0.8736	0.44	0.7743	0
G332_S	01/01/2001	1	7.5	16	7.5	32	O	19.25	1.154	0.3	1.181	0.3009	0.9	0.33	0.71	0.41
G332_S	01/01/2001	2	7.5	16	7.5	32	O	19.25	1.154	0.3	1.181	0.3009	0.9	0.33	0.71	0.41
G334_S	01/01/2001	1	8.2	16	6.75	16	O	19.25	1.1366	0.29	1.19	0.3	0.9	0.33	0.71	0.41
G334_S	01/01/2001	2	8.2	16	6.75	16	O	19.25	1.1366	0.29	1.19	0.3	0.9	0.33	0.71	0.41
G371_S	09/09/2005	1	14	20	-1	20	T	17.5	1.1857	0.4	1.19	0.3	0.9	0.33	0.71	
G371_S	09/09/2005	2	14	20	-1	20	T	17.5	1.1857	0.4	1.19	0.3	0.9	0.33	0.71	
G373_S	09/30/2005	1	12	25	0	25	O	16	1.0434	0.34	1.19	0.3	0.9	0.33	0.71	
G373_S	09/30/2005	2	12	25	0	25	O	16	1.0434	0.34	1.19	0.3	0.9	0.33	0.71	
GORDY_S	01/01/2000	1	6.22	17.95	3.04	72	O	18.5	1.0572	0.4	1.19	0.3	0.9	0.33	0.71	0.41
GORDY_S	01/01/2000	2	7.4	17.95	3.1	72	O	18.5	1.0572	0.4	1.19	0.3	0.9	0.33	0.71	0.41
GORDY_S	01/01/2000	3	7.4	17.95	3.1	72	O	18.5	1.0572	0.4	1.19	0.3	0.9	0.33	0.71	0.41
GORDY_S	01/01/2000	4	6.24	18	3.03	72	O	18.5	1.0572	0.4	1.19	0.3	0.9	0.33	0.71	0.41
S178_S	01/01/1967	1	8	8	-3	8	N-O	999	1.0599	0.53	2.5135	0.6618	0.9	0.33	0.71	0.41
S178_S	01/01/1967	2	8	8	-3	8	N-O	999	1.0599	0.53	2.5135	0.6618	0.9	0.33	0.71	0.41
S65NEW_S	01/01/2002	1	14.2	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65NEW_S	01/01/2002	2	14.2	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65NEW_S	01/01/2002	3	14.2	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65NEW_S	01/01/2002	4	18.7	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65NEW_S	01/01/2002	5	18.7	27	39.3	27	O	54.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41

Station	Effective Date	Number of Gates	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	CSFC		USFC		CFFC		UFFC	OTFC
									a	b	a	b	a	b	a	
S8_S	08/01/1962	1	12.4	16.5	1	16.5	O	19	1.11	0.34	0.98	0.3	0.9	0.33	0.71	0.41
S83X_S	02/01/2008	1	10	11	22	11	O	40	0.9542	0.42	1.19	0.3	0.9053	0.399	0.71	0.41
S84X_S	02/05/2008	1	10	11	15	11	O	35	1.05	0.3	1.19	0.3	0.7683	0.524	0.71	0.41
G720_S	07/28/2015	1	10	20	10.94	20	O	22	1.2442	0.2819	0.8903	0.1829	0.911	0.3991	0.7246	
G720_S	07/28/2015	2	10	20	10.94	20	O	22	1.2442	0.2819	0.8903	0.1829	0.911	0.3991	0.7246	
G720_S	07/28/2015	3	10	20	10.94	20	O	22	1.2442	0.2819	0.8903	0.1829	0.911	0.3991	0.7246	
G721_S	07/01/2015	1	10	20	10.45	20	O	19.8	1.2516	0.2918	0.9218	0.2467	0.8828	0.4285	0.7182	
G721_S	07/01/2015	2	10	20	10.45	20	O	19.8	1.2516	0.2918	0.9218	0.2467	0.8828	0.4285	0.7182	
S65DX2_S	08/01/2009	1	14.4	27	19	27	O	34.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S65DX2_S	08/01/2009	2	14.4	27	19	27	O	34.5	1.04	0.3	0.838	0.167	0.86	0.35	0.7	0.41
S68X_S	04/01/2009	1	12.16	11	29	11	O	47	1.0507	0.3528	1.19	0.3	0.9	0.33	0.71	0.41

Appendix D6 – Flow Parameters for Spillways in Case 6

Station	Effective Date	Gate No.	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	c1	c2	c3	ysa1	ysb1	ysb2	poly1	poly2	poly3	poly4	OTFC
S65A_S	01/01/2004	1	13.8	27	34.5	27	O	54	0.7905	0.3588	0.2534	0.7927	0.0488	-0.045	-6261.97	227.896	0	0	0.41
S65A_S	01/01/2004	2	13.8	27	34.5	27	O	54	0.7905	0.3588	0.2534	0.7927	0.0488	-0.045	-6261.97	227.896	0	0	0.41
S65A_S	01/01/2004	3	13.8	27	34.5	27	O	54	0.7905	0.3588	0.2534	0.7927	0.0488	-0.045	-6261.97	227.896	0	0	0.41
S65_S	01/01/2004	1	14.2	27	39.3	27	O	54.5	0.881	0.476	0.3127	0.7927	0.0488	-0.045	-5303.26	195.314	0	0	0.41
S65_S	01/01/2004	2	14.2	27	39.3	27	O	54.5	0.881	0.476	0.3127	0.7927	0.0488	-0.045	-5303.26	195.314	0	0	0.41
S65_S	01/01/2004	3	14.2	27	39.3	27	O	54.5	0.881	0.476	0.3127	0.7927	0.0488	-0.045	-5303.26	195.314	0	0	0.41
S65_S	01/01/2004	4	18.7	27	39.3	27	O	54.5	0.881	0.476	0.3127	0.7927	0.0488	-0.045	-5303.26	195.314	0	0	0.41
S65_S	01/01/2004	5	18.7	27	39.3	27	O	54.5	0.881	0.476	0.3127	0.7927	0.0488	-0.045	-5303.26	195.314	0	0	0.41

Appendix D7 – Flow Parameters for Spillways G300, G301, G302, G308, and G309

Station	Effective Date	Gate Number	Gate Height (ft)	Gate Width (ft)	Sill Elev. (ft)	Sill Length (ft)	Sill Type	Bypass Stage (ft)	UFFC	USFC	CFFC	CSFC	OTFC
G300_S	1/1/1959	2	8.4	20	11	22	O	22	See Table 8	See Table 8	See Table 8	See Table 8	See Table 8
G301_S	1/1/1959	3	11.7	22	7.6	22	T	22					
G302_S	1/1/1959	2	8.2	20	9.4	20	T	23.75					
G308_S	1/1/1959	1	6.7	14	7.4	14	O	16					
G309_S	1/1/1959	1	6.7	14	7.6	14	O	16					

Appendix E – Pumps

Appendix E1 – Flow Parameters for Pumps in Case 1

Station	Effective Date	Unit No.	C0	C1	C2	C3	Cp	Type*
G123_P	12/31/1799	1	116.59	-2.87	0.5554	-0.0838	0.9	C
G123_P	12/31/1799	2	116.59	-2.87	0.5554	-0.0838	0.9	C
G123_P	12/31/1799	3	116.59	-2.87	0.5554	-0.0838	0.9	C
G123_P	12/31/1799	4	116.59	-2.87	0.5554	-0.0838	0.9	C
G200B_P	01/01/1800	1	33.331	-2.9609	0.43927	-0.02491	0.9	C
G200B_P	01/01/1800	2	33.331	-2.9609	0.43927	-0.02491	0.9	C
G200B_P	01/01/1800	3	33.331	-2.9609	0.43927	-0.02491	0.9	C
G201_P	01/01/1800	1	43.40369	-0.30541	0.030946	-0.00754	0.9	C
G201_P	01/01/1800	2	43.40369	-0.30541	0.030946	-0.00754	0.9	C
G201_P	01/01/1800	3	43.40369	-0.30541	0.030946	-0.00754	0.9	C
G210_P	01/01/1800	1	135.68	0.2083	-0.0025	-0.0049	0.9	C
G350A_P	06/02/1999	1	29.594	-0.8583	0.0298	-0.0035		C
G350A_P	06/02/1999	2	28.568	-0.5805	0.0384	-0.008		C
S131 PMP_P	09/15/2011	1	1750	6/7/1900	-1.85	1.2	1.4	
S131 PMP_P	09/15/2011	2	1750	6/7/1900	-1.85	1.2	1.4	

*C = constant-speed pump; V = variable-speed pump.

Appendix E2 – Flow Parameters for Pumps in Case 3

Station	Effective Date	Unit No.	COEF10	COEF11	COEF12	COEF13	COEF20	COEF21	COEF22	COEF23	N1wr	Nupr	Cf	n	Cp	Type
S133_P	06/11/2012	1	135.64	-1.97	-0.0851	0	152.59	-2.222	-0.0343	0	1114.96	1232			0.9	V
S133_P	06/11/2012	2	135.64	-1.97	-0.0851	0	152.59	-2.222	-0.0343	0	1114.96	1232			0.9	V
S133_P	06/11/2012	3	135.64	-1.97	-0.0851	0	152.59	-2.222	-0.0343	0	1114.96	1232			0.9	V
S133_P	06/11/2012	4	135.64	-1.97	-0.0851	0	152.59	-2.222	-0.0343	0	1114.96	1232			0.9	V
S133_P	06/11/2012	5	135.64	-1.97	-0.0851	0	152.59	-2.222	-0.0343	0	1114.96	1232			0.9	V
S135 PMP_P	07/19/2011	1	135.64	-1.97	-0.0851	0	152.59	-2.22	-0.0343	0	1630	1800			0.9	V
S135 PMP_P	07/19/2011	2	135.64	-1.97	-0.0851	0	152.59	-2.22	-0.0343	0	1630	1800			0.9	V
S135 PMP_P	07/19/2011	3	135.64	-1.97	-0.0851	0	152.59	-2.22	-0.0343	0	1630	1800			0.9	V
S135 PMP_P	07/19/2011	4	135.64	-1.97	-0.0851	0	152.59	-2.22	-0.0343	0	1630	1800			0.9	V
S140_P	05/01/2012	1	409.57	-19.0714	-4.57143	0	529.52	-12.454	-2.60539	0	1387.5	1800			0.9	V
S140_P	05/01/2012	2	409.57	-19.0714	-4.57143	0	529.52	-12.454	-2.60539	0	1387.5	1800			0.9	V
S140_P	05/01/2012	3	409.57	-19.0714	-4.57143	0	529.52	-12.454	-2.60539	0	925	1200			0.9	V
S236_P	12/31/1799	1	109.33	-1.347	0.0073	-0.0005	84.9	-1.5979	-0.0138	-0.0005	1400	1800			0.9	
S236_P	12/31/1799	2	109.33	-1.347	0.0073	-0.0005	84.9	-1.5979	-0.0138	-0.0005	1400	1800			0.9	
S236_P	12/31/1799	3	109.33	-1.347	0.0073	-0.0005	84.9	-1.5979	-0.0138	-0.0005	1400	1800			0.9	
S4_P	12/31/1799	1	1005.52	-36.894	1.5	-0.463	1209.28	-30.411	0.9493	-0.1902	640	775			0.9	V
S4_P	12/31/1799	2	1005.52	-36.894	1.5	-0.463	1209.28	-30.411	0.9493	-0.1902	640	775			0.9	V
S4_P	12/31/1799	3	1005.52	-36.894	1.5	-0.463	1209.28	-30.411	0.9493	-0.1902	640	775			0.9	V
S6_P	12/21/2011	1	791.643	84.1988	-23.8745	1.260101	980.786	69.0429	-19.3463	1.063131	613	700	215.2	0.5	0.9	V
S6_P	12/21/2011	2	791.643	84.1988	-23.8745	1.260101	980.786	69.0429	-19.3463	1.063131	613	700	215.2	0.5		V
S6_P	12/21/2011	3	791.643	84.1988	-23.8745	1.260101	980.786	69.0429	-19.3463	1.063131	613	700	215.2	0.5		V

Appendix E3 – Flow Parameters for Pumps in Case 5

Station	Effective Date	Unit	US MIN	DS MIN	C0	C1	C2	Cp	Type
G250_P	10/21/1999	1	7.2	11.5	73.61	-0.12	-0.31	0.9	C
G250_P	10/21/1999	2	7.2	11.5	73.61	-0.12	-0.31	0.9	C
G250_P	10/21/1999	3	7.2	11.5	73.61	-0.12	-0.31	0.9	C
G250_P	10/21/1999	4	7.4	12.25	108.49	-0.6	-0.26		C
G250_P	10/21/1999	5	7.4	12.25	108.49	-0.6	-0.26		C
G250_P	10/21/1999	6	7.4	12.25	108.49	-0.6	-0.26		C
G251_P	01/01/1800	1	7.4	14.5	80.8235	-0.12071	-0.41882	0.9	
G251_P	01/01/1800	2	7.4	14.5	80.8235	-0.12071	-0.41882	0.9	
G251_P	01/01/1800	3	7.4	14.45	80.8235	-0.12071	-0.41882	0.9	
G251_P	01/01/1800	4	7.4	14.5	80.8235	-0.12071	-0.41882	0.9	
G251_P	01/01/1800	5	7.4	14.5	80.8235	-0.12071	-0.41882	0.9	
G251_P	01/01/1800	6	7.4	14.5	80.8235	-0.12071	-0.41882	0.9	
S322_P	08/01/2009	7	2	5.75	116	0	0		
S322_P	08/01/2009	8	2	5.75	116	0	0		
S322_P	08/01/2009	9	2	5.75	116	0	0		

Appendix E4 – Flow Parameters for Pumps in Case 6

Station	Effective Date	Unit No.	C0	C1	C2	C3	Cp	Type
G600I_P	01/01/2004	1	600	-1.1	29000	19		V
G600I_P	01/01/2004	2	600	-1.1	32000	20		V
G600I_P	01/01/2004	3	600	-1.1	36000	19		V
ACME1	01/02/2002	1	443	1.2	15500	15	0.9	
ACME1	01/02/2002	2	318	1.2	18100	9.7	0.9	
ACME2	05/09/2001	1	320	0.8	22800	8.6	0.9	
ACME2	05/09/2001	3	320	1.2	20000	8.1	0.9	

Appendix E5 – Flow Parameters for Pumps in Case 7

Station	Effective Date	Unit	Nr	C1	C2	C3	C4	Cp	Type
S332D_P	01/01/1800	2	1800	-4.6	4.6	137	137	0	V
S332D_P	01/01/1801	1	1800	-4.6	4.6	137	137	0	C
S332D_P	01/01/1802	3	588	0	0	68	68	0	V
S332D_P	01/01/1803	4	1800	-4.6	4.6	137	137	0	V
S332D_P	01/01/1804	5	1800	-4.6	4.6	137	137	0	V

Appendix E6 – Flow Parameters for Pumps in Case 8

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
CWPB2_P	01/01/1900	1	1767	159.432	-0.141	2.032	3.064	0			
CWPB2_P	01/01/1900	2	1500	158.3	-0.071	2.394	3.788	0			
CWPB2S_P	07/01/2014	1	595	88.829	-0.002	3.035	5.07	0			
CWPB2S_P	07/01/2014	2	595	92.661	-0.221	1.458	1.916	0			
CWPB2S_P	07/01/2014	3	595	87.545	-0.023	2.154	3.308	0			
CWPB2S_P	07/01/2014	4	595	92.948	-0.1846	1.564	2.128	0			
EBPS3_P	01/01/1800	1	1800	103.62	-0.102	2.54	4.08	0	V	0	0
EBPS3_P	01/01/1800	2	1800	103.62	-0.102	2.54	4.08	0	V	0	0
EBPS3_P	01/01/1800	3	1800	103.62	-0.102	2.54	4.08	0	V	0	0
EBPS3_P	01/01/1800	4	1800	103.62	-0.102	2.54	4.08	0	V	0	0
ESPS2_P	01/01/1800	1	1800	103.62	-0.102	2.54	4.08	0	V	0	0
ESPS2_P	01/01/1800	2	1800	103.62	-0.102	2.54	4.08	0	V	0	0
ESPS2_P	01/01/1800	3	1800	103.62	-0.102	2.54	4.08	0	V	0	0
ESPS2_P	01/01/1800	4	1800	103.62	-0.102	2.54	4.08	0	V	0	0
ESPS2_P	01/01/1800	5	1800	103.62	-0.102	2.54	4.08	0	V	0	0
G200_P	10/01/2014	1	435	106.1	-0.1819	1.8741	2.7482	0.9			
G200_P	10/01/2014	2	435	106.1	-0.1819	1.8741	2.7482	0.9			
G200_P	10/01/2014	3	435	106.1	-0.1819	1.8741	2.7482	0.9			
G250S_P	02/12/2009	1	383	74.1401	-0.1344	2.0716	3.1432	0.9			
G250S_P	02/12/2009	2	383	74.1401	-0.1344	2.0716	3.1432	0.9			
G250S_P	02/12/2009	3	383	74.1401	-0.1344	2.0716	3.1432	0.9			
G310_P	06/16/2004	1	440	105	-0.34	2	3	0	C	12.2	0.5
G310_P	06/16/2004	2	440	105	-0.34	2	3	0	C	12.2	0.5
G310_P	06/16/2004	3	720	592	-1.3	2	3	0	V	86.5	0.5

