InfoWorks ICM

Orifice Control

1 Introduction

This technical note describes orifices, sluices and weirs with roof controls. It supplements other information contained in the help. These controls are normally used to restrict the flow from a tank, pond or in the continuation pipe from a CSO. The equations used to determine the flow through an orifice depend on the hydraulic conditions upstream and downstream of the structure.

Figure 1 shows the up and downstream conditions. If the water level upstream of the orifice is below the soffit of the orifice, it is described as free discharge. If it is above the soffit, it is described as surcharged. If the water level downstream of the orifice is below the invert, it is described as independent. If it is above the invert it is described as a boundary condition.

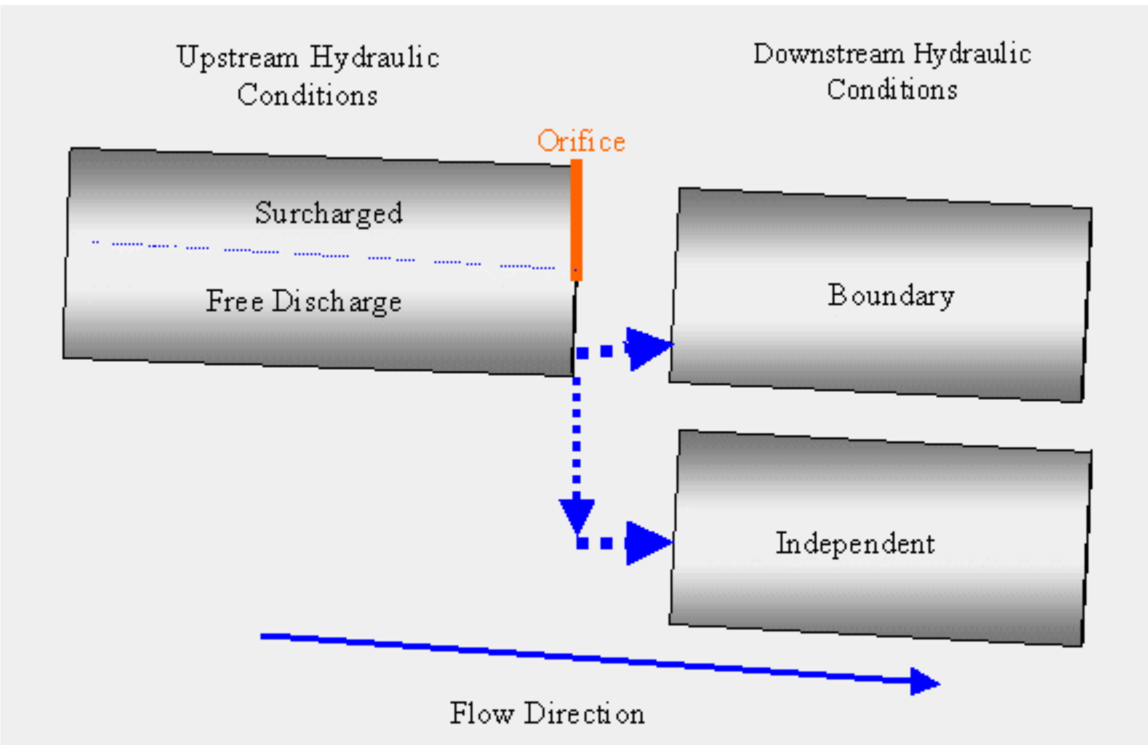

Figure 1 Four Scenarios of Orifice Operation

There are therefore four scenarios which can occur, depending on the upstream and downstream conditions.

1. Free discharge and independent
2. Surcharged and independent
3. Free discharge and boundary

4. Surcharged and boundary

Each of these scenarios is described in Sections 2 to 5 below, including worked examples. Chapter 6 provides a summary of the equations used in each case.

2 Scenario A, Free Discharge Upstream and Independent Downstream

Figure 2 shows flow passing through an orifice before entering a manhole chamber. The flow freely discharges into the manhole chamber and there are no downstream conditions affecting the flow. The depth is below the soffit of the orifice and therefore the rectangular weir equation is used.

