# CHAPTER 16
# DESIGN OF HYDRAULIC CONTROLS AND STRUCTURES

**16.1**. A spillway on a flood control dam is designed to pass a flood with an exceedance probability of 0.015. About how often will a flood of this magnitude or larger occur on this watershed? What is the risk that the spillway will fail at least once in 100 years?

**Solution**: $p = 0.015$, so $T = 1/p = 66.66$ years.
Risk: $R = 1-(1-p)^N = 1 - (1-0.015)^{100} = 0.779$ or 77.9%.

**16.2.** It is desired to design a hydraulic structure to a standard such that its risk of failure will be no greater than 5% in a time period of 50 years. What will be the exceedance probability and recurrence interval of the design discharge?

**Solution**: For a risk of 5%, $0.05 = 1 - (1-p)^{50}$, or
$0.95 = (1-p)^{50}$, or $0.9989 = 1-p$, or $p = 0.00102$.
Recurrence Interval, $T = 1/p = 980$ years

**16.3.** A sharp crested suppressed rectangular weir is to be used to regulate the depth of water in a navigation project. The depth in the channel must be maintained at least 10 m in order for vessels to navigate the channel. The channel slope is essentially horizontal, its width is 6 m, and its invert is at elevation 10 m above sea level. The design low flow discharge is 1.5 cms for a recurrence interval of 20 years.

a. What is the exceedance probability of the design?

b. What is the probability that vessels will not be able to navigate the channel at least once in the next 10 years?

c. What must be the elevation of the weir crest in order to meet the design specifications? Assume the discharge coefficient is 0.61.

**Solution**: a. Exceedance probability, $p = 1/T = 1/20 = 0.05$

b. $R = 1- (1-.05)^{10} = .401$ or about 40%.

c. $Q = C_d \frac{2}{3}\sqrt{2g}\ LH^{1.5} = 0.61 \times \frac{2}{3}\sqrt{2g}\ LH^{1.5} = 1.8\ LH^{1.5}$

For the low flow condition, $1.5 = 1.8 \times 6 \times H^{1.5}$, or $H = 0.27$ m.
Then, with the channel invert at 10 m NGVD and a required depth of 10 m, the weir elevation would need to be $10 + 10 - 0.27 = 19.73$ m NGVD.

**16.4.** A 1 acre lot is to be developed for residential dwellings. The original undeveloped condition is such that the longest watercourse length is 300 ft, the average slope is 3%, and the Manning *n* value of the ground cover is 0.1. After development, the *n* value reduces to 0.05. Assuming that the 24-hr two year rainfall depth for the area is 3.5 inches, use Figure 16.1 to estimate the peak storm water runoff for the 10-year event for this area under both present and future conditions. Use runoff coefficients of 0.25 and 0.6 for existing and improved conditions, respectively.

**Solution**:

Prior to development: $t_c = \dfrac{0.007x(nL)^{0.8}}{P_2^{0.5} x\ S^{0.4}} = \dfrac{0.007x(0.10x300)^{0.8}}{(3.5)^{0.5}\ x\ (0.03^{0.4}} = 0.23$ hr = 14 minutes

Post development: $t_c = \dfrac{0.007x(0.05x300)^{0.8}}{(3.5)^{0.5}\ x\ (0.03)^{0.4}} = 0.13$ hr = 8 minutes

From Figure 16.1: $I_{10}$ (predevelopment) = 5.5 in/hr, $I_{10}$ (post development) = 6.5 in/hr
Q (predevelopment) = CIA = 0.25 x 5.5 x 1 = 1.375 cfs
Q (post development) = 0.6 x 6.5 x 1 = 3.9 cfs

**16.5.** Design a sag inlet and a pipe to carry the runoff developed in problem 16.4. Assume the pipe will be concrete and will run on the same slope as the ground slope.

**Solution:**
Inlet: Using the Francis Weir Equation, $Q = CLH^{1.5}$ to determine the weir length with a typical C value of 3.1 and allowing 6 inches of ponding depth:

$3.9 = 3.1 \text{ x } L \text{ x } (0.5)^{1.5}$, then L = 3.56 ft, or about a 1 ft square inlet (allowing for end contractions).

Pipe: $D = 1.55\ \left(\dfrac{Q \text{ x } n}{1.49 \text{ x } S_o^{0.5}}\right)^{3/8} = \left(\dfrac{3.9 \text{ x } 0.012}{1.49 \text{ x } (0.03)^{0.5}}\right)^{3/8} = 0.81$ ft or approximately 1 ft.

Now, to determine the normal depth in the pipe:

$$AR^{2/3} = \frac{n \text{ x } Q}{1.49 \text{ x } S_o^{1/2}} = \frac{0.012 \text{ x } 3.9}{1.49 \text{ x } (0.03)^{1/2}} = 0.181$$

For the pipe, from Table 10.1: $A = (\ \ - \sin\ \ )\ \dfrac{d^2}{8}$, and $P = \ \ \dfrac{d}{2}$

Then, the following table is developed by assuming values of :

| (rad) | A (ft$^2$) | P (ft) | R (ft) | AR$^{2/3}$ |
|---|---|---|---|---|
| 3 | 0.357 | 1.5 | 0.238 | 0.137 |
| 3.5 | 0.481 | 1.75 | 0.275 | 0.203 |
| 3.3 | 0.432 | 1.65 | 0.262 | 0.177 |

Considering that 0.177 is close enough to the computed value of 0.181, we next proceed to find y from the relationship:

$= 2 \cos^{-1} (1 - 2\ \dfrac{y}{d})$, with d = 1 ft and  = 3.3 rad, we find the normal depth $y_o$ to be 0.54 ft, so the pipe is flowing at about 54% capacity which is less than the required ratio of 85%.

Next, with this depth, we find the area, $A = (3.22\text{-}(-0.158)\ \dfrac{1^2}{8} = 0.422$ ft$^2$

The, the velocity V = Q/A = 9.24 ft/s > 2, so Ok.