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
G310_P	06/16/2004	4	720	1220	-2.4	2	3	0	V	135.1	0.5
G310_P	06/16/2004	5	720	1220	-2.4	2	3	0	V	135.1	0.5
G310_P	06/16/2004	6	720	592	-1.3	2	3	0	V	86.5	0.5
G327B_P	01/01/2000	1	1785	84.557	-0.513	1.577	2.154	0			
G328_P	01/01/1800	1	1768	109.35	-0.49	1.46	1.92		V		
G328_P	01/01/1800	2	1768	109.35	-0.49	1.46	1.92		V		
G328_P	01/01/1800	3	1768	109.35	-0.49	1.46	1.92		V		
G328_P	01/01/1800	4	1768	109.35	-0.49	1.46	1.92		V		
G328I_P	07/10/2001	1	1768	109.35	-0.49	1.46	1.92	0	V		
G335_P	08/25/2008	1	440	104.4	-0.00074	3.6	6.2	0	C	0.01	0.01
G335_P	08/25/2008	2	440	104.4	-0.00074	3.6	6.2	0	C	0.01	0.01
G335_P	08/25/2008	3	720	609.2	-4.31	1.48	1.96	0	V	67.05	0.5
G335_P	08/25/2008	4	720	1147.9	-13.18	1.34	1.68	0	V	158.89	0.5
G335_P	08/25/2008	5	720	1147.9	-13.18	1.34	1.68	0	V	158.89	0.5
G335_P	08/25/2008	6	720	609.2	-4.31	1.48	1.96	0	V	67.05	0.5
G337_P	06/04/2008	1	347	103.4	-0.076	2.51	4.02	0			
G337_P	06/04/2008	2	347	108.5	-0.18	2.18	3.36	0			
G337_P	06/04/2008	3	347	98.76	-0.046	2.64	4.28	0			
G349A_P	01/10/2009	1	725	28.0044	-0.0267	2.1232	3.2464				
G349A_P	01/10/2009	2	725	28.0044	-0.0267	2.1232	3.2464				
G349B_P	01/10/2009	1	730	44.9174	-0.1077	1.6352	2.2704				
G349C_P	03/01/2008	1	1785	26.0296	-0.0141	2.1399	3.2798				
G349C_P	03/01/2008	2	1785	26.0296	-0.0141	2.1399	3.2798				
G350B_P	01/10/2009	1	730	44.9466	-0.0957	1.6739	2.3478				
G370_P	01/01/2003	1	720	1020	-6.67	1.6	2.2		V		
G370_P	01/01/2003	2	720	1020	-6.67	1.6	2.2		V		
G370_P	01/01/2003	3	720	1020	-6.67	1.6	2.2		V		
G370S_P	01/01/2003	1	435	83	-0.057	2.5	4		C		
G370S_P	01/01/2003	2	435	83	-0.057	2.5	4		C		
G370S_P	01/01/2003	3	435	83	-0.057	2.5	4		C		
G372_P	01/01/2003	1	720	1050	-5.5	1.6	2.2		V		
G372_P	01/01/2003	2	720	1050	-5.5	1.6	2.2		V		
G372_P	01/01/2003	3	720	1050	-5.5	1.6	2.2		V		
G372_P	01/01/2003	4	720	1050	-5.5	1.6	2.2		V		
G372S_P	01/01/2003	1	435	90	-0.18	2	3		C		
G372S_P	01/01/2003	2	435	90	-0.18	2	3		C		
G372S_P	01/01/2003	3	435	90	-0.18	2	3		C		
G385_P	01/01/1800	1	1785	58.9329	-0.2193	1.5676	2.1352				
G386_P	01/01/1800	1	1780	33.4886	-0.1109	1.7187	2.4374				
G387_P	01/01/1800	1	1780	33.453	-0.1173	1.6995	2.399				
G388_P	08/11/2011	1	330	103.3	-0.525	1.6745	2.349				
G388_P	08/11/2011	2	224	66.1032	-1.4956	1.675	2.35				
G404_P	05/06/2000	1	1800	207.33	-1.5	1.6	2.2		V		
G404_P	05/06/2000	2	1800	207.33	-1.5	1.6	2.2		V		
G404_P	05/06/2000	3	1800	207.33	-1.5	1.6	2.2		V		
G409_P	01/01/1800	1	1800	64.37	-0.023	2.41	3.82		V		

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
G409_P	01/01/1800	2	1800	64.37	-0.023	2.41	3.82		V		
G409_P	01/01/1800	3	1800	64.37	-0.023	2.41	3.82		V		
G410_P	01/01/1800	1	1822	131.46	-0.2	1.96	2.92		V		
G410_P	01/01/1800	2	1822	131.46	-0.2	1.96	2.92		V		
G420_P	01/01/1800	1	1800	242	-0.89	1.6	2.2		V		
G420_P	01/01/1800	2	1800	242	-0.89	1.6	2.2		V		
G420_P	01/01/1800	3	1800	242	-0.89	1.6	2.2		V		
G420S_P	01/01/2004	1	1750	86	-1.21	1.4	1.8		C		
G422_P	02/01/2006	1	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	2	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	3	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	4	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	5	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	6	1780	91.844	-0.333	1.914	2.828		C		
G422_P	02/01/2006	7	1780	91.844	-0.333	1.914	2.828		C		
G434_P	06/25/2012	1	1750	476.3	-7.804	1.489	1.978				
G434_P	06/25/2012	2	1750	476.3	-7.804	1.489	1.978				
G434_P	06/25/2012	3	440	102.1	-1.17	1.328	1.656				
G434_P	06/25/2012	4	440	102.1	-1.17	1.328	1.656				
G436_P	07/05/2012	1	1150	607.4	-4.453	1.52	2.04				
G436_P	07/05/2012	2	1150	607.4	-4.453	1.52	2.04				
G436_P	07/05/2012	3	1150	607.4	-4.453	1.52	2.04				
G436_P	07/05/2012	4	440	108.2	-1.018	1.401	1.802				
G436_P	07/05/2012	5	440	108.2	-1.018	1.401	1.802				
G507_P	08/01/2012	1	1800	42.785	-0.689	1.371	1.742				
G508_P	08/01/2012	1	1640	478.4	-9.192	1.416	1.832				
G508_P	08/01/2012	2	1640	478.4	-9.192	1.416	1.832				
G508_P	08/01/2012	3	1640	478.4	-9.192	1.416	1.832				
G508_P	08/01/2012	4	1640	478.4	-9.192	1.416	1.832				
G508_P	08/01/2012	5	440	111	-1.201	1.364	1.728				
G508_P	08/01/2012	6	440	111	-1.201	1.364	1.728				
G508S_P	08/01/2012	1	880	26.561	-0.186	1.554	2.108				
G508S_P	08/01/2012	2	880	26.561	-0.186	1.554	2.108				
G508S_P	08/01/2012	3	880	26.561	-0.186	1.554	2.108				
G600_P	08/31/2005	1	1800	83.365	-0.008	3.125	5.25		V		
G600_P	08/31/2005	2	1800	83.365	-0.008	3.125	5.25		V		
G600_P	08/31/2005	3	1800	83.365	-0.008	3.125	5.25		V		
G600_P	08/31/2005	4	1800	83.365	-0.008	3.125	5.25		V		
G600_P	08/31/2005	5	1800	83.365	-0.008	3.125	5.25		V		
L8RES_P	01/01/2000	1	440	97.34	-0.186	1.476	1.952				
LHPS_P	11/01/2004	1	1800	88.7	-0.05	2.5	4		C		
LHPS_P	11/01/2004	2	1800	88.7	-0.05	2.5	4		C		
LHPS_P	11/01/2004	3	1800	88.7	-0.05	2.5	4		C		
S127_P	06/13/2012	1	1209	143	-1.52	1.2	1.4		V		
S127_P	06/13/2012	2	1209	143	-1.52	1.2	1.4		V		
S127_P	06/13/2012	3	1209	143	-1.52	1.2	1.4		V		

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
S127_P	06/13/2012	4	1209	143	-1.52	1.2	1.4		V		
S127_P	06/13/2012	5	1209	143	-1.52	1.2	1.4		V		
S129 PMP_P	09/02/2011	1	1750	162	-1.84	1.2	1.4		V		
S129 PMP_P	09/02/2011	2	1750	162	-1.84	1.2	1.4		V		
S129 PMP_P	09/02/2011	3	1750	162	-1.84	1.2	1.4		V		
S13_P	03/01/1995	1	1800	197.3	-2.4771	1.391	1.782		V		
S13_P	03/01/1995	2	1800	197.3	-2.4771	1.391	1.782		V		
S13_P	03/01/1995	3	1800	197.3	-2.4771	1.391	1.782		V		
S155A_P	10/12/2007	1	1800	73.6382	-0.0145	2.4634	3.9268				
S155A_P	10/12/2007	2	1800	73.6382	-0.0145	2.4634	3.9268				
S155A_P	10/12/2007	3	1800	73.6382	-0.0145	2.4634	3.9268				
S155A_P	10/12/2007	4	1800	73.6382	-0.0145	2.4634	3.9268				
S199_P	12/01/2011	1	588	79.439	-0.489	1.287	1.574	0.9			
S199_P	12/01/2011	2	588	79.439	-0.489	1.287	1.574	0.9			
S199_P	12/01/2011	3	588	79.439	-0.489	1.287	1.574	0.9			
S2_P	11/18/2008	1	630	1116	-7.836	1.687	2.374	0	V	148.97	0.5
S2_P	11/18/2008	2	630	1116	-7.836	1.687	2.374	0	V	148.97	0.5
S2_P	11/18/2008	3	630	1116	-7.836	1.687	2.374	0	V	148.97	0.5
S2_P	11/18/2008	4	630	1116	-7.836	1.687	2.374	0	V	148.97	0.5
S200_P	12/01/2011	1	79.661	-0.503	1.299	1.598	0.9	0.9			
S200_P	12/01/2011	2	588	79.661	-0.503	1.299	1.598	0.9			
S200_P	12/01/2011	3	588	79.661	-0.503	1.299	1.598	0.9			
S25B_P	12/31/2000	1	1780	210	-0.19	2	3	0	C		
S25B_P	12/31/2000	2	1780	210	-0.19	2	3	0	C		
S25B_P	12/31/2000	3	1780	210	-0.19	2	3	0	C	0	0
S26_P	01/01/2004	1	1780	223	-2.01	1.2	1.4		C		
S26_P	01/01/2004	2	1780	223	-2.01	1.2	1.4		C		
S26_P	01/01/2004	3	1780	223	-2.01	1.2	1.4		C		
S3_P	04/07/1958	1	720	1082.1	-6.666	1.854	2.708	0.9		148.97	0.5
S3_P	04/07/1958	2	720	1082.1	-6.666	1.854	2.708	0.9		148.97	0.5
S3_P	04/07/1958	3	720	1082.1	-6.666	1.854	2.708	0.9		148.97	0.5
S319_P	11/17/2008	1	720	659.7	-2.554	1.2	1.4	0	V	99	0.5
S319_P	11/17/2008	2	720	659.7	-2.554	1.2	1.4	0	V	99	0.5
S319_P	11/17/2008	3	720	1156.7	-1.845	1.584	2.168	0	V	99	0.5
S319_P	11/17/2008	4	720	1156.7	-1.845	1.584	2.168	0	V	99	0.5
S319_P	11/17/2008	5	720	1156.7	-1.845	1.584	2.168	0	V	99	0.5
S331_P	11/18/2008	1	1800	440	-25	1.5	2	0	V	151.07	0.7438
S331_P	11/18/2008	2	1800	440	-25	1.5	2	0	V	151.07	0.7438
S331_P	11/18/2008	3	1800	440	-25	1.5	2	0	V	151.07	0.7438
S332_P	08/01/2009	1	590	56.8967	-0.1706	1.8341	2.6682		C		
S332_P	08/01/2009	2	590	56.2649	-0.3678	1.3956	1.7912		C		
S332_P	08/01/2009	3	875	23.1482	-0.1838	1.2939	1.5878		C		
S332_P	08/01/2009	4	700	34.8927	-0.2173	1.4516	1.9032		C		
S332_P	08/01/2009	5	1745	5.5844	-0.0132	1.6833	2.3666		C		
S332_P	08/01/2009	6	1165	11.2818	-0.0673	1.5159	2.0318		C		
S332B_P	01/01/1800	1	1800	139.57	-0.44	1.45	1.9	0.9	V		

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
S332B_P	01/01/1800	2	1800	139.57	-0.44	1.45	1.9	0.9	V		
S332B_P	01/01/1800	3	1800	82.96	-0.0023	2.93	4.86	0.9	V		
S332B_P	01/01/1800	4	1800	139.57	-0.44	1.45	1.9	0.9	V		
S332B_P	01/01/1800	5	1800	139.57	-0.44	1.45	1.9	0.9	V		
S332B1_P	01/01/1960	1	1800	139.57	-0.44	1.45	1.9		V		
S332B1_P	01/01/1960	2	1800	139.57	-0.44	1.45	1.9		V		
S332B2_P	01/30/2006	1	588	82.96	-0.0023	2.93	4.86	0.9	V		
S332B2_P	01/30/2006	2	1800	139.57	-0.44	1.45	1.9	0.9	V		
S332B2_P	01/30/2006	3	1800	139.57	-0.44	1.45	1.9	0.9	V		
S332C_P	03/30/2007	1	1800	140	-0.195	1.818	2.636	0			
S332C_P	03/30/2007	2	1800	140	-0.195	1.818	2.636	0			
S332C_P	03/30/2007	3	1780	78.38	-0.0298	2.014	3.028	0			
S332C_P	03/30/2007	4	1800	140	-0.195	1.818	2.636	0			
S332C_P	03/30/2007	5	1800	140	-0.195	1.818	2.636	0			
S357_P	04/13/2009	1	1800	159.4	-0.751	1.278	1.555	0			
S357_P	04/13/2009	2	1800	159.4	-0.751	1.278	1.555	0			
S357_P	04/13/2009	3	1800	159.4	-0.751	1.278	1.555	0			
S357_P	04/13/2009	4	1800	159.4	-0.751	1.278	1.555	0			
S357_P	04/13/2009	5	590	96.2	-0.411	1.337	1.675	0			
S361_P	08/25/2008	1	444	33.2498	-0.0617	1.6578	2.3156	0	C		
S361_P	08/25/2008	2	444	33.2498	-0.0617	1.6578	2.3156	0	C		
S361_P	08/25/2008	3	444	33.2498	-0.0617	1.6578	2.3156	0	C		
S362_P	08/26/2008	1	720	620.4	-7.616	1.248	1.496	0	V		
S362_P	08/26/2008	2	720	620.4	-7.616	1.248	1.496	0	V		
S362_P	08/26/2008	3	720	1106.4	-14.218	1.3266	1.6532	0	V		
S362_P	08/26/2008	4	720	1106.4	-14.218	1.3266	1.6532	0	V		
S362_P	08/26/2008	5	720	1106.4	-14.218	1.3266	1.6532	0	V		
S362_P	08/26/2008	6	442	125.3	-1.4256	1.253	1.506	0	V		
S362_P	08/26/2008	7	442	125.3	-1.4256	1.253	1.506	0	V		
S382_P	06/15/1985	1	1200	196.7	-0.0824	1.99	2.98	0			
S382_P	06/15/1985	2	1200	196.7	-0.0824	1.99	2.98	0			
S382_P	06/15/1985	3	1200	82.079	-0.067	1.845	2.69	0			
S383_P	09/17/2007	1	880	33.202	-0.0503	1.7	2.4	0		0	0
S383_P	09/17/2007	2	1190	19.343	-0.0184	1.838	2.676	0		0	0
S385_P	12/01/2006	1	710	43.06	-0.216	1.132	1.264				
S385_P	12/01/2006	2	710	81.911	-0.399	1.135	1.27				
S385_P	12/01/2006	3	710	114.9	-0.562	1.13	1.26				
S385_P	12/01/2006	4	710	142.6	-0.852	1.074	1.148				
S390_P	01/01/1800	1	1160	8.2242	-0.0945	1.2899	1.5798				
S390_P	01/01/1800	2	1160	15.9251	-0.1561	1.3366	1.6732				
S390_P	01/01/1800	3	1160	23.4528	-0.2509	1.3094	1.6188				
S390_P	01/01/1800	4	1160	29.9502	-0.2822	1.3462	1.6924				
S5A_P	05/01/2011	1	714	895	-1.46	2	3	0.9	V		
S5A_P	05/01/2011	2	714	895	-1.46	2	3	0.9	V		
S5A_P	05/01/2011	3	714	895	-1.46	2	3	0.9	V		
S5A_P	05/01/2011	4	714	895	-1.46	2	3	0.9	V		