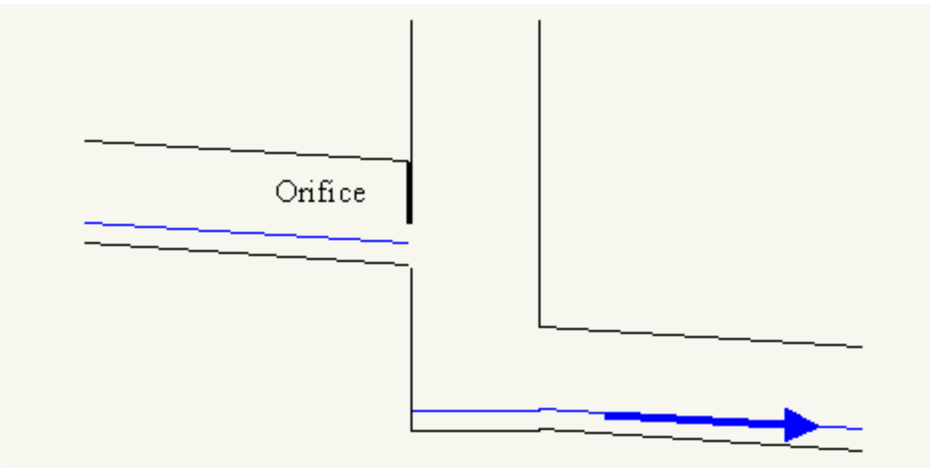

Figure 2 Free Discharge Upstream and Independent Downstream

The discharge is calculated using the following equations:

$$Qs = C_d B D_u \sqrt{g D_u} \qquad (1)$$

Where:
Qs = Discharge
C_d = Discharge coefficient
B = Width of weir
g = Acceleration due to gravity
D_u = Upstream depth relative to weir crest level or orifice level

$$B = A_o \mid D_o \qquad (2)$$

Where:
A_o = Area of an Orifice
D_o = Diameter of an Orifice

2.1 Scenario A, Worked Example

The network shown in Figure 3 was created to allow comparison between InfoWorks ICM and hand calculation under scenario A. In all worked examples, the diameter of the orifice is 150mm.

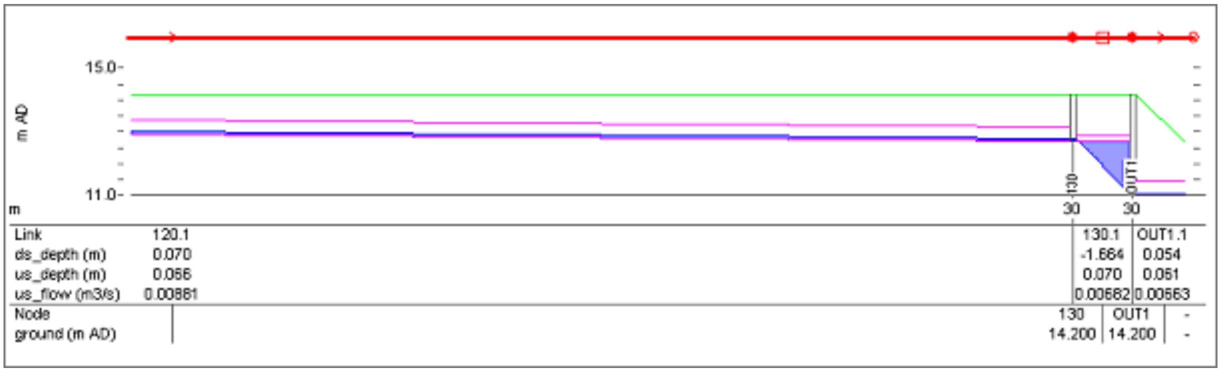

Figure 3 InfoWorks ICM Model of Scenario A

For Equation 1 (see Section 1):

$C_d = 1$

A_o = 0.0177 m 2

D_o = 0.15 m

B = 0.0177 / 0.15 = 0.1178 m

D_u = 0.07 (from Figure 3)

g = 9.80665 m/s 2

Therefore:

Qs = 1 x 0.1178 x 0.07 x (0.07 x 9.81) 0.5

Qs = 0.008246 x 0.8285321

Qs = 0.00683 m 3/s

This matches the flow in the orifice (link 130.1) shown in Figure 3.

3 Scenario B, Surcharged Upstream and Independent Downstream

If the water depth is greater than the soffit of the orifice, as shown in Figure 4 below, the flow will be calculated using the orifice equation.

