

MEMORANDUM

TO: Basin 71 and 72 IDF&G Fish Bypass Permit Files

FROM: Corey Skinner

DATE: August 24, 2011

SUBJECT: Methodology for Flow Measurements

Recently Benny Walker and I conducted several licensing exams for IDF&G bypass permits in Basins 71 and 72. In general, these permits are for an amount of non consumptive flow that is diverted from a stream through existing diversions. The diverted water flows down a ditch, into a fish screen structure, and then flows through a bypass pipe back to the original stream source at a point downstream of the original diversion. The purpose of this flow is to flush fish back to the stream that may otherwise be trapped in the ditch. The fish screen structures include a slide gate plate with an opening that allows water to flow through the plate into the bypass pipe back to the stream. Due to the variability in diverted flows, difficulty in measuring flows for certain structures due to the way they were constructed, distance between structures, and other variables a methodology is needed to estimate maximum flows that are diverted and utilized by the IDF&G bypass permits.

After examining several of the structures and bypass systems and examining several different sources of water measurement literature, it was determined that the most appropriate method would be to utilize an orifice flow equation that is typically used to estimate flow through orifice openings in tanks. Attachment "A" discusses the equation, and the associated orifice coefficient, in particular C_d (coefficient of discharge). The equation is as follows...

$$Q = C_d A_o (2gh)^{1/2}$$

Where C_d = coefficient of discharge for orifice

A_o = Area of orifice opening in feet²

g = 32.2 ft per second²

h = measured head above center of orifice opening (in feet)

All variables can be measured in the field except for C_d (coefficient of discharge). Based on water measurement literature, this particular coefficient can vary from numbers around 0.6 to approximately 1.0 as shown in Table 3.10 in "Attachment A". In addition, the exact geometry of the opening (orifice) in the various slide gate plates that Benny and I observed is not shown in Table 3.10 in "Attachment A". Examination of various sources of water measurement literature and websites on the internet did not reveal much more in the way of appropriate C_d (coefficient of discharge) values. One reputable published source indicated that " *C_d values can vary, but are generally around 0.70*".

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Due to the uncertainty in the possible C_d values, but considering the similarity in the opening (orifice) in the various slide gate plates and the overall bypass systems that Benny and I observed, it was determined that if an accurate measurement of the actual flow through a bypass system could be obtained, and using the orifice area and head reading at the time of measurement, the orifice discharge equation could be used to obtain an actual C_d (coefficient of discharge) value for the openings (orifices) in the various slide gate plates Benny and I were observing. This calculated C_d (coefficient of discharge) value could then be used in the same equation, for other similar bypass systems, and would result in more accurate calculated results. In addition, the equation could be utilized to estimate maximum flows through the bypass systems by measuring high water marks on the fish screen structures even if very little, or even no, flow was flowing through the bypass at the time of the exam.

Yesterday, Benny and I found a fish screen bypass system that we felt could be accurately measured and was very typical of the various systems. This system was located on Fourth of July Creek, and happened to be one of the permits, 71-10909, that needed to be examined for licensing. A Sparling Meter, mounted in a pipe section (State of Idaho ID# 4335) that could be mounted on the bypass discharge pipe was utilized to obtain flow measurements at a given head reading. Two separate, timed, measurements were conducted with both measurements resulting in measured flows of 0.68 cfs.. The following photo shows one of these measurements being conducted...



Using this measured flow, the orifice discharge equation, an orifice measurement, and head measurements, finds that the C_d (coefficient of discharge) is calculated to be 0.67 as shown below...

$$Q = C_d A_o (2gh)^{1/2}$$

Where C_d = coefficient of discharge for orifice

A_o = 0.087 feet² (based on measured 4 inch diameter orifice opening)

g = 32.2 ft per second²

h = 2.125 feet (measured at 25.5 inches)

$$0.68 \text{ cfs} = C_d (0.087 \text{ ft}^2) [2(32.2 \text{ ft per second}^2)(2.125 \text{ ft})]^{1/2}$$

$$C_d = 0.67$$

It is appropriate to use a C_d (coefficient of discharge) value of 0.67 and the orifice discharge equation to estimate the maximum flow for the permits for IDF&G bypass permits in Basins 71 and 72.