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
S5A_P	05/01/2011	5	714	895	-1.46	2	3	0.9	V		
S5A_P	05/01/2011	6	714	895	-1.46	2	3	0.9	V		
S7_P	02/07/2013	1	720	1010.4	-9.239	1.785	2.57	0.9	V		
S7_P	02/07/2013	2	720	1010.4	-9.239	1.785	2.57	0.9	V		
S7_P	02/07/2013	3	720	1010.4	-9.239	1.785	2.57	0.9	V		
S700_P	04/01/2012	1	880	30.344	-0.066	1.656	2.312				
S700_P	04/01/2012	2	880	30.344	-0.066	1.656	2.312				
S700_P	04/01/2012	3	588	64.33	-0.207	1.549	2.098				
S8_P	11/29/2011	1	707	1177.3	-10.5676	1.7003	2.4006	0.9	V		
S8_P	11/29/2011	2	707	1177.3	-10.5676	1.7003	2.4006	0.9	V		
S8_P	11/29/2011	3	707	1177.3	-10.5676	1.7003	2.4006	0.9	V		
S8_P	11/29/2011	4	707	1177.3	-10.5676	1.7003	2.4006	0.9	V		
S9_P	09/22/2009	1	733	1126.1	-2.4965	1.8287	2.6574	0.9	V	184	0.5
S9_P	09/22/2009	2	733	1126.1	-2.4965	1.8287	2.6574	0.9	V	184	0.5
S9_P	09/22/2009	3	733	1126.1	-2.4965	1.8287	2.6574	0.9	V	184	0.5
S9A_P	11/12/2008	1	1800	219.7	-0.0845	2.0233	3.0466		V		
S9A_P	11/12/2008	2	588	95.1484	-0.0442	1.9679	2.9358		V		
S9A_P	11/12/2008	3	588	95.1484	-0.0442	1.9679	2.9358		V		
S9A_P	11/12/2008	4	1800	219.7	-0.0845	2.0233	3.0466		V		
SFCD5E_P	01/25/2007	1	2100	99.538	-0.526	1.759	2.519		V		
SFCD5E_P	01/25/2007	2	2100	99.538	-0.526	1.759	2.519		V		
SFCD5E_P	01/25/2007	3	2100	99.538	-0.526	1.759	2.519		V		
SFCD5E_P	01/25/2007	4	2100	99.538	-0.526	1.759	2.519		V		
SFCD5E_P	01/25/2007	5	2100	99.538	-0.526	1.759	2.519		V		
SSDDMC_P	01/01/2004	1	1872	100	-0.44	1.6	2.2		V		
SSDDMC_P	01/01/2004	2	1872	100	-0.44	1.6	2.2		V		
ACME1	01/02/2002	1	326	121.5475	-0.019877	3.0941	5.1882	0.9	V		
ACME2	05/09/2001	2	265	89.34	-1.5	1.5	2	0.9	V		
G207	02/08/2008	1	334	174.9	-1.286	1.331	1.662				
G208	02/08/2008	1	334	177.5	-0.983	1.42	1.84				
G372SHL_P	06/01/2005	1	435	90	-0.18	2	3				
G372SHL_P	06/01/2005	2	435	90	-0.18	2	3				
G372SHL_P	06/01/2005	3	435	90	-0.18	2	3				
G372SSTA_P	06/01/2005	1	435	90	-0.18	2	3				
G372SSTA_P	06/01/2005	2	435	90	-0.18	2	3				
G372SSTA_P	06/01/2005	3	435	90	-0.18	2	3				
G434S_P	08/03/2012	1	440	108.8	-1.145	1.353	1.706				
G434S_P	08/03/2012	2	440	108.8	-1.145	1.353	1.706				
G434S_P	08/03/2012	3	440	108.8	-1.145	1.353	1.706				
G435_P	06/28/2012	1	394	182.2	-2.586	1.074	1.148				
G435_P	06/28/2012	2	394	182.2	-2.586	1.074	1.148				
G435_P	06/28/2012	3	394	182.2	-2.586	1.074	1.148				
G445_P	07/06/2012	1	890	13.656	-0.114	1.417	1.834				
G445_P	07/06/2012	2	890	13.656	-0.114	1.417	1.834				
G509_P	01/01/2011	1	588	55.848	-0.588	1.251	1.502				
G509_P	01/01/2011	2	588	55.848	-0.588	1.251	1.502				

Station	Effective Date	Unit No.	C0	C1	C2	C3	C4	Cp	Type	Cf	n
G700_P	03/01/2013	1	705	45.8721	-0.0112	3.58	6.16				
G700_P	03/01/2013	2	705	45.8721	-0.0112	3.58	6.16				
S351_TEMP	03/28/2007	1	1757	122.4	-3.0177	1.1407	1.2814				
S351_TEMP	03/28/2007	2	1757	122.4	-3.0177	1.1407	1.2814				
S351_TEMP	03/28/2007	3	1757	122.4	-3.0177	1.1407	1.2814				
S351_TEMP	03/28/2007	4	1757	122.4	-3.0177	1.1407	1.2814				
S351_TEMP	03/28/2007	5	1757	122.4	-3.0177	1.1407	1.2814				
S351_TEMP	03/28/2007	6	1757	122.4	-3.0177	1.1407	1.2814				
S352_TEMP	04/04/2007	1	1757	122.4	-3.0177	1.1407	1.2814				
S352_TEMP	04/04/2007	2	1757	122.4	-3.0177	1.1407	1.2814				
S352_TEMP	04/04/2007	3	1757	122.4	-3.0177	1.1407	1.2814				
S352_TEMP	04/04/2007	4	1757	122.4	-3.0177	1.1407	1.2814				
S354_TEMP	03/28/2007	1	1757	122.4	-3.0177	1.1407	1.2814				
S354_TEMP	03/28/2007	2	1757	122.4	-3.0177	1.1407	1.2814				
S354_TEMP	03/28/2007	3	1757	122.4	-3.0177	1.1407	1.2814				
S354_TEMP	03/28/2007	4	1757	122.4	-3.0177	1.1407	1.2814				
S356_P	08/13/2015	1	1800	136	-0.12	2	3				
S356_P	08/13/2015	2	1800	136	-0.12	2	3				
S356_P	08/13/2015	3	1800	136	-0.12	2	3				
S356_P	08/13/2015	4	1800	136	-0.12	2	3				
S488_P	10/15/2014	1	1750	249.2	-0.546	1.8455	2.691				
S488_P	10/15/2014	2	1750	249.2	-0.546	1.8455	2.691				
S488_P	10/15/2014	3	1750	249.2	-0.546	1.8455	2.691				
S488_P	10/15/2014	4	1750	249.2	-0.546	1.8455	2.691				
S488_P	10/15/2014	5	394	94.4405	-1.0495	1.3946	1.7892				
S488_P	10/15/2014	6	394	94.4405	-1.0495	1.3946	1.7892				
S650_P1	02/01/2013	1	591	117.6	-1.229	1.04	1.08				
S650_P2	02/01/2013	1	591	96.839	-0.956	1.094	1.188				
S650_P3	02/01/2013	1	591	96.839	-0.956	1.094	1.188				

Appendix F – Culverts

Appendix F1 – Case 1 Flow Parameters for Box Culverts

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)	Gate Cdg
S120_C	12/31/1799	1	104	9	9	-3	-3	0.012	0.5	SG	1	6	6	0.6
S12E_C	12/31/1799	1	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S12E_C	12/31/1799	2	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S12E_C	12/31/1799	3	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S12E_C	12/31/1799	4	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S14_C	01/31/1963	1	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S14_C	01/31/1963	2	65	7	7	0	0	0.012	0.4	SG	1	7	7	0.6
S195_C	12/31/1799	1	90	8.08	12.7	-1.8	-1.8	0.024	0.8	SG	1	6	6	0.6
G379C	01/01/2003	1	40	10	10	0	0	0.012	0.5					
G383	01/14/2005	1	40	10	10	0	0	0.012	0.5					
G442_C	07/24/2012	1	151	8	8	-1.54	-1.54	0.012	0.5					
G442_C	07/24/2012	2	151	8	8	-1.54	-1.54	0.012	0.5					
G442_C	07/24/2012	3	151	8	8	-1.54	-1.54	0.012	0.5					
S369C	05/01/2004	1	66.8	8	8	3.75	3.75	0.012	0.5	SG	1	8	8	

Appendix F2 – Case 1 Flow Parameters for Circular Culverts

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Barrel Control Type	Barrel Control Number	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)	Gate Cdg
G124_C	12/31/1799	3	50	6	4.68	5.02	0.024	0.8	RG	1	6			0.5
G124_C	12/31/1799	5	50	6	4.72	4.9	0.024	0.8	RG	1	6			0.5
G255B_C	01/01/1800	1	62.5	6	4.94	5.43	0.024	0.8						
G119_C	12/31/1799	1	64	6	-3.5	-3.5	0.024	0.8	SG	1		6	6	0.65
G119_C	12/31/1799	2	64	6	-3.5	-3.5	0.024	0.8	SG	1		6	6	0.65
G254A_C	01/10/1995	1	60	6	5	5	0.024	0.5		0				
G255B_C	01/01/1800	1	62.5	6	4.94	5.43	0.024	0.8						
G258_C	01/01/1800	1	78	5	1.5	2.5	0.024	2.3	SG	1		5	5	0.6
G305G_C	01/01/1900	1	90	7	3.5	3.4	0.024	0.5						
G305N_C	01/01/1900	1	90	7	3.8	3.85	0.024	0.5						
G64_C	12/31/1799	1	72	6	2.5	2.5	0.024	0.8	SG	1		6	6	0.65

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Barrel Control Type	Barrel Control Number	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)	Gate Cdg
G65_C	12/31/1799	1	999.9	4.5	0	0	0.012	0.5	SG	1		5	5	0.5
G69_C	12/31/1799	1	80	6	-1.5	-1.5	0.022	0.8	SG	1		6	6	0.65
G69_C	12/31/1799	2	80	6	-1.5	-1.5	0.022	0.8	SG	1		6	6	0.65
G69_C	12/31/1799	3	80	6	-1.5	-1.5	0.022	0.8	SG	1		6	6	0.65
G69_C	12/31/1799	4	80	6	-1.5	-1.5	0.022	0.8	SG	1		6	6	0.65
LWD.S3_C	12/31/1799	1	70	6	7	7	0.024	0.8	SG	1		6	6	0.6
LWD.S3_C	12/31/1799	2	70	6	7	7	0.024	0.8	SG	1		6	6	0.6
S10E_C	12/31/1799	1	40	6	9	9	0.024	0.5	SG	1		6	6	0.5
S10E_C	12/31/1799	2	40	6	9	9	0.024	0.5	SG	1		6	6	0.65
S10E_C	12/31/1799	3	40	6	9	9	0.024	0.5	SG	1		6	6	0.65
S125_C	12/31/1799	1	40	4	2	2	0.024	0.78	SG	1		4	4	0.6
S13A_C	11/15/1956	1	60	6	-4	-4	0.024	0.8	RG	1	6			0.5
S13A_C	11/15/1956	2	60	6	-4	-4	0.024	0.8	RG	1	6			0.5
S13A_C	11/15/1956	3	60	4.5	-4	-4	0.024	0.8	RG	1	4.5			0.5
S13A_C	11/15/1956	4	60	4.5	-4	-4	0.024	0.8	RG	1	4.5			0.5
S142_C	12/31/1799	1	42	6	2	2	0.024	0.2	SG	1		6	6	0.65
S142_C	12/31/1799	2	42	6	2	2	0.024	0.2	SG	1		6	6	0.65
S24_C	10/15/1952	1	83	4.5	-8	-8	0.024	0.8	RG	1	4.5			0.65
S24A_C	10/15/1952	1	83	4.5	2	2	0.024	0.8	RG	1	4.5			0.65
S24A_C	10/15/1952	2	83	4.5	2	2	0.024	0.8	RG	1	4.5			0.65
S24B_C	07/12/1963	1	72	6	-3	-3	0.024	0.8	RG	1	6			0.65
S24B_C	07/12/1963	2	72	6	-3	-3	0.024	0.8	RG	1	6			0.65
S25_C	12/31/1799	1	54	8	-4	-4	0.024	0.5	SG	1		8	8	0.65
S25A_C	12/31/1799	1	73	4.5	-1.7	-1.7	0.024	0.8	RG	1	4.5			0.65
S30_C	07/01/1983	1	228	7	-5	-5	0.012	0.5	SG	1		7	7	0.65
S30_C	07/01/1983	2	228	7	-5	-5	0.012	0.5	SG	1		7	7	0.65
S30_C	07/01/1983	3	228	7	-5	-5	0.012	0.5	SG	1		7	7	0.65
S30_C	07/01/1983	4	66	6	-2.6	-2.6	0.024	0.8	RG	1	6			0.5
S31_C	07/12/1963	1	172	7	-3	-3	0.024	0.8	SG	1		7	7	0.5
S31_C	07/12/1963	2	172	7	-3	-3	0.024	0.8	SG	1		7	7	0.5
S31_C	07/12/1963	3	172	7	-3	-3	0.024	0.8	SG	1		7	7	0.5
S32A_C	09/15/1952	1	102	4.5	-2	-2	0.024	0.8	SG	1		4.5	4.5	0.6
S336_C	12/31/1799	1	85	4.5	-1.8	-1.8	0.024	0.8	SG	1		4.5	4.5	0.65
S336_C	12/31/1799	2	85	4.5	-1.8	-1.8	0.024	0.8	SG	1		4.5	4.5	0.65

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Barrel Control Type	Barrel Control Number	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)	Gate Cdg
S336_C	12/31/1799	3	85	4.5	-1.8	-1.8	0.024	0.8	SG	1		4.5	4.5	0.65
S337_C	12/31/1799	1	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S337_C	12/31/1799	2	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S337_C	12/31/1799	3	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S337_C	12/31/1799	4	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S337_C	12/31/1799	5	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S337_C	12/31/1799	6	164	7	-3	-4	0.024	0.8	SG	1		7	7	0.5
S342_C	01/01/1800	1	105	6	7	7	0.024	0.5	SG	1		6	6	0.6
S38_C	07/03/1961	1	52	6	3	2	0.024	0.8	RG	1	6			0.6
S38_C	07/03/1961	2	52	6	3	2	0.024	0.8	RG	1	6			0.6
S39A_C	12/31/1799	1	54	6	3	3	0.024	0.8	RG	1	6			0.6
S39A_C	12/31/1799	1	54	6	3.2	3.2	0.024	0.8	RG	1	6			0.6
S47B_C	12/31/1799	1	38	8	7.7	7.7	0.024	0.5	SG	1		8	8	0.8
S47B_C	12/31/1799	2	38	8	7.7	7.7	0.024	0.5	SG	1		8	8	0.8
S5AX_C	08/27/1956	1	68	6	5.5	5.5	0.024	0.8	RG	1	6			0.5
S5AX_C	08/27/1956	2	68	6	5.5	5.5	0.024	0.8	RG	1	6			0.5
S5AX_C	08/27/1956	3	68	6	5.5	5.5	0.024	0.8	RG	1	6			0.5
S5AX_C	08/27/1956	4	68	6	5.5	5.5	0.024	0.8	RG	1	6			0.5
S65AX_C	01/01/1800	1	145	6	34	34	0.024	0.5	SG	1		9	9	0.5
S65AX_C	01/01/1800	2	145	6	34	34	0.024	0.5	SG	1		9	9	0.5
S65BX1_C	10/31/1990	1	70	5.5	28.5	28.5	0.024	0.8	SG	1		5.5	5.5	0.65
S65BX1_C	10/31/1990	2	70	5.5	28.5	28.5	0.024	0.8	SG	1		5.5	5.5	0.65
S65BX2_C	10/31/1990	1	99	4.5	29.5	29.5	0.024	0.8	SG	1		4.5	4.5	0.65
S65CX_C	06/15/1988	1	72	5.5	21.5	21.5	0.024	0.8	SG	1		5.5	5.5	0.65
S65CX_C	06/15/1988	2	72	5.5	21.5	21.5	0.024	0.8	SG	1		5.5	5.5	0.65
S65DX_C	04/07/1988	1	80	5.5			0.012	0	SG	1		5.5	5.5	0.65
S65DX_C	04/07/1988	2	80	5.5			0.012	0	SG	1		5.5	5.5	0.65
SHING.PE	01/01/1800	1	23	3	73.75	73.97	0.024	0.5						
SHING.PN	01/01/1800	1	24	1.67	75.38	75.56	0.014	0.5						
SHING.PS	01/01/1800	1	24	1.67	74.92	74.83	0.014	0.5						
SHING.SS	01/01/1800	1	60	6	70	70	0.024	0.5						