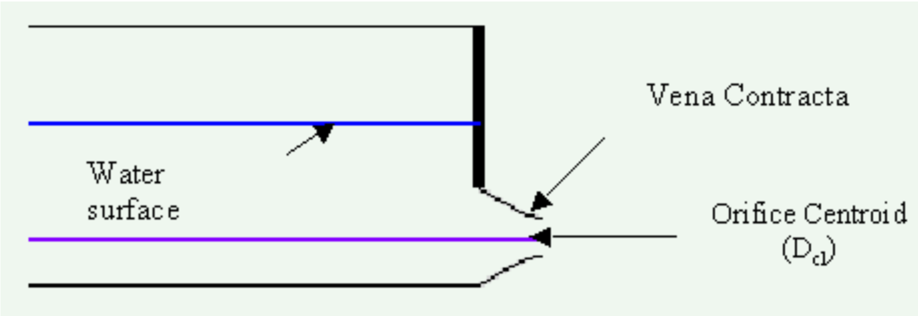

Figure 4 Surcharged Upstream and Independent Downstream

The equation takes the form:

$$Qs = C_d A_o \sqrt{g D_{cl}} \qquad (3)$$

Where:

D_{cl} = Height above the orifice centre

3.1 Scenario B, Worked Example

Figure 5 below shows a network where the upstream depth is greater than the orifice soffit.

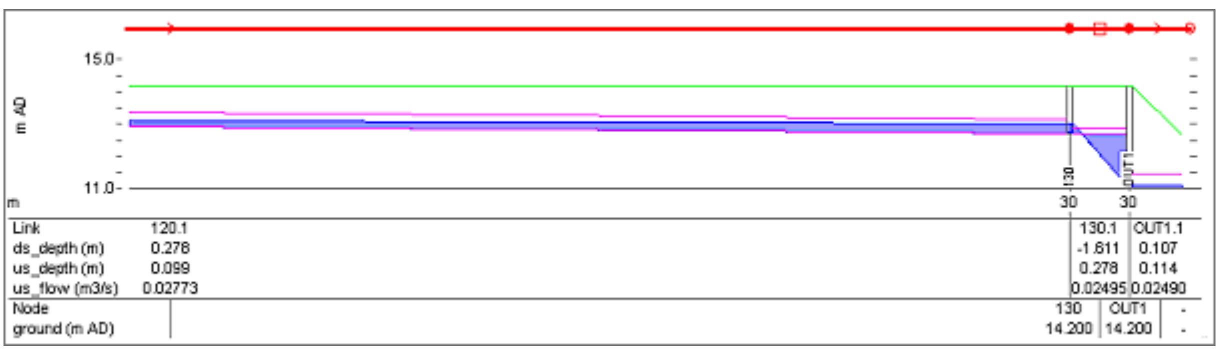

Figure 5 InfoWorks ICM Model of Scenario B

From Equation 3:

A_0 = 0.0177 m^2

D_{cl} = 0.278 - 0.075 = 0.203

Where 0.278 is taken from Figure 5.

Therefore:

Qs = 1 x 0.0177 x (9.81 x 0.203) 0.5

Qs = 0.02493 m^3

This matches the flow in Link 130.1, shown in Figure 5.

4 Scenario C, Free Discharge Upstream and Boundary Downstream

Figure 6 shows scenario C, where the upstream water depth is influenced by that downstream.

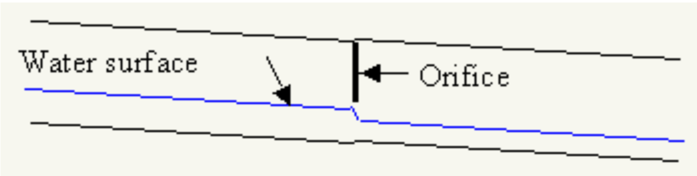

Figure 6 Free Discharge Upstream and Boundary Downstream

If there is a downstream depth that is affecting the flow conditions, but the depth is below the soffit of the orifice, the rectangular weir equation used. The discharge is calculated from the difference in the upstream and downstream depth.

$$Qs = C_d B D_u \sqrt{g(D_u - D_d)} \qquad (4)$$

Where:
D_d = Downstream depth relative to the weir crest level
(taken as orifice invert)

If the head difference < 0.01, the drowned weir equation (4) is linearised by the ICM simulation engine. This is because the iterative solver needs to calculate the derivatives of the flow with respect to upstream and downstream depth and these tend to infinity as the head difference tends to zero.

$$Qs = C_d B D_u \sqrt{g D_u}\, \frac{(D_u - D_d)}{0.01} \qquad (4a)$$

4.1 Scenario C, Worked Example

Figure 7 shows a simple 5 pipe network in plan and long section. The orifice is 150 mm in diameter and is connected to an upstream pipe with a diameter of 450 mm and downstream pipe with a 300mm diameter.