Gradual, $\phi < 22^\circ$ Sudden, $\phi > 22^\circ$

Enlargement	$2.6(\sin \phi)(1 - \beta^2)^2$	$(1 - \beta^2)^2$	3.81
Contraction	$0.8(\sin \phi)(1 - \beta^2)$	$\frac{1}{2}(1 - \beta^2)\sqrt{\sin \phi}$	3.82

4 HEAD ADDITIONS/EXTRACTIONS

A pump adds head (energy) to the fluid stream. A turbine extracts head from the fluid stream. The amount of head added or extracted can be found by evaluating Bernoulli's equation (equation 3.55) on both sides of the device.

$$h_A = H_2 - H_1 \quad (\text{pumps}) \quad 3.83$$

$$h_E = H_1 - H_2 \quad (\text{turbines}) \quad 3.84$$

The head increase from a pump is given by equation 3.85.

$$h_A = \frac{(550)(\text{pump input horsepower})\eta_{\text{pump}}}{\dot{m}} \left(\frac{g_c}{g} \right) \quad 3.85$$

Bernoulli's equation also can be used to calculate the power available to a turbine in a fluid stream by multiplying the total energy by the mass flow rate. This is called the *water horsepower*.

$$P = \dot{m}H \left(\frac{g}{g_c} \right) = \dot{m} \left(\frac{p}{\gamma} + \frac{v^2}{2g} + z \right) \left(\frac{g}{g_c} \right) \quad 3.86$$

$$\dot{m} = \rho A v \quad 3.87$$

$$\text{whp} = \frac{P}{550} \quad 3.88$$

Pumps and turbines are covered in greater detail in chapter 4.

5 DISCHARGE FROM TANKS

Flow from a tank discharging liquid to the atmosphere through an opening in the tank wall (figure 3.14) is affected by both the area and the shape of the opening. At the orifice, the total head of the fluid is converted into kinetic energy according to equation 3.89.⁶

$$v_o = C_v \sqrt{2gh} \quad 3.89$$

⁶ Although the term g_c appears in the equation for velocity head (equation 3.53), here it is the local gravity, g , which appears in equation 3.89. An analysis of equation 3.197 will show you why this is so.

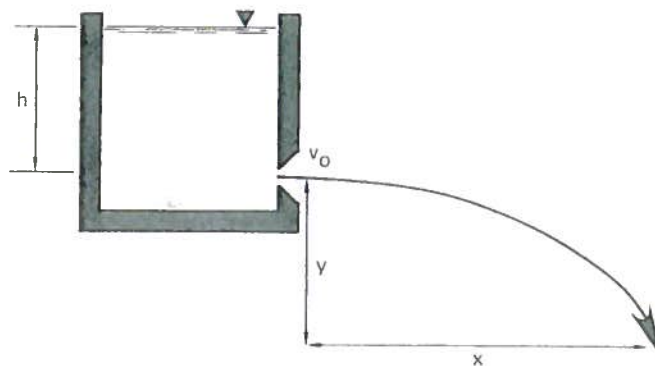


Figure 3.14 Discharge From a Tank

C_v is the *coefficient of velocity* which can be calculated from the *coefficients of discharge and contraction*. Typical values of C_v , C_d , and C_c are given in table 3.10.

$$C_v = \frac{C_d}{C_c} \quad 3.90$$

The discharge from the orifice is

$$\begin{aligned} \dot{V} &= (C_c A_o) v_o = C_c A_o C_v \sqrt{2gh} \\ &= C_d A_o \sqrt{2gh} \end{aligned} \quad 3.91$$

The head loss due to turbulence at the orifice is

$$h_f = \left(\frac{1}{C_v^2} - 1 \right) \frac{v_o^2}{2g} \quad 3.92$$

The discharge stream coordinates (see figure 3.14) are

$$x = v_o t = v_o \sqrt{\frac{2y}{g}} = 2C_v \sqrt{hy} \quad 3.93$$

$$y = \frac{gt^2}{2} = \frac{g}{2} \left(\frac{x}{v_o} \right)^2 \quad 3.94$$

The fluid velocity at a point downstream of the orifice is

$$v_x = v_o \quad 3.95$$

$$v_y = gt \quad 3.96$$

If the liquid in a tank is not being replenished constantly, the static head forcing discharge through the orifice will decrease. For a tank with a constant cross-sectional area, the time required to lower the fluid level from level h_1 to h_2 is calculated from equation 3.97.