Appendix F3 – New Flow Parameters for Box Culverts

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G113_C	06/16/2012	1	86	6	8	51.83	51.83	0.012	0.75	1.364	0.3604	SQ	1	8	8
G113_C	06/16/2012	2	86	6	8	51.83	51.83	0.012	0.75	1.364	0.3604	SQ	1	8	8
G248A_C	01/01/1900	1	80	5	8	5.87	5.82	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248A_C	01/01/1900	2	80	5	8	5.87	5.82	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248B_C	01/01/1900	1	80	5	8	5.87	5.89	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248B_C	01/01/1900	2	80	5	8	5.87	5.89	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248C_C	01/01/1900	1	80	5	8	5.88	5.91	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248C_C	01/01/1900	2	80	5	8	5.88	5.91	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248D_C	01/01/1900	1	80	5	8	5.99	6.01	0.012	0.71	1.364	0.3604	SQ	1	8	5
G248D_C	01/01/1900	2	80	5	8	5.99	6.01	0.012	0.71	1.364	0.3604	SQ	1	8	5
G255_C	01/07/2005	1	60	6	8	5.11	5.05	0.012	0.75	1.364	0.3604	SQ	1	8	6
G255_C	01/07/2005	2	60	6	8	5.11	5.05	0.012	0.75	1.364	0.3604	SQ	1	8	6
G255_C	01/07/2005	3	60	6	8	5.11	5.05	0.012	0.75	1.364	0.3604	SQ	1	8	6
G307_C	01/01/1900	1	105	4	6	5	5	0.012	0.75	1.364	0.3604	SQ	1	8	4
G337A_C	01/01/1900	1	30	5	6.7	-2	-2	0.012	0.67	1.364	0.3604	SQ	2	6.7	5
G337A_C	01/01/1900	2	30	5	6.7	-2	-2	0.012	0.67	1.364	0.3604	SQ	3	6.7	5
G337A_C	01/01/1900	3	30	5	6.7	-2	-2	0.012	0.67	1.364	0.3604	SQ	4	6.7	5
G337A_C	01/01/1900	4	30	5	6.7	-2	-2	0.012	0.67	1.364	0.3604	SQ	5	6.7	5
G342A_C	11/20/1998	1	68	6	10	7.25	7.25	0.012	0.81	1.364	0.3604	SQ	1	10	6
G342B_C	11/20/1998	1	68	6	10	7.25	7.25	0.012	0.87	1.364	0.3604	SQ	1	10	6
G342C_C	01/01/1800	1	68	6	10	7.25	7.25	0.012	0.87	1.364	0.3604	SQ	1	10	6
G342D_C	11/02/1998	1	68	6	10	7.25	7.25	0.012	0.79	1.364	0.3604	SQ	1	10	6
G342E_C	01/01/1900	1	36.5	6	10	5.92	5.94	0.012	0.85	1.364	0.3604	SQ	1	10	6
G342F_C	01/01/1900	1	36.5	6	10	5.97	5.95	0.012	0.85	1.364	0.3604	SQ	1	10	6
G342O_C	12/13/2012	1	88.8	8	7	0.94	0.94	0.012	0.75	1.364	0.3604	SQ	1	7	8
G342O_C	12/13/2012	2	88.8	8	7	0.94	0.94	0.012	0.75	1.364	0.3604	SQ	1	7	8
G344A_C	05/10/1999	1	53	10	10	0	0	0.012	0.78	1.364	0.3604	SQ	1	10	10
G344B_C	05/10/1999	1	53	10	10	0	0	0.012	0.78	1.364	0.3604	SQ	1	10	10
G344C_C	05/10/1999	1	53	10	10	0	0	0.012	0.82	1.364	0.3604	SQ	1	10	10
G344D_C	05/10/1999	1	45	10	10	-0.04	-0.04	0.012	0.82	1.364	0.3604	SQ	1	10	10

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G353A_C	01/01/1900	1	44	6	8	6	6	0.012	0.85	1.364	0.3604	SQ	1	8	6
G353B_C	01/01/1900	1	44	6	8	6	6	0.012	0.85	1.364	0.3604	SQ	1	8	6
G353C_C	01/01/1900	1	44	6	8	6	6	0.012	0.85	1.364	0.3604	SQ	1	8	6
G357_C	01/01/1800	1	25	10	10	2.8	2.8	0.013	0.85	0.9686	0.3164	SQ	1	8	8
G357_C	01/01/1800	2	25	10	10	2.8	2.8	0.013	0.9	0.9686	0.3164	SQ	1	8	8
G368_C	01/01/1800	1	136	8	8	-1.59	-1.55	0.012	0.781	1.364	0.3604	SQ	1	8	8
G368_C	01/01/1800	2	136	8	8	-1.6	-1.58	0.012	0.781	1.364	0.3604	SQ	1	8	8
G368_C	01/01/1800	3	136	8	8	-1.66	-1.65	0.012	0.781	1.364	0.3604	SQ	1	8	8
G368_C	01/01/1800	4	136	8	8	-1.7	-1.7	0.012	0.781	1.364	0.3604	SQ	1	8	8
G372HL_C	12/01/2013	1	183	10	10	4	4	0.012	0.85	1.364	0.3604	SQ	1	10	10
G372HL_C	12/01/2013	2	183	10	10	4	4	0.012	0.85	1.364	0.3604	SQ	1	10	10
G374A_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G374B_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G374C_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G374D_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G374E_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G374F_C	01/01/2003	1	76.1	8	10	2	2	0.012	0.795	1.364	0.3604	SQ	1	10	8
G375A_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G375B_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G375C_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G375D_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G375E_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G375F_C	01/01/2003	1	75.7	8	10	2	2	0.012	0.712	1.364	0.3604	SQ	1	10	8
G376A_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G376B_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G376C_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G376D_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G376E_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G376F_C	01/01/2003	1	115	8	10	2	2	0.012	0.75	1.364	0.3604	SQ	1	10	8
G377A_C	01/01/2003	1	40	9	10	2.06	2.06	0.012	0.828	1.364	0.3604	SQ	1	10	9
G377B_C	01/01/2003	1	40	9	10	2.06	2.26	0.012	0.828	1.364	0.3604	SQ	1	10	9
G377C_C	01/01/2003	1	40	9	10	1.96	2.06	0.012	0.828	1.364	0.3604	SQ	1	10	9

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G377D_C	01/01/2003	1	40	9	10	2.06	2.26	0.012	0.828	1.364	0.3604	SQ	1	10	9
G377E_C	01/01/2003	1	40	9	10	1.96	2.16	0.012	0.828	1.364	0.3604	SQ	1	10	9
G378A_C	01/01/2003	1	123	10	10	0	0	0.012	0.747	1.364	0.3604	SQ	1	10	10
G378B_C	01/01/2003	1	123	10	10	0	0	0.012	0.747	1.364	0.3604	SQ	1	10	10
G378C_C	01/01/2003	1	123	10	10	0	0	0.012	0.747	1.364	0.3604	SQ	1	10	10
G378D_C	01/01/2003	1	123	10	10	0	0	0.012	0.747	1.364	0.3604	SQ	1	10	10
G378E_C	01/01/2003	1	123	10	10	0	0	0.012	0.743	1.364	0.3604	SQ	1	10	10
G379A_C	01/01/2003	1	123	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G379B_C	01/01/2003	1	123	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G379C_C	01/01/2003	1	123	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G379D_C	01/01/2003	1	123	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G379E_C	01/01/2003	1	123	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G380A_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G380B_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G380C_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G380D_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G380E_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G380F_C	01/01/2003	1	77.6	7	7	3	3	0.012	0.78	1.364	0.3604	SQ	1	7	7
G381A_C	01/01/2003	1	40	8	8	2	2	0.012	0.831	1.364	0.3604	SQ	1	8	8
G381B_C	01/01/2003	1	40	8	8	2	2	0.012	0.831	1.364	0.3604	SQ	1	8	8
G381C_C	01/01/2003	1	40	8	8	2	2	0.012	0.831	1.364	0.3604	SQ	1	8	8
G381D_C	01/01/2003	1	40	8	8	2	2	0.012	0.75	1.364	0.3604	SQ	1	8	8
G381E_C	01/01/2003	1	40	8	8	2	2	0.012	0.75	1.364	0.3604	SQ	1	8	8
G381F_C	01/01/2003	1	40	8	8	2	2	0.012	0.75	1.364	0.3604	SQ	1	8	8
G382A_C	01/14/2005	1	127	10	10	0	0	0.012	0.815	1.24	0.354	SQ	1	10	10
G382B_C	01/14/2005	1	119	10	10	0	0	0.012	0.815	1.24	0.354	SQ	1	10	10
G383_C	01/14/2005	1	114	10	10	0	0	0.012	0.75	1.364	0.3604	SQ	1	10	10
G383_C	01/14/2005	2	114	10	10	0	0	0.012	0.5	1.364	0.3604	SQ	1	10	10
G384A_C	01/01/1900	1	75	8	10	2.01	2.22	0.012	0.754	1.364	0.3604	SQ	1	10	8
G384B_C	01/01/1900	1	75	8	10	2.1	2.12	0.012	0.754	1.364	0.3604	SQ	1	10	8
G384C_C	01/01/1900	1	75	8	10	2.27	2	0.012	0.754	1.364	0.3604	SQ	1	10	8
G384D_C	01/01/1900	1	75	8	10	2.04	2.03	0.012	0.754	1.364	0.3604	SQ	1	10	8

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G384E_C	01/01/1900	1	75	8	10	2.09	2.12	0.012	0.754	1.364	0.3604	SQ	1	10	8
G384F_C	01/01/1900	1	75	8	10	1.54	1.48	0.012	0.754	1.364	0.3604	SQ	1	10	8
G390A_C	07/17/2006	1	125	6	6	2	2	0.0121	0.644	1.364	0.3604	SQ	1	6	6
G396A_C	01/01/1900	1	44	8	8	4	4	0.012	0.85	1.364	0.3604	SQ	1	8	8
G396B_C	01/01/1900	1	44	8	8	4	4	0.012	0.85	1.364	0.3604	SQ	1	8	8
G396C_C	01/01/1900	1	44	8	8	4	4	0.012	0.85	1.364	0.3604	SQ	1	8	8
G406_C	11/28/1998	1	50	9	10	6.11	6.1	0.012	0.838	1.164	0.312	SQ	1	10	9
G406_C	11/28/1998	2	50	9	10	6.11	6.1	0.012	0.838	1.164	0.312	SQ	1	10	9
G407_C	01/01/1900	1	38	9	10	3	3	0.012	0.85	1.364	0.3604	SQ	1	10	9
G407_C	01/01/1900	2	38	9	10	3	3	0.012	0.85	1.364	0.3604	SQ	1	10	9
G441_C	07/20/2012	1	244	8	8	-1.55	-1.55	0.012	0.716	1.364	0.3604	SQ	1	8	8
G441_C	07/20/2012	2	244	8	8	-1.55	-1.55	0.012	0.716	1.364	0.3604	SQ	1	8	8
G443A_C	07/24/2012	1	169	8	8	-1.46	-1.53	0.012	0.75	1.364	0.3604	SQ	1	8	8
G443B_C	07/24/2012	1	169	8	8	-1.54	-1.49	0.012	0.75	1.364	0.3604	SQ	1	8	8
G81_C	09/04/1998	1	92	10	8	8	8	0.012	0.704	1	0.35	SQ	1	8	10
G81_C	09/04/1998	2	92	10	8	8	8	0.012	0.704	1	0.35	SQ	1	8	10
G92_C	12/01/2009	1	50	8	10	3	3	0.012	0.766	1.133	0.3154	SQ	1	10	8
HC1_C	05/08/2001	1	3.7	4	4	0.5	0.5	0.024	0.85	1.364	0.3604	SQ	1	4	4
HC1_C	05/08/2001	1	3.7	4	4	0.5	0.5	0.024	0.85	1.364	0.3604	SQ	2	4	4
S121_C	12/15/1965	1	128	8	8	-4.5	-4.5	0.012	0.72	1.105	0.334	SQ	1	8	8
S124_C	02/10/2012	1	43	6	10	-3	-3	0.012	0.63	1.364	0.3604	SQ	1	10	6
S124_C	02/10/2012	2	43	6	10	-3	-3	0.012	0.63	1.364	0.3604	SQ	1	10	6
S124_C	02/10/2012	3	43	6	10	-3	-3	0.012	0.63	1.364	0.3604	SQ	1	10	6
S13AW_C	05/27/2008	1	47	5	10	-4	-4	0.012	0.7	1.364	0.3604	SQ	1	10	5
S13AW_C	05/27/2008	2	47	5	10	-4	-4	0.012	0.7	1.364	0.3604	SQ	1	10	5
S154_C	12/10/1965	1	117	8	10	5	3	0.012	0.753	1.22	0.28	SQ	1	10.7	8.25
S154_C	12/10/1965	2	117	8	10	5	3	0.012	0.753	1.22	0.28	SQ	1	10.7	8.25
S154OLD_C	12/31/1799	1	117	8	10	5	4	0.012	0.5	1.364	0.3604	SQ	1	10.7	8.25
S154OLD_C	12/31/1799	1	117	8	10	5	4	0.012	0.5	1.364	0.3604	SQ	2	10.7	8.25
S197_C	08/23/2012	1	28	10	11	-12	-12	0.012	0.85	1.364	0.3604	SQ	1	10	10
S197_C	08/23/2012	2	28	10	11	-12	-12	0.012	0.85	1.364	0.3604	SQ	1	10	10
S197_C	08/23/2012	3	28	10	11	-12	-12	0.012	0.85	1.364	0.3604	SQ	1	10	10