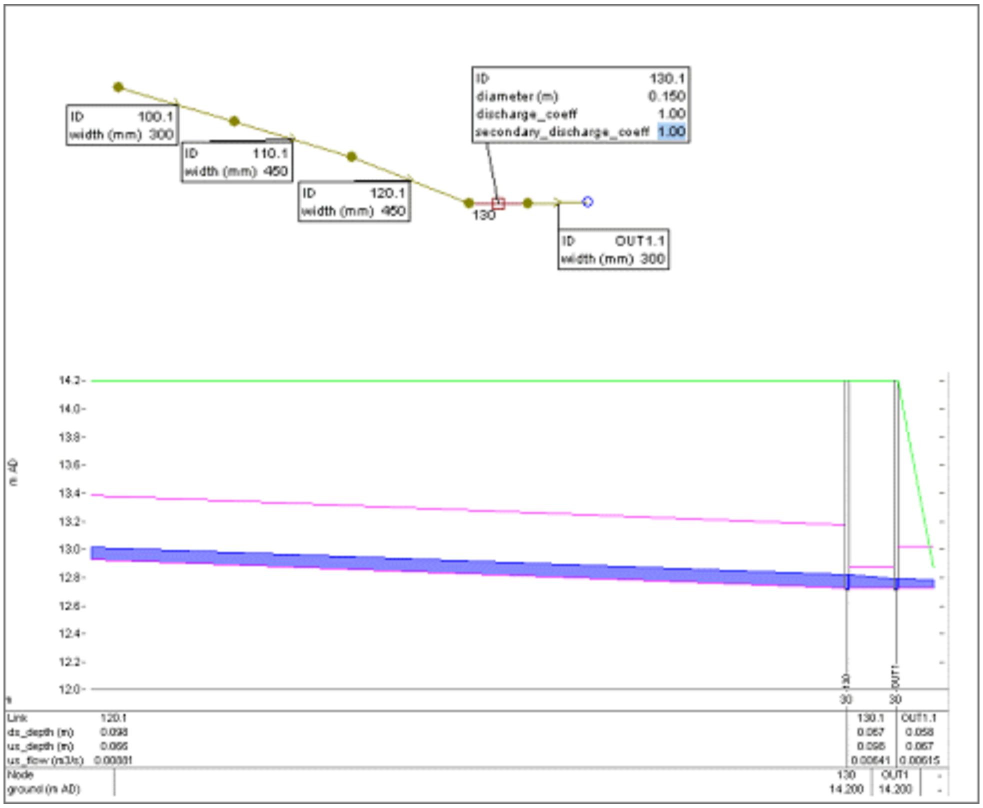

Figure 7 InfoWorks ICM Model of Scenario C

In scenario C, the equation used is similar to that of the rectangular weir:

From Figure 7:

D_u = 0.098 m

D_d = 0.067 m

Therefore from Equation 4:

Qs = 1 x 0.1178 x 0.098 x (9.81 x (0.098 - 0.067)) 0.5

Qs = 0.0115 x 0.55136

Qs = 0.0064 m^3

Note: Equation 4a does not apply to Scenario C as the head difference is larger than 0.1.

5 Scenario D, Surcharged Upstream and Boundary Downstream

Figure 8 shows scenario D, where the upstream depth is surcharged and influenced by the downstream boundary condition.

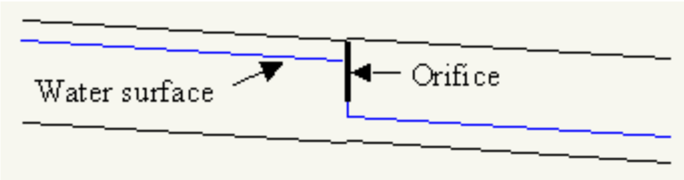

Figure 8 Surcharged Upstream and Boundary Downstream

For scenario D, the equation used is as follows:

$$Qs = C_d A_o \sqrt{g(D_u - D_d)} \quad (5)$$

5.1 Scenario D, Worked Example

Figure 9 shows the same network as Figure 7. Here the flow rate upstream has been increased so that the orifice is surcharged upstream.