$$t = \frac{2A_t(\sqrt{h_1} - \sqrt{h_2})}{C_d A_o \sqrt{2g}} \quad 3.97$$

If the tank has a varying cross section, the following basic relationship holds.

$$Q dt = -A_t dh \quad 3.98$$

Table 3.10
Orifice Coefficients for Water
(fully turbulent)

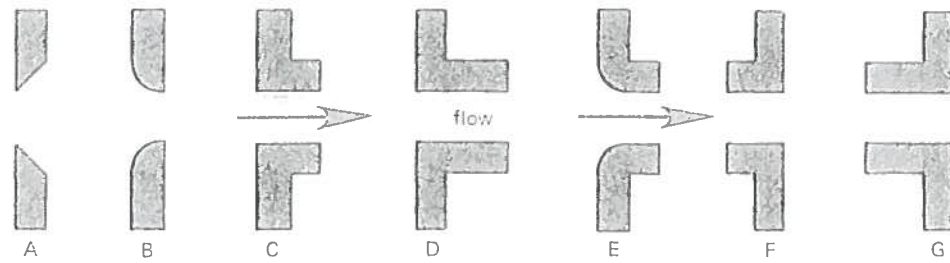


illustration	description	C_d	C_c	C_t
A	sharp-edged	0.62	0.63	0.98
B	round-edged	0.98	1.00	0.98
C	short tube (fluid separates from walls)	0.61	1.00	0.61
D	short tube (no separation)	0.82	1.00	0.82
E	short tube with rounded entrance	0.97	0.99	0.98
F	reentrant tube, length less than one-half of pipe diameter	0.54	0.55	0.99
G	reentrant tube, length 2 to 3 pipe diameters	0.72	1.00	0.72
not shown	smooth, well-tapered nozzle	0.98	0.99	0.99

An expression for the tank area, A_t , as a function of h , must be determined. Then, the time to empty the tank from height h_1 to lower height h_2 is

$$t = \int_{h_1}^{h_2} \frac{A_t dh}{C_d A_o \sqrt{2gh}} \quad 3.99$$

For a tank being fed at a rate, $\dot{V}_{in}$, which is less than the discharge through the orifice, the time to empty expression is

$$t = \int_{h_1}^{h_2} \frac{A_t dh}{(C_d A_o \sqrt{2gh}) - \dot{V}_{in}} \quad 3.100$$

When a tank is being fed at a rate greater than the discharge, equation 3.100 will become positive, indicating a rising head. t then will be the time it takes to raise the fluid level from h_1 to h_2 .

The preceding discussion has assumed that the tank has been open or vented to the atmosphere. If the fluid is discharging from a pressurized tank, the total head will be increased by the gage pressure converted to head of fluid by means of equation 3.52.

Example 3.22

A 15' diameter tank discharges 150°F water through a sharp edged 1" diameter orifice. If the original water depth is 12' and the tank is continually pressurized to 50 psig, find the time to empty the tank.

At 150°F, $\rho = 61.20 \text{ lbm/ft}^3$

For the orifice,

$$A_o = 0.00545 \text{ ft}^2, C_d = 0.62$$

$$h_1 = 12 + \frac{(50)(144)}{61.2} = 129.65 \text{ ft}$$

$$h_2 = \frac{(50)(144)}{61.20} = 117.65 \text{ ft}$$

From equation 3.97,

$$t = \frac{2[\pi(7.5)^2](\sqrt{129.65} - \sqrt{117.65})}{(0.62)(0.00545)\sqrt{(2)(32.2)}} = 7035 \text{ seconds}$$

6 CULVERTS AND SIPHONS

A culvert is a water path used to drain runoff from an obstructing geographical feature. Most culvert designs are empirical. However, if the entrance and exit of the culvert both are submerged, the discharge will be independent of the barrel slope. (Chapter 5 treats this subject in greater detail.) In that case, equation 3.101 can be used to evaluate the discharge. h is the difference in surface levels of the headwater and tailwater.

$$\dot{V} = C_d A \sqrt{2gh} \quad 3.101$$