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
S197_C	08/23/2012	4	28	10	11	-12	-12	0.012	0.85	1.364	0.3604	SQ	1	10	10
S363A_C	05/01/2004	1	67.5	8	8	9.5	9.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S363B_C	05/01/2004	1	67.5	8	8	9.5	9.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S363C_C	05/01/2004	1	67.5	8	8	9.5	9.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S364A_C	05/01/2004	1	65.8	8	8	7.75	7.75	0.012	0.85	1.364	0.3604	SQ	1	8	8
S364B_C	05/01/2004	1	65.8	8	8	7.75	7.75	0.012	0.85	1.364	0.3604	SQ	1	8	8
S364C_C	05/01/2004	1	65.8	8	8	7.75	7.75	0.012	0.85	1.364	0.3604	SQ	1	8	8
S365A_C	05/01/2004	1	63.8	8	8	6.25	6.25	0.012	0.85	1.364	0.3604	SQ	1	8	8
S365B_C	05/01/2004	1	63.8	8	8	6.25	6.25	0.012	0.85	1.364	0.3604	SQ	1	8	8
S366A_C	05/01/2004	1	73.5	8	8	7.5	7.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S366B_C	05/01/2004	1	73.5	8	8	7.5	7.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S366C_C	05/01/2004	1	73.5	8	8	7.5	7.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S366D_C	05/01/2004	1	73.5	8	8	7.5	7.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S366E_C	05/01/2004	1	73.5	8	8	7.5	7.5	0.012	0.81	1.364	0.3604	SQ	1	8	8
S367A_C	05/01/2004	1	64.5	8	8	7	7	0.012	0.7	1.364	0.3604	SQ	1	8	8
S367B_C	05/01/2004	1	64.5	8	8	7	7	0.012	0.7	1.364	0.3604	SQ	1	8	8
S367C_C	05/01/2004	1	64.5	8	8	7	7	0.012	0.7	1.364	0.3604	SQ	1	8	8
S367D_C	05/01/2004	1	64.5	8	8	7	7	0.012	0.7	1.364	0.3604	SQ	1	8	8
S367E_C	05/01/2004	1	64.5	8	8	7	7	0.012	0.7	1.364	0.3604	SQ	1	8	8
S368A_C	05/01/2004	1	66.8	8	8	5.25	5.25	0.012	0.685	1.364	0.3604	SQ	1	8	8
S368B_C	05/01/2004	1	66.8	8	8	5.25	5.25	0.012	0.685	1.364	0.3604	SQ	1	8	8
S368C_C	05/01/2004	1	66.8	8	8	5.25	5.25	0.012	0.685	1.364	0.3604	SQ	1	8	8
S368D_C	05/01/2004	1	66.8	8	8	5.25	5.25	0.012	0.685	1.364	0.3604	SQ	1	8	8
S368E_C	05/01/2004	1	66.8	8	8	5.25	5.25	0.012	0.685	1.364	0.3604	SQ	1	8	8
S369A_C	05/01/2004	1	66.8	8	8	3.75	3.75	0.012	0.663	1.086	0.2966	SQ	1	8	8
S369B_C	05/01/2004	1	66.8	8	8	3.75	3.75	0.012	0.663	1.086	0.2966	SQ	1	8	8
S369C_C	05/01/2004	1	66.8	8	8	3.75	3.75	0.012	0.663	1.086	0.2966	SQ	1	8	8
S369D_C	05/01/2004	1	66.8	8	8	3.75	3.75	0.012	0.663	1.086	0.2966	SQ	1	8	8
S370A_C	05/01/2004	1	70.5	8	8	6.5	6.5	0.012	0.76	0.955	0.2556	SQ	1	8	8
S370B_C	05/01/2004	1	70.5	8	8	6.5	6.5	0.012	0.76	0.955	0.2556	SQ	1	8	8
S370C_C	05/01/2004	1	70.5	8	8	6.5	6.5	0.012	0.76	0.955	0.2556	SQ	1	8	8
S371A_C	05/01/2004	1	67.5	8	8	3.78	3.78	0.012	0.67	1.364	0.3604	SQ	1	8	8

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
S371B_C	05/01/2004	1	67.5	8	8	4.5	4.5	0.012	0.67	1.364	0.3604	SQ	1	8	8
S371C_C	05/01/2004	1	67.5	8	8	3.78	3.78	0.012	0.67	1.364	0.3604	SQ	1	8	8
S372A_C	05/01/2004	1	66	8	8	3	3	0.012	0.67	1.364	0.3604	SQ	1	8	8
S372B_C	05/01/2004	1	66	8	8	3	3	0.012	0.67	1.364	0.3604	SQ	1	8	8
S372C_C	05/01/2004	1	66	8	8	3	3	0.012	0.67	1.364	0.3604	SQ	1	8	8
S372D_C	05/01/2004	1	66	8	8	3	3	0.012	0.67	1.364	0.3604	SQ	1	8	8
S372E_C	05/01/2004	1	66	8	8	3	3	0.012	0.67	1.364	0.3604	SQ	1	8	8
S373A_C	05/01/2004	1	73.5	8	8	5.5	5.5	0.012	0.674	1.0443	0.3438	SQ	1	8	8
S373B_C	05/01/2004	1	73.5	8	8	5.5	5.5	0.012	0.674	1.0443	0.3438	SQ	1	8	8
S374A_C	05/01/2004	1	66	8	8	4.5	4.5	0.012	0.67	1.364	0.3604	SQ	1	8	8
S374B_C	05/01/2004	1	66	8	8	4.5	4.5	0.012	0.67	1.364	0.3604	SQ	1	8	8
S374C_C	05/01/2004	1	66	8	8	4.5	4.5	0.012	0.67	1.364	0.3604	SQ	1	8	8
S375_C	06/13/2012	1	48	8	8	4	4	0.012	0.791	1.364	0.3604	SQ	1	8	8
S375_C	06/13/2012	2	48	8	8	4	4	0.012	0.791	1.364	0.3604	SQ	1	8	8
S375_C	06/13/2012	3	48	8	8	4	4	0.012	0.791	1.364	0.3604	SQ	1	8	8
S5AE_C	04/15/1954	1	65.5	7	7	0.67	1.17	0.013	0.783	1.364	0.3604	SQ	1	7	7
S5AE_C	04/15/1954	2	65.5	7	7	0.67	1.17	0.013	0.783	1.364	0.3604	SQ	1	7	7
S5AW_C	04/15/1954	1	73	7	7	1.17	1.17	0.012	0.775	1.364	0.3604	SQ	1	7	7
S5AW_C	04/15/1954	2	73	7	7	1.17	1.17	0.012	0.775	1.364	0.3604	SQ	1	7	7
S65DX1_C	06/12/2009	1	120	5	5	18	18	0.012	0.75	1.35	0.31	SQ	1	6.5	6.5
S65DX1_C	06/12/2009	2	120	5	5	18	18	0.012	0.75	1.35	0.31	SQ	1	6.5	6.5
S65DX1_C	06/12/2009	3	120	5	5	18	18	0.012	0.751	1.094	0.3	SQ	1	6.5	6.5
S65DX1_C	06/12/2009	4	120	5	5	18	18	0.012	0.751	1.094	0.3	SQ	1	6.5	6.5
G249D_C	02/27/2007	1	70	4	8	7.02	7	0.012	0.85	1.364	0.3604				
G342G_C	07/26/2012	1	34	6	10	5.98	5.87	0.012	0.75	1.364	0.3604	SG	1	10	6
G342H_C	07/26/2012	1	34	6	10	5.99	6	0.012	0.75	1.364	0.3604	SG	1	10	6
G342I_C	08/03/2012	1	34	6	10	6	5.98	0.012	0.75	1.364	0.3604	SG	1	10	6
G342J_C	08/03/2012	1	34	6	10	6.11	6.12	0.012	0.75	1.364	0.3604	SG	1	10	6
G342K_C	08/08/2012	1	34	6	10	5.89	5.89	0.012	0.75	1.364	0.3604	SG	1	10	6
G342L_C	08/08/2012	1	34	6	10	5.96	5.9	0.012	0.75	1.364	0.3604	SG	1	10	6
G342M_C	08/08/2012	1	34	6	10	5.94	5.94	0.012	0.75	1.364	0.3604	SG	1	10	6
G342N_C	08/08/2012	1	34	8	10	5.9	5.91	0.012	0.706	1.047	0.305	SG	1	10	8

Station	Effective Date	Barrel Number	Culvert Length (ft)	Culvert Height (ft)	Culvert Width (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	culvT5Coef1	culvT5Coef2	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G342N_C	08/08/2012	2	34	8	10	5.9	5.91	0.012	0.706	1.047	0.305	SG	1	10	8
G343K_C	08/09/2012	1	34	9	10	2.03	2	0.012	0.75	1.364	0.3604	SG	1	10	9
G343L_C	08/09/2012	1	34	9	10	1.99	1.96	0.012	0.75	1.364	0.3604	SG	1	10	9
G343M_C	08/09/2012	1	34	9	10	2	1.98	0.012	0.75	1.364	0.3604	SG	1	10	9
G343N_C	08/06/2012	1	34	9	10	2.01	1.96	0.012	0.75	1.364	0.3604	SG	1	10	9
G343O_C	08/09/2012	1	34	9	10	1.94	1.96	0.012	0.75	1.364	0.3604	SG	1	10	9
G344G_C	08/06/2012	1	34	10	10	0.04	0.05	0.012	0.75	1.364	0.3604	SG	1	10	10
G344H_C	08/06/2012	1	34	10	10	0.21	0.2	0.012	0.75	1.364	0.3604	SG	1	10	10
G344I_C	08/06/2012	1	34	10	10	0.07	0.09	0.012	0.75	1.364	0.3604	SG	1	10	10
G344J_C	08/10/2012	1	34	10	10	0.07	0.09	0.012	0.75	1.364	0.3604	SG	1	10	10
G344K_C	08/10/2012	1	34	10	10	0.04	0.02	0.012	0.75	1.364	0.3604	SG	1	10	10
G351_C	08/06/2012	1	37.6	9	10	5	5	0.012	0.75	1.364	0.3604	SG	1	10	9
G351_C	08/06/2012	2	37.6	9	10	5	5	0.012	0.75	1.364	0.3604	SG	1	10	9
G408_C	08/14/2012	1	22	9	10	3	2.95	0.012	0.75	1.364	0.3604	SG	1	10	9
G408_C	08/14/2012	2	22	9	10	3	2.95	0.012	0.75	1.364	0.3604	SG	1	10	9
G411_C	08/10/2012	1	22	8	10	-0.01	-0.01	0.012	0.75	1.364	0.3604	SG	1	10	8
G411_C	08/10/2012	2	22	8	10	0.08	0	0.012	0.75	1.364	0.3604	SG	1	10	8
G722_C	08/27/2015	1	31	10.75	11.5	-5.5	-5.5	0.012	0.85	1.364	0.3604	SG	1	10	10
G722_C	08/27/2015	2	31	10.75	11.5	-5.5	-5.5	0.012	0.85	1.364	0.3604	SG	1	10	10
G722_C	08/27/2015	3	31	10.75	11.5	-5.5	-5.5	0.012	0.85	1.364	0.3604	SG	1	10	10
S372D	01/11/2005	1	66	8	8	3	3	0.012	0.75	1.364	0.3604	SG	1	8	8
S67_C	09/11/2012	1	111.3	4	8	31	31	0.012	0.75	1.364	0.3604	SG	1	9.33	4.33
S67_C	09/11/2012	2	111.3	4	8	31	31	0.012	0.75	1.364	0.3604	SG	1	9.33	4.33

Appendix F4 – New Flow Parameters for Circular Culverts

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
CULV5A_C	01/01/2000	1	160	10	5.5	5.5	0.024	0.85	1.364	0.3604	1	RG	1	10		
CULV5A_C	01/01/2000	2	160	10	5.5	5.5	0.024	0.85	1.364	0.3604	1	SG	1		10	10
CULV5A_C	01/01/2000	3	160	10	5.5	5.5	0.024	0.85	1.364	0.3604	1	RG	1	10		
CV10A_C	01/01/1990	1	70.6	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	RG	1	10		
CV10A_C	01/01/1990	2	70.6	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	RG	1	10		
CV10A_C	01/01/1990	3	70.6	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	SG	1		10	10
CV10A_C	01/01/1990	4	70.6	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	RG	1	10		
CV10A_C	01/01/1990	5	70.6	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	RG	1	10		
G113_C	06/16/2012	3	86	1	53.88	53.51	0.012	0.75	1.364	0.3604	1	SG	1		1	1
G150_C	01/01/1800	1	40	7	8.5	8.5	0.024	0.85	1.025	0.477	1	SG	1		7	7
G150_C	01/01/1800	2	40	7	8.5	8.5	0.024	0.85	1.025	0.477	1	SG	1		7	7
G150_C	01/01/1800	3	40	7	8.5	8.5	0.024	0.85	1.025	0.477	1	SG	1		7	7
G161_C	01/01/1900	1	240	5	11.14	11.17	0.012	0.721	1.129	0.247	1	SG	1		5	5
G161_C	01/01/1900	2	240	5	11.14	11.17	0.012	0.721	1.129	0.247	1	SG	1		5	5
G211_C	01/01/1800	1	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G211_C	01/01/1800	2	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G211_C	01/01/1800	3	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G211_C	01/01/1800	4	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G211_C	01/01/1800	5	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G211_C	01/01/1800	6	60	6	-2.5	-2.5	0.024	0.7	1.364	0.3604	1	SG	1		6	6
G259_C	01/01/2006	1	78.5	6	0.5	1.5	0.024	0.8	1.364	0.3604	1	SG	1		6	6
G327A_C	01/01/1800	1	130	7	0.5	0.5	0.024	0.749	1.157	0.247	1	SG	1		7	7
G328I_C	12/01/2000	1	32	3	7.16	7.16	0.024	0.7	0.9	0.42	1	SG	1		3.55	3.2
G329A_C	01/01/1800	1	64.4	6	8.88	8.9	0.024	0.85	1.265	0.342	1	SG	1		6	6
G329B_C	01/01/1800	1	64.1	6	9.19	9.1	0.024	0.85	1.265	0.342	1	SG	1		6	6
G329C_C	01/01/1800	1	64.4	6	9.09	9	0.024	0.85	1.265	0.342	1	SG	1		6	6
G329D_C	01/01/1800	1	63.9	6	8.75	8.85	0.024	0.85	1.265	0.342	1	SG	1		6	6
G33_C	01/01/1800	1	158.9	6	5.74	5.74	0.012	0.5	1.364	0.3604	1	RG	1		6	6
G331A_C	01/01/1800	1	64.3	5.5	8.83	8.8	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G331B_C	01/01/1800	1	64.8	5.5	9	9.1	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
G331C_C	01/01/1800	1	64	5.5	8.52	8.52	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G331D_C	01/01/1800	1	64.7	5.5	8.81	8.8	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G331E_C	01/01/1800	1	65	5.5	8.6	8.6	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G331F_C	01/01/1800	1	64.5	5.5	8.83	8.9	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G331G_C	01/01/1800	1	64	5.5	9.3	9.2	0.02	0.85	1.384	0.307	0.897	SQ	1		5.5	5.5
G333A_C	01/01/1800	1	75	5.5	8.14	8.17	0.024	0.85	1.105	0.495	0.94	SQ	1		5.5	5.5
G333B_C	01/01/1800	1	75	5.5	8.24	8.38	0.024	0.85	1.105	0.495	0.94	SQ	1		5.5	5.5
G333C_C	01/01/1800	1	75	5.5	8.34	8.19	0.024	0.85	1.105	0.495	0.94	SQ	1		5.5	5.5
G333D_C	01/01/1800	1	75	5.5	8.34	8.56	0.024	0.85	1.105	0.495	0.94	SQ	1		5.5	5.5
G333E_C	01/01/1800	1	75	5.5	8.17	8.38	0.024	0.85	1.105	0.495	0.94	SQ	1		5.5	5.5
G34_C	01/01/1800	1	162.5	6	5.74	5.74	0.024	0.85	1.364	0.3604	1	RG	1	6		
G34_C	01/01/1800	2	162.5	6	5.75	5.75	0.024	0.85	1.364	0.3604	1	RG	1	6		
G34_C	01/01/1800	3	162.5	6	5.73	5.73	0.024	0.85	1.364	0.3604	1	RG	1	6		
G367A_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G367B_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G367C_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G367D_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G367E_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G367F_C	01/01/1900	1	120	6	-1	-2	0.012	0.85	1.364	0.3604	1	SG	1		8	8
G389A_C	07/17/2006	1	130	7	3	3	0.024	0.75	1.364	0.3604	1	N/A	0			
G389B_C	07/17/2006	1	130	7	3	3	0.024	0.75	1.364	0.3604	1	N/A	0			
G390B_C	10/24/2011	1	125	3	2	2	0.017	0.598	1.364	0.3604	1	SG	1		6	6
G402A_C	01/01/1800	1	85	4.5	7.13	7.13	0.024	0.8	1.157	0.228	1	SG	1		4.5	4.5
G402B_C	01/01/1800	1	93	4.5	7.23	7.23	0.024	0.8	1.157	0.228	1	SG	1		4.5	4.5
G402C_C	01/01/1800	1	110	4.5	7.57	7.57	0.024	0.8	1.157	0.228	1	SG	1		4.5	4.5
G402D_C	01/01/1800	1	134	3.5	6.01	6.01	0.024	0.8	1.157	0.228	1	SG	1		3.5	3.5
G438A_C	07/06/2012	1	142	6	0.54	0.52	0.012	0.7	1.364	0.3604	1	SG	1		6	6
G438B_C	07/06/2012	1	142	6	0.52	0.55	0.012	0.7	1.364	0.3604	1	SG	1		6	6
G438C_C	07/06/2012	1	142	6	0.44	0.48	0.012	0.7	1.364	0.3604	1	SG	1		6	6
G438D_C	07/09/2012	1	142	6	0.5	0.51	0.012	0.7	1.364	0.3604	1	SG	1		6	6
G438E_C	07/10/2012	1	142	6	0.47	0.34	0.012	0.7	1.364	0.3604	1	SG	1		6	6
G438F_C	07/13/2012	1	142	6	0.5	0.51	0.012	0.75	1.364	0.3604	1	SG	1		6	6