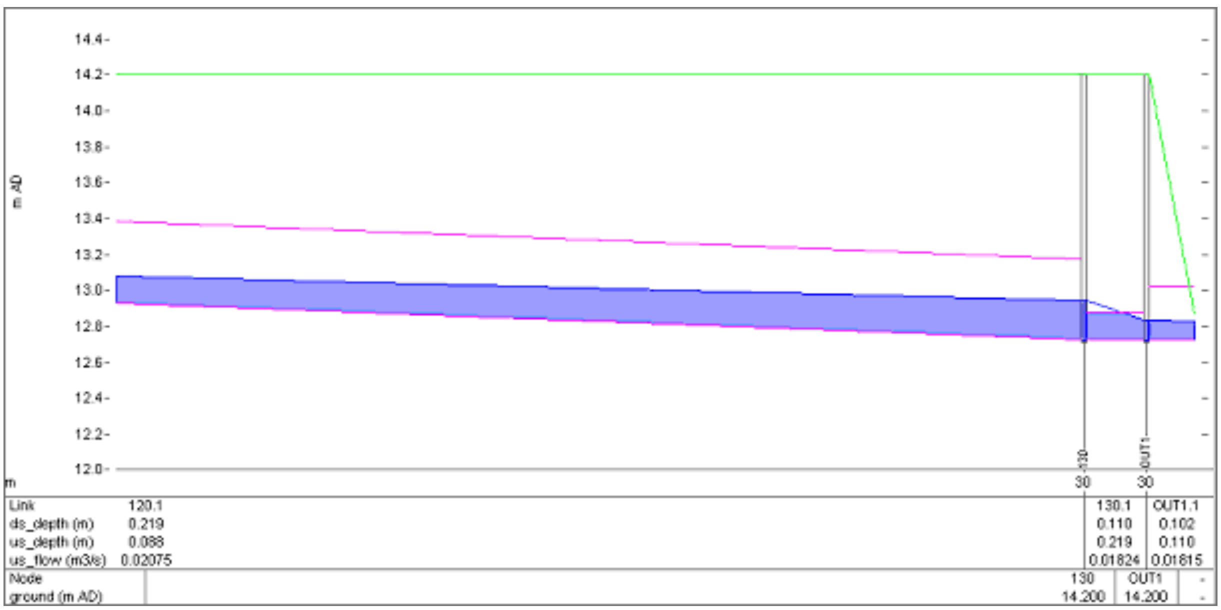

Figure 9 InfoWorks ICM Model of Scenario D

From Figure 9:

D_u = 0.219 m

D_d = 0.110 m

Therefore from Equation 5:

Qs = 1 x 0.017671 x (9.81 x (0.219 - 0.110)) 0.5

Qs = 0.0176715 x 1.03389

Qs = 0.01827

Slight differences may occur due to the linearisation of the values when D_u-D_d is less than 0.01.

6 Weir/Orifice Flow Check

An additional check for weir/orifice flow is also performed by ICM to distinguish between Scenarios C and D. Weir flow is still possible for an orifice if the following applies:

$$(D_U > D_o)\ AND\ (D_o \geq \max\left(D_U \times \frac{2}{3}, D_d\right)) \qquad (6)$$

In such cases, both weir flow and orifice flow are calculated by the ICM simulation engine, and whichever returns the lower value will be used in the simulation.

7 Summary

Table 1 presents a summary of the four combinations of upstream and downstream conditions including the equation which will be used in each case.

		Upstream Condition	
		Free Discharge	Surcharged
Downstream Condition	Independent	$Qs = C_d B D_u \sqrt{g D_u}$ Scenario A	$Qs = C_d A_o \sqrt{g D_d}$ Scenario B
	Boundary	$Qs = C_d B D_u \sqrt{g(D_u - D_d)}$ Scenario C	$Qs = C_d A_o \sqrt{g(D_u - D_d)}$ Scenario D

Table 1 Summary of Conditions and Equations

Parent topic: Technical Notes