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
G438G_C	07/13/2012	1	142	6	0.44	0.48	0.012	0.757	1.364	0.3604	1	SG	1		6	6
G438H_C	07/13/2012	1	142	6	0.47	0.34	0.012	0.75	1.364	0.3604	1	SG	1		6	6
G438I_C	07/13/2012	1	142	6	0.5	0.43	0.012	0.75	1.364	0.3604	1	SG	1		6	6
G438J_C	07/13/2012	1	142	6	0.55	0.44	0.012	0.75	1.364	0.3604	1	SG	1		6	6
G58_C	12/31/1799	1	224	5	-7	-7	0.024	0.8	1.364	0.3604	1	SG	1		5	5
G58_C	12/31/1799	2	207	6	-7	-7	0.024	0.8	1.364	0.3604	1	SG	1		6	6
G58_C	12/31/1799	3	190	6	-7	-7	0.024	0.8	1.364	0.3604	1	SG	1		6	6
G58_C	12/31/1799	4	173	6	-7	-7	0.024	0.8	1.364	0.3604	1	SG	1		6	6
G600C_C	07/23/2004	1	60	5			0.024	0.2	1.364	0.3604	1	SG	1		5.2	5
G600C_C	07/23/2004	2	60	5			0.024	0.2	1.364	0.3604	1	SG	1		5.1	5
G74_C	01/01/1800	1	80.4	6	11.8	10.72	0.024	0.75	1.185	0.286	1	SG	1		7	7
G74_C	01/01/1800	1	80.4	6	11.8	10.72	0.024	0.75	1.185	0.286	1	SG	2		7	7
G74_C	01/01/1800	2	80.4	6	11.2	10.71	0.024	0.75	1.185	0.286	1	SG	1		7	7
G74_C	01/01/1800	2	80.4	6	11.2	10.71	0.024	0.75	1.185	0.286	1	SG	2		7	7
G75_C	06/01/1999	1	81.2	7	9.85	9.95	0.024	0.5	1.364	0.3604	1	SG	1		7	7
G75_C	06/01/1999	1	81.2	7	9.85	9.95	0.024	0.5	1.364	0.3604	1	SG	2		7	7
G75_C	06/01/1999	2	81.2	7	9.85	9.95	0.024	0.5	1.48	0.3604	1	SG	1		7	7
G75_C	06/01/1999	2	81.2	7	9.85	9.95	0.024	0.5	1.48	0.3604	1	SG	2		7	7
G76_C	06/01/1998	1	75	6	7.91	7.79	0.024	0.5	1.364	0.3604	1	SG	1		6	6
G76_C	06/01/1998	1	75	6	7.91	7.79	0.024	0.5	1.364	0.3604	1	SG	2		6	6
G76_C	06/01/1998	2	75	6	8.12	7.74	0.024	0.5	1.482	0.3604	1	SG	1		6	6
G76_C	06/01/1998	2	75	6	8.12	7.74	0.024	0.5	1.482	0.3604	1	SG	2		6	6
G94A_C	01/01/1800	1	70	6	7	7	0.024	0.854	1.364	0.3604	1	SG	1		6	6
G94A_C	01/01/1800	2	70	6	7	7	0.024	0.854	1.364	0.3604	1	SG	1		6	6
G94B_C	01/01/1990	1	70	6	7	7	0.012	0.854	1.364	0.3604	1	SG	1		6	6
G94B_C	01/01/1990	2	70	6	7	7	0.012	0.854	1.364	0.3604	1	SG	1		6	6
G94C_C	01/01/2000	1	69	6.33	7.13	7.13	0.024	0.854	1.364	0.3604	1	SG	1		6.13	6.13
G94C_C	01/01/2000	2	69.4	6.33	7.13	7.13	0.024	0.854	1.364	0.3604	1	SG	1		6.33	6.33
L8RES1_C	01/01/2000	1	100	6	7.5	7.5	0.023	0.883	0.878	0.38	1	SG	1		6	6
L8RES2_C	01/01/2000	1	100	6	7.5	7.5	0.023	0.883	0.878	0.38	1	SG	1		6	6
S122_C	05/10/1965	1	60	6	-4	-4	0.012	0.7	1.239	0.33	1	SG	1		6	6
S122_C	05/10/1965	2	60	6	-4	-4	0.012	0.7	1.239	0.33	1	SG	1		6	6

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
S124_C	02/10/2012	4	48	6	-1	-1	0.024	0.8	1.364	0.3604	1	SG	1		6	6
S124_C	02/10/2012	5	48	6	-1	-1	0.024	0.8	1.364	0.3604	1	SG	1		6	6
S129_C	01/01/1800	1	119	8	6	5	0.024	0.85	1.17	0.244	1	SG	1		8	8
S129_C	01/01/1800	2	119	8	6	5	0.024	0.85	1.17	0.244	1	SG	1		8	8
S131_C	01/01/1800	1	217	8	6	5	0.024	0.85	1.17	0.244	1	RG	1	8		
S131_C	01/01/1800	1	217	8	6	5	0.024	0.85	1.17	0.244	1	SG	2		8	8
S135_C	01/01/1800	1	151	8	5	5	0.024	0.85	1.17	0.244	1	SG	1		8	8
S135_C	01/01/1800	1	151	8	5	5	0.024	0.85	1.17	0.244	1	SG	2		8	8
S135_C	01/01/1800	2	151	8	5	5	0.024	0.85	1.17	0.244	1	SG	1		8	8
S135_C	01/01/1800	2	151	8	5	5	0.024	0.85	1.17	0.244	1	SG	2		8	8
S143_C	12/31/1799	1	70	6	2	2	0.024	0.708	1.07	0.3	1	SG	1		6	6
S143_C	12/31/1799	2	70	6	2	2	0.024	0.708	1.07	0.3	1	SG	1		6	6
S144_C	03/27/1993	1	98	6.5	2.34	2.36	0.024	0.816	1.364	0.3604	1	SG	1		6	6
S145_C	12/31/1799	1	98	6.5	4	4	0.024	0.816	1.364	0.3604	1	SG	1		6	6
S146_C	12/31/1799	1	98	6.5	4	4	0.024	0.816	1.364	0.3604	1	SG	1		6	6
S149_C	12/31/1799	1	63	7	-3	-3	0.012	0.75	1.142	0.244	0.878	SG	1		7	7
S149_C	12/31/1799	2	63	7	-3	-3	0.012	0.75	1.142	0.244	0.878	SG	1		7	7
S150_C	04/15/2015	1	92	7	3.02	3.1	0.024	0.76	1.364	0.3604	1	SG	1		7	7
S150_C	04/15/2015	2	92	7	2.98	3.34	0.024	0.76	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	1	98	7	-2.58	-2.37	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	2	98	7	-2.48	-2.44	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	3	98	7	-2.48	-2.42	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	4	98	7	-2.53	-2.47	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	5	98	7	-2.5	-2.47	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S151_C	07/27/1962	6	98	7	-2.54	-2.46	0.024	0.732	1.364	0.3604	1	SG	1		7	7
S154C_C	05/12/2008	1	136.5	6	8	8	0.012	0.85	1.364	0.3604	1	RG	1	6		
S169_C	12/31/1799	1	60	7	6	6	0.024	0.85	1.046	0.3065	1	SG	1		7	7
S169_C	12/31/1799	2	60	7	6	6	0.024	0.85	1.046	0.3065	1	SG	1		7	7
S169_C	12/31/1799	3	60	7	6	6	0.024	0.85	1.046	0.3065	1	SG	1		7	7
S173_C	10/04/1982	1	70	6	-2.5	-2.5	0.012	0.692	1.364	0.3604	1	SG	1		6	6
S175_C	06/19/1970	1	56	7	-5	-5	0.012	0.804	1.364	0.3604	1	SG	1		7	7
S175_C	06/19/1970	2	56	7	-5	-5	0.012	0.804	1.364	0.3604	1	SG	1		7	7

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
S175_C	06/19/1970	3	56	7	-5	-5	0.012	0.804	1.364	0.3604	1	SG	1		7	7
S194_C	12/31/1799	1	90	7	-2.5	-3.5	0.012	0.735	1.364	0.3604	1	SG	1		7	7
S194_C	12/31/1799	2	90	7	-2.5	-3.5	0.012	0.735	1.364	0.3604	1	SG	1		7	7
S196_C	12/31/1799	1	58	7	-2.5	-3.5	0.012	0.821	1.364	0.3604	1	SG	1		7	7
S197_C	08/23/2012	5	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	6	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	7	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	8	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	9	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	10	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	11	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	12	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S197_C	08/23/2012	13	66	7	-8	-8	0.024	0.8	1.364	0.3604	1	SG	1		8	12
S235_C	12/31/1799	1	70	6	4.1	4.1	0.012	0.771	1.364	0.3604	1	SG	1		6	6
S235_C	12/31/1799	2	70	6	4.1	4.1	0.012	0.771	1.364	0.3604	1	SG	1		6	6
S32_C	09/15/1952	1	40	6	-2	-2	0.024	0.779	1.203	0.2234	1	SG	1		6	6
S32_C	09/15/1952	2	40	6	-2	-2	0.024	0.779	1.203	0.2234	1	SG	1		6	6
S332DX1_C	11/01/2009	1	164.2	5	1	1	0.024	0.792	1.364	0.3604	1	SG	1		5	5.2
S332DX1_C	11/01/2009	2	164.2	5	1	1	0.024	0.792	1.364	0.3604	1	SG	1		5	5.2
S332DX1_C	11/01/2009	3	164.2	5	1	1	0.024	0.792	1.364	0.3604	1	SG	1		5	5.2
S332DX1_C	11/01/2009	4	164.2	5	1	1	0.024	0.792	1.364	0.3604	1	SG	1		5	5.2
S338_C	12/31/1799	1	85	7	-5.98	-4.4	0.024	0.874	1.364	0.3604	1	SG	1		7	7
S338_C	12/31/1799	2	85	7	-5.98	-4.45	0.024	0.874	1.364	0.3604	1	SG	1		7	7
S34_C	09/15/1952	1	130	6	-2.5	-4.1	0.022	0.862	1.364	0.3604	1	SG	1		6	6
S34_C	09/15/1952	2	130	6	-2.5	-4.1	0.022	0.862	1.364	0.3604	1	SG	1		6	6
S343A_C	12/31/1799	1	82	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S343A_C	12/31/1799	2	82	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S343A_C	12/31/1799	3	82	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S343B_C	12/31/1799	1	84	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S343B_C	12/31/1799	2	84	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S343B_C	12/31/1799	3	84	6	0	0	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S344_C	12/31/1799	1	80	6	1	1	0.024	0.851	1.364	0.3604	1	SG	1		6	6

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
S344_C	12/31/1799	2	80	6	1	1	0.024	0.851	1.364	0.3604	1	SG	1		6	6
S376_C	06/17/2009	1	76	4	6.5	6.5	0.024	0.75	1.364	0.3604	1	SG	1		6	5
S376_C	06/17/2009	2	76	4	6.5	6.5	0.024	0.75	1.364	0.3604	1	SG	1		6	5
S380_C	06/26/2004	1	96	6	-3	-3	0.024	0.789	1.364	0.3604	1	RG	1	6		
S380_C	06/26/2004	2	96	6	-3	-3	0.024	0.789	1.364	0.3604	1	RG	1	6		
S380_C	06/26/2004	3	96	6	-3	-3	0.024	0.789	1.364	0.3604	1	RG	1	6		
S380_C	06/26/2004	4	96	6	-3	-3	0.024	0.789	1.364	0.3604	1	RG	1	6		
S380_C	06/26/2004	5	96	6	-3	-3	0.024	0.789	1.364	0.3604	1	RG	1	6		
S38B_C	12/31/1799	1	72	5.5	0	0	0.024	0.8	1.364	0.3604	1	SG	1		6	6
S38C_C	01/27/2004	1	26	6	0.8	0.8	0.024	0.5	1.364	0.3604	1	SG	1		9	8
S38C_C	01/27/2004	2	26	6	0.8	0.8	0.024	0.5	1.364	0.3604	1	SG	1		9	8
S57_C	12/31/1799	1	80	4.5	52.5	52.5	0.024	0.78	1.364	0.3604	1	SG	1		5	5
S57_C	12/31/1799	2	80	4.5	52.5	52.5	0.024	0.78	1.364	0.3604	1	SG	1		5	5
S58_C	12/31/1799	1	73.8	4.5	53.67	53.69	0.024	0.69	1.364	0.3604	1	SG	1		5	5
S58_C	12/31/1799	2	73.8	4.5	53.67	53.69	0.024	0.69	1.364	0.3604	1	SG	1		5	5
CV5	01/01/1800	1	60	10	5.5	5.5	0.024	0.5	1.364	0.3604	1	SG	1		10	10
G440A_C	07/19/2012	1	135	5	2.45	2.45	0.024	0.75	1.364	0.3604	1	SG	1		6	6
G440B_C	07/19/2012	1	127	5	2.45	2.45	0.024	0.787	1.364	0.3604	1	SG	1		6	6
G440C_C	07/19/2012	1	127	5	2.45	2.45	0.024	0.75	1.364	0.3604	1	SG	1		6	6
G440D_C	07/19/2012	1	127	5	2.45	2.45	0.024	0.75	1.364	0.3604	1	SG	1		6	6
G440E_C	07/19/2012	1	127	5	2.45	2.45	0.024	0.75	1.364	0.3604	1	SG	1		6	6
G440F_C	07/19/2012	1	127	5	2.45	2.45	0.024	0.75	1.364	0.3604	1	SG	1		6	6
G510_C	09/17/2012	1	54.5	3	8.24	8.21	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G511_C	09/20/2012	1	47.5	3	9.84	8.45	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G512_C	09/20/2012	1	59	3	8.36	8.38	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G512_C	09/20/2012	2	59	3	8.36	8.38	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G513_C	09/20/2012	1	33	3	8.36	8.45	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G514_C	09/20/2012	1	66.5	3	9.36	8.48	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G515_C	09/20/2012	1	23.5	3	9.91	9.75	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G516_C	09/20/2012	1	23.5	3	9.8	9.8	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G517_C	09/20/2012	1	19	3	9.78	9.82	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G518_C	09/20/2012	1	19	3	9.82	9.82	0.012	0.75	1.364	0.3604	1	SG	1		3	3

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Culv T5 Coef1	Culv T5 Coef2	Culv T3 Coeff	Barrel Control Type	Barrel Control No.	Gate Diameter (ft)	Gate Width (ft)	Gate Height (ft)
G519_C	09/20/2012	1	32	3	8.95	8.95	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G519_C	09/20/2012	2	32	3	8.95	8.95	0.012	0.75	1.364	0.3604	1	SG	1		3	3
G700X1_C	01/01/2014	1	95	6	45	45	0.024	0.8	1.364	0.3604	1	SG	1		6	6
G700_C	03/01/2013	1	22	6	45.2	45.2	0.012	0.75	1.364	0.3604	1	SG	1		6	6
G715_C	02/27/2013	1	90	3	6.76	6.76	0.024	0.75	1.364	0.3604	1	SG	1		3	3
S154C	01/01/1800	1	136	6	8	8	0.012	0.5	1.364	0.3604	1	SG	1		6	6
S154C	01/01/1800	1	136	6	8	8	0.012	0.5	1.364	0.3604	1	SG	2		6	6
S377_C	10/14/2010	1	119.5	4	6.5	6.5	0.024	0.75	1.364	0.3604	1	SG	1		6	5
S377_C	10/14/2010	2	119.5	4	6.5	6.5	0.024	0.75	1.364	0.3604	1	SG	1		6	5
S67X_C	09/11/2012	1	90	4	34	34	0.024	0.75	1.364	0.3604	1	SG	1		6	6
S67X_C	09/11/2012	2	90	4	34	34	0.024	0.75	1.364	0.3604	1	SG	1		6	6
S67X_C	09/11/2012	3	90	4	34	34	0.024	0.75	1.364	0.3604	1	SG	1		6	6
S67X_C	09/11/2012	4	90	4	34	34	0.024	0.75	1.364	0.3604	1	SG	1		6	6

Appendix F5 – Flow Parameters for Double-Leaf Culverts

Station	Effective Date	Barrel No.	Culvert Length (ft)	Barrel Shape	Culvert Height (ft)	Culvert Width (ft)	Culvert Diameter (ft)	Inlet Inv. Elev.	Outlet Inv. Elev.	Manning Coef. Barrel	Entr. Loss Coef. Ke	Barrel Control Type	Barrel Control Number	Gate Width (ft)	Gate Height (ft)
G136_C	02/18/2010	1	109	C			7	7	7	0.024	0.8	SQ	1, 2	9.33	5
G136_C	02/18/2010	2	109	C			7	7	7	0.024	0.8	SQ	1, 2	9.33	5
G136_C	02/18/2010	3	109	C			7	7	7	0.024	0.8	SQ	1, 2	9.33	5
G343I_C	01/01/1900	1	44	B	8	10		4.19	4.19	0.012	0.85	SQ	1, 2	10	4
G343J_C	01/01/1900	1	44	B	8	10		4.09	4.09	0.012	0.85	SQ	1, 2	10	4
G344E_C	01/01/1900	1	45	B	10	10		-0.04	-0.04	0.012	0.85	SQ	1, 2	10	5
G344F_C	01/01/1900	1	45	B	10	10		0.06	0.06	0.012	0.85	SQ	1, 2	10	5
G352A_C	01/01/1900	1	36	B	10	10		0	0	0.012	0.85	SQ	1, 2	10	5
G352B_C	01/01/1900	1	36	B	10	10		0	0	0.012	0.85	SQ	1, 2	10	5
G352C_C	01/01/1900	1	36	B	10	10		0	0	0.012	0.85	SQ	1, 2	10	5
G78_C	04/03/2003	1	57	C			3	14.87	14.98	0.024	0.75	SQ	1, 2	3.4	5
G78_C	04/03/2003	2	57	C			3	14.87	14.98	0.024	0.75	SQ	1, 2	3.4	5
G79_C	06/01/1998	1	46	C			6	15.52	15.54	0.024	0.75	SQ	1, 2	8	3
G79_C	06/01/1998	2	46	C			6	15.55	15.64	0.024	0.75	SQ	1, 2	8	3
G79_C	06/01/1998	3	46	C			6	15.57	15.65	0.024	0.75	SQ	1, 2	8	3
MILLER3_C	03/25/2015	1	17	B	8	8		3.5	3.5	0.012	0.75	SG	1,2	8	4
MILLER3_C	03/25/2015	2	17	B	8	8		3.5	3.5	0.012	0.75	SG	1,2	8	4
MILLER3_C	03/25/2015	3	17	B	8	8		3.5	3.5	0.012	0.75	SG	1,2	8	4

Appendix F6 – Flow Parameters for Type 1 Weir-Box Culverts

Station	Effective Date	Culvert								Inlet Weir													
		Barrel No.	Culvert Length (ft)	Barrel Shape	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef.	Weir Length (ft)	Weir Elev. (ft)	Gate Loss Coef	wbCSFC	wbUSFC	wbCFFC	wbUFFC	spCSFC1	spCSFC2	spCFFC1	spCFFC2	spUSFC1
G354_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	25	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G354_C	05/01/2000	2	85	C	7	5	5	0.024	0.85	25	13.96	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G354_C	05/01/2000	3	85	C	7	5	5	0.024	0.85	25	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G354A_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	25	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G354B_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	25	13.96	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G354C_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	25	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	27	13.92	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393_C	05/01/2000	2	85	C	7	5	5	0.024	0.85	27	13.95	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393_C	05/01/2000	3	85	C	7	5	5	0.024	0.85	27	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393A_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	27	13.92	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393B_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	27	13.95	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02
G393C_C	05/01/2000	1	85	C	7	5	5	0.024	0.85	27	13.97	0.5	0.75	0.9	0.75	3	1.07	0.32	0.86	0.35	1.02

Appendix F7 – Flow Parameters for Type 2 Weir-Box Culverts

Station	Effective Date	Culvert								Inlet Weir												
		Barrel No.	Culvert Length (ft)	Barrel Shape	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef.	Weir Length (ft)	Weir Elev. (ft)	Gate Loss Coef	wbCSFC	wbUSFC	wbCFFC	wbUFFC	spCSFC1	spCSFC2	spCFFC1	spCFFC2	spUSFC1
G304A_C	07/19/2000	1	95.8	C	6	4.76	4.86	0.024	0.5	8.75	11.11	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304B_C	07/19/2000	1	97	C	6	4.77	5.07	0.057	0.5	8.75	11.09	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304C_C	07/20/2000	1	96.6	C	6	4.28	5.08	0.057	0.5	8.75	11.13	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304D_C	07/20/2000	1	96.5	C	6	4.58	4.98	0.057	0.5	8.75	11.16	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304E_C	07/20/2000	1	93.7	C	6	4.58	4.78	0.024	0.5	8.75	11.08	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304F_C	07/20/2000	1	95	C	6	4.78	4.98	0.057	0.5	8.75	11.17	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304G_C	07/20/2000	1	96.5	C	6	4.78	4.98	0.057	0.5	8.75	11.17	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304H_C	07/20/2000	1	96	C	6	4.91	5.21	0.057	0.5	8.75	11.2	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304I_C	07/20/2000	1	96.5	C	6	4.77	5.07	0.057	0.5	8.75	11.17	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G304J_C	07/20/2000	1	96.7	C	6	5.17	5.47	0.057	0.5	8.75	11.17	0.5	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G306A_C	06/08/2000	1	126	C	6	0.78	0.78	0.022	0.5	8.8	7.77	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306B_C	06/08/2000	1	130	C	6	0.77	0.77	0.022	0.5	8.8	7.75	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306C_C	06/08/2000	1	131	C	6	0.78	0.78	0.024	0.5	8.8	7.75	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306D_C	06/08/2000	1	131	C	6	0.67	0.77	0.024	0.5	8.8	7.76	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306E_C	06/08/2000	1	125	C	6	0.86	0.76	0.022	0.5	8.8	7.74	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306F_C	06/08/2000	1	133	C	6	0.77	0.77	0.022	0.5	8.8	7.69	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306G_C	06/01/2000	1	132	C	6	0.66	0.86	0.022	0.5	8.8	7.76	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306H_C	06/01/2000	1	131	C	6	0.76	0.46	0.022	0.5	8.8	7.71	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306I_C	06/08/2000	1	133	C	6	0.75	0.85	0.022	0.5	8.8	7.73	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G306J_C	06/08/2000	1	133	C	6	0.65	0.76	0.024	0.5	8.8	7.69	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02

Appendix F8 – Flow Parameters for Type 3 Weir-Box Culverts

Station	Effective Date	Culvert									Inlet Weir												
		Barrel No.	Culvert Length (ft)	Barrel Shape	Culvert Width (ft)	Culvert Height (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef	Entr Loss Coef	Weir Length (ft)	Weir Elev. (ft)	Gate Loss Coef	wbCSFC	wbUSFC	wbCFFC	wbUFFC	spCSFC1	spCSFC2	spCFFC1	spCFFC2	spUSFC1
G343A_C	01/01/2003	1	60	B	8	10	5.5	5.5	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343B_C	09/01/2003	1	60	B	8	10	5.36	5.36	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343C_C	09/15/2003	1	60	B	8	10	5.41	5.41	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343D_C	01/01/1900	1	60	B	8	10	5.41	5.41	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343E_C	01/01/1900	1	60	B	8	10	5.44	5.44	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343F_C	09/15/2003	1	60	B	8	10	5.49	5.49	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343G_C	09/15/2003	1	60	B	8	10	5.41	5.41	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G343H_C	01/01/1900	1	60	B	8	10	5.49	5.49	0.012	0.85	10	9	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02

Appendix F9 – Flow Parameters for Type 4 Weir-Box Culverts

Station	Effective Date	Culvert										Inlet Weir											
		Barrel No.	Culvert Length (ft.)	Barrel Shape	Culvert D (ft)	H (ft)	W (ft)	Up Inv. Elev (ft.)	Down Inv. Elev. (ft.)	Manning Coef.	Entr. Loss Coef.	Weir Length (ft.)	Weir Elev. (ft.)	Gate Loss Coef	wbCSFC	wbUSFC	wbCFFC	wbUFFC	spCSFC1	spCSFC2	spCFFC1	spCFFC2	spUSFC1
G33_C	01/01/1800	1	158.9	C	6			5.74	5.74	0.012	0.5	7.5	12.5	0.5	0.75	0.9	3.09	3.1	1.07	0.32	0.86	0.35	1.02
G34_C	01/01/1800	1	162.5	C	6			5.74	5.74	0.024	0.85	7.5	12.5	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G34_C	01/01/1800	2	162.5	C	6			5.75	5.75	0.024	0.85	7.5	12.5	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
G34_C	01/01/1800	3	162.5	C	6			5.73	5.73	0.024	0.85	7.5	12.5	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.86	0.35	1.02
S154C_C	05/12/2008	1	136.5	C	6			8	8	0.012	0.85	8	14	0.7	0.75	0.9	0.75	3.1	1.07	0.32	0.85	0.35	1.02
S387A_C	01/20/2010	1	70	C	3			22.5	22.5	0.012	0.85	5	27.25	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S387B_C	01/20/2010	1	80	C	3			22.5	22.5	0.012	0.85	5	27.25	0.65	0.75	0.9	0.75	0.31			0.85	0.35	
S387C_C	01/20/2010	1	80	C	3			24.5	24.5	0.012	0.85	5	27.25	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S391_C	01/01/1900	1	60	C	3			18.5	18.5	0.012	0.85	5	22.6	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S392_C	01/01/1900	1	72	C	3			17.5	17.5	0.012	0.85	5	22	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S386A_C	12/28/2009	1	60	C	3			27.5	25.5	0.012	0.75	5	33.5	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S386B_C	12/28/2009	1	60	C	3			27.5	25.5	0.012	0.75	5	33.5	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S651_C	10/07/2012	1	60.3	B		5	5	21.23	21.23	0.012	0.85	6	26.5	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S651_C	10/07/2012	2	60.3	B		5	5	21.24	21.24	0.012	0.85	6	26.5	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S652A_C	10/08/2012	1	30.6	B		2.5	2.5	19.79	19.79	0.012	0.85	6	25	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S652A_C	10/08/2012	2	30.6	B		2.5	2.5	19.77	19.77	0.012	0.85	6	25	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S653_C	10/08/2012	1	60.3	B		5	5	21.27	21.27	0.012	0.85	6	26.4	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S653_C	10/08/2012	2	60.3	B		5	5	21.29	21.29	0.012	0.85	6	26.4	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S654A_C	10/08/2012	1	30.6	B		5	5	19.79	19.79	0.012	0.85	6	24.9	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S654A_C	10/08/2012	2	30.6	B		5	5	19.8	19.8	0.012	0.85	6	24.9	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S655_C	10/08/2012	1	60.3	B		5	5	21.29	21.29	0.012	0.85	6	26.4	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S655_C	10/08/2012	2	60.3	B		5	5	21.29	21.29	0.012	0.85	6	26.4	0.65	0.75	0.9	0.75	3.1	1.05	0.3	0.85	0.35	
S656A_C	10/09/2012	1	30.6	B		5	5	19.77	19.77	0.012	0.75	6	24.9	0.65	0.75	0.9	0.75	3.1			0.85	0.35	
S656A_C	10/09/2012	2	30.6	B		5	5	19.73	19.73	0.012	0.75	6	24.9	0.65	0.75	0.9	0.75	3.1			0.85	0.35	

Appendix F10 – Flow Parameters for Type 5 Weir-Box Culverts

Station	Effective Date	Culvert										Inlet Weir									
		Barrel No.	Culvert Length (ft.)	Barrel Shape	Culvert D (ft.)	Barrel Height (ft)	Barrel Width (ft)	Up Inv. Elev. (ft.)	Down Inv. Elev. (ft.)	Manning Coef.	Entr. Loss Coef.	Weir Length (ft.)	Weir Elev. (ft.)	Gate Loss Coef	wbUFFC	spCSFC1	spCSFC2	spCFFC1	spCFFC2	spUSFC1
G330A_C	7/1/2002	1	89.5	C	5.5			5.82	5.68	0.024	0.85	50.45	13.12	0	3	1.07	0.32	0.86	0.35	1.02
G330B_C	7/1/2002	1	89.2	C	5.5			6.63	6.61	0.024	0.5	49.91	13.24	0	3	1.07	0.32	0.86	0.35	1.02
G330C_C	7/1/2002	1	90	C	5.5			6.72	6.5	0.024	0.5	50.18	13.18	0	3	1.07	0.32	0.86	0.35	1.02
G330D_C	7/1/2002	1	89.6	C	5.5			7.04	6.7	0.024	0.5	50.11	13.19	0	3	1.07	0.32	0.86	0.35	1.02
G330E_C	7/1/2002	1	100.5	C	5.5			7.17	6.96	0.024	0.5	49.85	13.2	0	3	1.07	0.32	0.86	0.35	1.02
S65AX2_C	01/01/1998	1	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX2_C	01/01/1998	2	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX2_C	01/01/1998	3	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX2_C	01/01/1998	4	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX3_C	01/01/1998	1	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX3_C	01/01/1998	2	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX3_C	01/01/1998	3	43.33	B		6	7	43	43	0.012	0.85	60	48							
S65AX3_C	01/01/1998	4	43.33	B		6	7	43	43	0.012	0.85	60	48							

Appendix F11 – Flow Parameters for Weir-Gated Culverts

Station	Effective Date	Culvert								Inlet Weir						
		Barrel No.	Barrel Shape	Barrel Length (ft)	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef. Ke	Control No.	Riser Length (ft)	Riser Elev. (FT-NGVD)	Weir Width (ft)	Weir Crest Elev. (FT-NGVD)	Gate Height (ft)	Cd
G108_C	06/29/1999	1	C	86	6	7	6.35	0.022	0.7	1	12.56	22	4	14.56	5	3
G108_C	06/29/1999	1	C	86	6	7	6.35	0.022	0.7	2	12.56	22	4	14.57	5	3
G108_C	06/29/1999	2	C	86	6	7	6.62	0.022	0.7	1	12.56	22	4	14.93	4.8	3
G108_C	06/29/1999	2	C	86	6	7	6.62	0.022	0.7	2	12.56	22	4	14.91	4.9	3
G108_C	06/29/1999	3	C	86	6	6.43	6.35	0.022	0.7	1	12.56	22	4	14.48	4.8	3
G108_C	06/29/1999	3	C	86	6	6.43	6.35	0.022	0.7	2	12.56	22	4	14.5	5	3
G108_C	06/29/1999	4	C	86	6	6.43	6.35	0.022	0.7	1	12.56	22	4	14.64	4.8	3
G108_C	06/29/1999	4	C	86	6	6.43	6.35	0.022	0.7	2	12.56	22	4	14.66	5	3
G108_C	06/29/1999	5	C	86	6	6.43	6.35	0.022	0.7	1	12.56	22	4	14.76	5	3
G108_C	06/29/1999	5	C	86	6	6.43	6.35	0.022	0.7	2	12.56	22	4	14.82	5	3
G108_C	06/29/1999	6	C	86	6	6.43	6.35	0.022	0.7	1	12.56	22	4	14.73	5	3
G108_C	06/29/1999	6	C	86	6	6.43	6.35	0.022	0.7	2	12.56	22	4	14.8	5	3
PC17A_C	08/04/2009	1	C	81.3	6	8.44	7.79	0.024	0.7	1	14	22.13	3.65	15.14	2.99	3.91
PC17A_C	08/04/2009	1	C	81.3	6	8.44	7.79	0.024	0.7	2	14	22.13	3.65	15.16	2.99	3.91
PC17A_C	08/04/2009	2	C	81.3	6	8.43	7.85	0.024	0.7	1	14	22.12	3.65	15.12	2.99	3.91
PC17A_C	08/04/2009	2	C	81.3	6	8.43	7.85	0.024	0.7	2	14	22.12	3.65	15.13	2.99	3.91

Appendix F12 – Flow Parameters for Case 1 Flashboard Culverts

Station	Effective Date	Culvert								Inlet Flashboard				
		Barrel No.	Barrel Shape	Barrel Length (ft)	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef. Ke	Control No.	Riser Length (ft)	Riser Elev. (ft)	Weir Width (ft)	Weir Cd
BONEY.SC_C	12/13/1799	1	C	85	4.5	34.87	34.87	0.024	0.8	1	12.57	44.95	7.36	3.3
BONEY.SC_C	12/13/1799	2	C	85	4.5	34.87	34.87	0.024	0.8	1	12.57	44.95	7.36	3.3
G124_C	12/13/1799	1	C	50	3	5.71	5.71	0.024	0.8	1	6.42	13.78	3.73	3.3
G124_C	12/13/1799	2	C	50	5.5	5.19	5.19	0.024	0.8	1	11	13.57	6.3	3.3
G124_C	12/13/1799	4	C	50	6	5.12	5.12	0.024	0.8	1	11	14.03	6.38	3.3
G124_C	12/13/1799	6	C	50	6	4.86	4.86	0.024	0.8	1	11	13.86	6.29	3.3
G124_C	12/13/1799	7	C	50	5.5	4.75	4.75	0.024	0.8	1	11	13.52	6.34	3.3
G134_C	12/13/1799	1	C	80	6	12.24	12.24	0.024	0.8	1	12.57	24.24	7.25	3.3
G135_C	12/13/1799	1	c	60	7	12.13	12.13	0.024	0.8	1	14.66	24.13	8.79	3.3
G152_C	07/06/2000	1	C	47.8	6	10.2	10.31	0.024	0.5	1	12.48	21.49	7	3.3
G152_C	07/06/2000	2	C	48.1	6	9.98	9.91	0.024	0.5	1	12.48	21.49	7	3.3
G152_C	07/06/2000	3	C	48	6	10	10.39	0.024	0.5	1	12.48	21.49	7	3.3
G152_C	07/06/2000	4	C	48.3	6	9.96	10.05	0.024	0.5	1	12.48	21.49	7	3.3
G204_C	12/09/2003	1	C	72	6	6.01	6.01	0.024	0.8	1	9.42	13.15	5.67	3.3
G204_C	12/09/2003	2	C	72	6	6.01	6.01	0.024	0.8	1	9.42	13.15	5.67	3.3
G204_C	12/09/2003	3	C	72	6	6.01	6.01	0.024	0.8	1	9.42	13.15	5.67	3.3
G204_C	12/09/2003	4	C	72	6	6.01	6.01	0.024	0.8	1	9.42	13.15	5.67	3.3
G204_C	12/09/2003	5	C	72	6	6.01	6.01	0.024	0.8	1	9.42	13.15	5.67	3.3
G205_C	01/01/1800	1	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G205_C	01/01/1800	2	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G205_C	01/01/1800	3	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G205_C	01/01/1800	4	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G205_C	01/01/1800	5	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G205_C	01/01/1800	6	C	72	6	4.44	4.44	0.024	0.8	1	9.42	13.89	5.67	3.3
G206_C	12/03/2003	1	C	66	5.5	3.75	3.75	0.024	0.8	1	8.64	13.75	5	3.3
G206_C	12/03/2003	2	C	66	5.5	3.75	3.75	0.024	0.8	1	8.64	13.75	5	3
G206_C	12/03/2003	3	C	66	5.5	3.75	3.75	0.024	0.8	1	8.64	13.75	5	3.3
G206_C	12/03/2003	4	C	66	5.5	3.75	3.75	0.024	0.8	1	8.64	13.75	5	3.3
G255A_C	01/01/1800	1	C	62.5	6	4.94	5.43	0.024	0.8	1	18	13.98	6.17	3.3

Station	Effective Date	Culvert								Inlet Flashboard				
		Barrel No.	Barrel Shape	Barrel Length (ft)	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef. Ke	Control No.	Riser Length (ft)	Riser Elev. (ft)	Weir Width (ft)	Weir Cd
G256_C	01/01/1800	1	C	65	6	5.15	5.4	0.024	0.8	1	18	14.08	7.7	3.3
G256_C	01/01/1800	2	C	65	6	5.01	5.04	0.024	0.8	1	18	14.08	7.17	3.3
G256_C	01/01/1800	3	C	65	6	4.94	4.94	0.024	0.8	1	18	14.02	7.17	3.3
G256_C	01/01/1800	4	C	65	6	5.17	4.98	0.024	0.8	1	18	14	7.17	3.3
G256_C	01/01/1800	5	C	65	6	5.06	5.15	0.024	0.8	1	18	14.05	7.17	3.3
G336G_C	01/09/2007	1	C	67	8	4.05	4.06	0.024	0.5	1	9.95	13.95	25.12	3.3
G336G_C	01/09/2007	2	C	67	8	4.05	4.05	0.024	0.5	1	9.95	13.95	25.12	3.3
G336G_C	01/09/2007	3	C	67	8	3.85	4.25	0.024	0.5	1	10.15	13.95	25.12	3.3
G336G_C	01/09/2007	4	C	67	8	3.95	3.75	0.024	0.5	1	10.05	13.95	25.12	3.3
G336G_C	01/09/2007	5	C	67	8	3.85	4.05	0.024	0.5	1	10.15	13.95	25.12	3.3
G345_C	01/10/2003	1	C	92	4	7	7	0.012	0.5	1	10	17	4	3.3
G345_C	01/10/2003	2	C	92	4	7	7	0.012	0.5	1	10	17	4	3.3
G607_C	01/01/1800	1	C	70	5.5	4.16	4.29	0.024	0.8	1	9.42	19	7.38	3.3
G607_C	01/01/1800	2	C	70	5.5	4.11	4.29	0.024	0.8	1	9.42	19	7.38	3.3
G607_C	01/01/1800	3	C	70	5.5	4.15	4.4	0.024	0.8	1	9.42	19	7.38	3.3
G607_C	01/01/1800	4	C	70	5.5	4.03	4.4	0.024	0.8	1	9.42	19	7.38	3.3
G607_C	01/01/1800	5	C	70	7	3.57	4.12	0.024	0.8	1	9.42	19	7.38	3.3
G607_C	01/01/1800	6	C	70	7	3.87	4.24	0.024	0.8	1	9.42	19	7.38	3.3
G72_C	12/13/1799	1	C	75	6	-2.3	-2.3	0.024	0.8	1	9.42	6.8	6	3.3
G72_C	12/13/1799	2	C	75	6	-2.3	-2.3	0.024	0.8	1	9.42	6.8	6	3.3
G72_C	12/13/1799	3	C	75	6	-2.3	-2.3	0.024	0.8	1	9.42	6.8	6	3.3
G72_C	12/13/1799	4	C	75	6	-2.3	-2.3	0.024	0.8	1	9.42	6.8	6	3.3
G86N_C	01/01/1800	1	C	135	5	-1	-1	0.024	0.8	1	12.57	7	7.5	3.3
G86S_C	01/01/1800	1	C	135	5	-1.14	-1.14	0.024	0.8	1	12.57	7.51	7.5	3.3
G88_C	12/31/1799	1	C	91	6	6	6	0.024	0.8	1	9.42	19	7.38	3.3
G88_C	12/31/1799	2	C	91	6	6	6	0.024	0.8	1	9.42	19	7.36	3.3
G88_C	12/31/1799	3	C	91	6	6	6	0.024	0.8	1	9.42	19	7.37	3.3
G88_C	12/31/1799	4	C	91	6	6	6	0.024	0.8	1	9.42	19	7.5	3.3
G89_C	12/31/2011	1	C	60	6	8.03	8.03	0.024	0.8	1	12.57	18	8	3.3
G89_C	12/31/2011	2	C	60	6	8.03	8.03	0.024	0.8	1	12.57	18	8	3.3
G89_C	12/31/2011	3	C	60	6	8.03	8.03	0.024	0.8	1	12.57	18	8	3.3

Station	Effective Date	Culvert								Inlet Flashboard				
		Barrel No.	Barrel Shape	Barrel Length (ft)	Culvert D (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef. Ke	Control No.	Riser Length (ft)	Riser Elev. (ft)	Weir Width (ft)	Weir Cd
G96_C	12/13/1799	1	C	40	5.5	7.28	7.28	0.024	0.8	1	12.57	21.56	7.88	3.3
G96_C	12/13/1799	2	C	40	5.5	7.85	7.85	0.024	0.8	1	12.57	21.48	7.88	3.3
HENRC_C	12/13/1799	1	C		6			0.024	0.8	1				
LETTC_C	12/13/1799	1	C	68	6	13.65	13.3	0.024	0.8	1				
NUBBC_C	12/13/1799	1	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	2	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	3	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	4	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	5	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	6	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
NUBBC_C	12/13/1799	7	C	72	6	11	11	0.024	0.8	1	26.5	26.5	6	3.3
S38A_C	12/13/1799	1	C	70	5	2	2	0.024	0.8	1	12.77	12.37	6.5	3.3
S38A_C	12/13/1799	1	C	70	5	2	2	0.024	0.8	2	12.77	12.37	6.5	3.3
S38A_C	12/13/1799	2	C	70	5	2	2	0.024	0.8	1	12.77	12.37	6.5	3.3
S38A_C	12/13/1799	2	C	70	5	2	2	0.024	0.8	2	12.77	12.37	6.5	3.3
S39A_C	12/31/1799	3	C	54	6	3.2	3.2	0.024	0.8					
S9XN_C	12/31/1799	1	C	84	6	-4.8	-4.8	0.024	0.8	1	10.21	10.32	6.17	3.3
S9XN_C	12/31/1799	2	C	84	6	-4.8	-4.8	0.024	0.8	1	10.21	10.32	6.17	3.3
S9XS_C	12/31/1799	1	C	42	6	-1	-1	0.024	0.8	1	10.21	8.76	6.17	3.3
S9XS_C	12/31/1799	2	C	42	6	-1	-1	0.024	0.8	1	10.21	8.76	6.17	3.3
S346	01/01/1800	1	C	65	6	0	0	0.024	0.8	1	24.8	12	7.5	3.3
S346	01/01/1800	2	C	65	6	0	0	0.024	0.8	1	24.8	12	7.5	3.3
S347	01/01/1800	1	C	77	6	-0.5	-0.5	0.024	0.8	1	10	10.5	7.5	3.3
S347	01/01/1800	2	C	77	6	-0.5	-0.5	0.024	0.8	1	10	10.5	7.5	3.3

Appendix F13 – Flow Parameters for Case 2 Flashboard Culverts

Station	Effective Date	Culvert										Inlet Flashboard				
		Barrel No.	Barrel Shape	Barrel Length (ft)	Culvert D (ft)	Culvert Width (ft)	Culvert Height (ft)	Up Inv. Elev. (ft)	Down Inv. Elev. (ft)	Manning Coef.	Entr. Loss Coef. Ke	Control No.	Riser Length (ft)	Riser Elev. (ft)	Weir Width (ft)	Weir Cd
G151_C	01/01/1800	1	B	60		8	8	9	9	0.012	0.5	1	5.79	18.33	5.79	3.71
G151_C	01/01/1800	1	B	60		8	8	9	9	0.012	0.5	2	5.79	18.33	5.79	3.71
G151_C	01/01/1800	2	B	60		8	8	9	9	0.012	0.5	1	5.79	18.33	5.79	3.71
G151_C	01/01/1800	2	B	60		8	8	9	9	0.012	0.5	2	5.79	18.33	5.79	3.71
G255_C	01/07/2005	4	C	62.5	6			5.17	5.12	0.024	0.8	1	18	13.92	6.17	3.3
G255_C	01/07/2005	5	C	62.5	6			5.03	5.1	0.024	0.8	1	18	13.92	6.17	3.3
G711_C	04/21/2011	1	C	100	6			11.5	11.5	0.024	0.7	1	8	23.2	7.85	2.5
G711_C	04/21/2011	2	C	100	6			11.5	11.5	0.024	0.7	1	8	23.2	7.85	2.5
G711_C	04/21/2011	3	C	100	6			11.5	11.5	0.024	0.7	1	8	23.2	7.85	2.5
G711_C	04/21/2011	4	C	100	6			11.5	11.5	0.024	0.7	1	8	23.2	7.85	2.5
USSO_C	11/14/2008	1	C	41	6			4.36	4.36	0.024	0.7	1	6.2	18.31	3.2	2.5
USSO_C	11/14/2008	2	C	41	6			4.36	4.36	0.024	0.7	1	6.2	18.31	3.2	2.5
USSO_C	11/14/2008	3	C	41	6			4.36	4.36	0.024	0.7	1	6.2	18.31	3.2	2.5
USSO_C	11/14/2008	4	C	41	6			4.36	4.36	0.024	0.7	1	6.2	18.31	3.2	2.5

Appendix F14 – Flow Parameters for Case 3 Culverts

Station	Effective Date	Barrel No.	Culvert Length (ft)	Culvert Shape	Culvert D (ft)	Inlet Inv. Elev	Outlet Inv. Elev	Manning Coef.	Entr. Loss Coef. Ke	culvT5 Coef1	culvT5 Coef2	culvT5 Coef1CSPO	culvT5 Coef2CSPO	culvT5 Coef1USPO	Barrel Control Type	Barrel Control No.	Gate Width/ Height
S127_C	03/03/2009	1	131	C	8	6	5	0.024	0.75	0.972	0.264	1.24	0.251	1.24	In series	1,2	8 / 8

Appendix G – Weirs

Appendix G1 – Flow Equation Parameters for Ogee Weirs

Station	Effective Date	Crest Length (ft)	Crest Elev. (ft)	Cd	Ce	N
GOLD.W4	11/08/1994					
HENDTAMI	09/07/1982					
S154WEIR_W	08/06/1974					
S48_S	07/08/1963	113	8	3.165	5.624	1.5
S50_S	06/12/1961	126	12	3.32	-0.2	1.5
S59WEIR_W	02/18/1971					
S48_S	07/08/1963	113	8	3.165	5.624	1.5
S50_S	06/12/1961	126	12	3.32	-0.2	1.5
HC1_W	05/08/2001	45	5	3.08	-0.2	1.5

Appendix G2 – Flow Parameters for Trapezoidal Weirs

Station	Effective Date	Crest Length (ft)	trap Channel Width (ft)	Trap CrestElev (ft-NGVD)	Trap CrestWidth (ft)	Trap NotchDepth (ft)	Trap TopWidth (ft)	Discharge Cofficient
C18	12/21/1979	93		17.64	0.1	3	93	3.15
C18W_W	12/21/1979	95	144	17.64	0.75	6.3	115	3.1
COCO1_W	06/28/1994	25	40	6.5	2.33	2.5	30	3.1
COCO3_W	06/02/2004	25.75	45	12	1.5	3.5	25.75	3.1
G601	11/30/1998	13	11	14.23	14	2.4	40	4.8
G602	11/30/1998	14	11	14.03	16	2.4	40	4.49
G603	11/30/1998	18	20	14.38	28	3.3	80	2.21
LNHRT_W	12/23/2009	25	25	10.25	0.75	3	25	3.1
S178_W	02/10/2005	15.86	53	4.94	1.67	1.56	15.86	3
WEIR1_W	08/15/1985	38.84	300	35		8.08	38.84	3
WEIR2_W	04/26/1985	39.46	300	35		9.1	39.46	3
WEIR3_W	04/26/1985	38.94	300	35		10.08	38.94	3
WFEED_O	01/31/1996							
WFEED_W	03/29/1999	136.19	250	16.86	2.5	4	136.19	3
S385_W	01/21/2010	24	100	20	1.67	8	40	3.1
S65AXA_W	01/01/1998	177	201	48	14	1	201	2.62
S65AXB_W	01/01/1998	247	271	48	14	1	271	2.62
S65AXC_W	01/01/1998	177	201	48	14	1	201	2.62
S660_W	08/21/2012	12	43	15.27	3	2	12	3.1
S71W_W	09/04/2008	45	175	1.5	1	16.9	45	3.31
SM00.4TW2	01/01/2014	35.8	63	16.08	2.125	3.3	49.5	2.62

Appendix G3 – Flow Parameters for Variable Weirs

Station	Effective Date	Crest Length (ft)	varChannelWidth (ft)	varCrestMinElev (ft-NGVD)	varCrestWidth (ft)	varNotchDepth (ft)	varTransElev (ft-NGVD)	varTransWidth (ft)
BONEY.SW_W	10/25/1977	7		38.5	0.48	10		
G155_W	01/01/1978	5.2	100	10.09	0.33	6.7	10.09	0.33
G54	01/01/1940	5.78	46.25	-3.6	0.2	14.1	-3.6	0.2
G85_W	07/04/1974	99.99		31	0.33	11	31	1
GOLD.W1_W	06/17/2003	26.67	92.98	-1	1	6	-1	21.97
S141_W	12/18/1994	5.33	144	7	0.62	5	8	2.2
GG1_W	01/01/1900	26.67	92.98	-1	3.1	6	2.46	6.92
GG2_W	12/15/2008	26.67	100	0	1	10.75	1.5	8.01
GG3_W	06/20/2011	26.67	140	1	1	14.42	2.5	13.25
S381_W	06/22/2006	30	130	-11.5	1	20.3	-9	21.58
SM00.4TW1	01/01/2014	10.3	63	9.18	0.1354	6.9	9.18	0.1354

Appendix G4 – Flow Parameters for FAKA

Station	Effective Date	Crest Length (ft)	dimaCrestElev (ft-NGVD)	Discharge Cofficient	weirFFCa	weirSFCa	weirSFCb
FAKA	12/31/1799	200	2	3.1	0.7095	1.19	0.3