

THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

RECOMMENDATIONS FOR DESIGN OF OUTFLOW CONTROL DEVICES OF STORMWATER DETENTION FACILITIES

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Introduction: Several types of fluid flow devices are commonly used as outflow control devices of stormwater detention facilities. These include pipes and culverts; short restrictor pipes that are inserted into the ends of outlet pipes of larger diameter (these are sometimes also called choke or throttle pipes); orifices (generally circular or rectangular opening in walls); weirs and spillways; pumps; and specialized devices such as flow control roof drains.

Which device to use for a particular detention storage facility depends on the type of storage facility and the elevation and location of its outlet with respect to the elevation and location of the receiving drainageway. However, there are certain useful guidelines applicable to all outflow control devices, and these are presented below under "General Recommendations".

To further aid engineers and designers, acceptable methods for calculating size and discharge of two commonly used outflow control devices – orifices and pipes – are also presented herein under the section entitled "Sizing".

General Recommendations:

1. Outflow control devices should be constructed of durable materials and should be installed in a structurally sound manner that discourages misadjustment or removal. For example, the MWRD recommends that a restrictor pipe be at least two feet long and be cemented securely in place over its entire length. Orifice restrictor plates made of thin sheet metal can be removed or enlarged too easily by unauthorized persons. Similarly, drilled holes serving as orifices in manhole covers can be enlarged, or additional holes may be drilled, or the entire cover can be removed or it may be replaced by a perforated type cover, thus precluding the function of the detention facilities.
2. Outflow control devices should be as self-operating and self-maintaining as possible. Whenever possible, facilities should empty by gravity. Pumps and other devices which may become inoperable during power outages should be avoided (usually power outages occur when the flood control facilities are needed most – during the most severe storms). Also avoid manually operated valves and sluice gates, which may be left in wrong

positions at inopportune times.

3. In order to help prevent clogging, it is generally advisable not to specify outlets that are smaller than 4" diameter. Where an initial project design calls for multiple outlets, any one or more of which is less than 4" diameter, try redesigning and combining facilities so that no outlet is less than 4" diameter. (Note: The MWRD permit application package for any project that proposes a restrictor less than 4" in diameter must include letters from the Permittee and Co-Permittee acknowledging that the restrictor may cause operational problems and will require additional maintenance.)
4. For larger detention facilities, if it is anticipated that debris will enter a system and cause clogging problems, provide special debris racks, grids, or fins. Make sure, though, that these devices themselves don't promote problems, as might occur by installing window screening or other fine-mesh material on the entrance of an outlet pipe.
5. Provide safe and easy access and working space for maintenance personnel and equipment so that the facilities can be readily inspected and maintained. Install restrictors in a manner which facilitates cleaning and helps prevent blockages; for example, it is generally better to install restrictors in manholes on the upstream end of a sewer run.
6. Safety bars or grids (maximum 6" spacing) should be installed wherever there is a possibility of children or large animals entering drainage conduits. Fences, railings, life preservers, warning signs, and other safety equipment should be employed as deemed necessary.
7. Where high flow velocities capable of causing erosion or other problems are expected, provide rip-rap, concrete aprons, or other stabilization as may be necessary. Severe cases may call for energy dissipators such as baffles or stilling basins.
8. Under certain conditions, excessive vortexing (swirling) may occur which may erode the sides or bottom of a detention facility or may damage the outflow control structure. Although this is not a common occurrence, it should be taken into consideration with larger detention facilities especially when vertical outflow devices are involved (e.g., standpipes). Appropriately placed vanes or baffles in the area immediately upstream of the outflow control device will help prevent or eliminate this problem.
9. As a safeguard in the event that outflow devices become clogged or actual inflows exceed design inflows, emergency outflow devices such as overflow weirs, spillways, or scuppers (in the case of roof detention) should be provided. The inverts of these devices should not, of course, be

lower than the maximum required highwater elevation (the elevation at which the required or desired storage volume is achieved). As with the design of all other outlets, make sure the discharge from the overflow device is directed to an area or facility capable of safely handling the flow.

Sizing:

Permissible Discharge Rate Typically the designer of a flood control facility determines or is given a maximum permissible discharge rate which, under a set of given conditions, is not to be exceeded. This permissible discharge rate is usually based on the capacity of the receiving drainage system.

Head Proper sizing of the outflow control device so that the permissible discharge rate is not exceeded involves taking into account the differential head (difference in water levels) across the device. The water level used in calculating the head on the upstream side of the device should not be lower than the maximum highwater elevation of the detention storage facility (as mentioned previously, the maximum highwater elevation is the elevation at which the required or desired amount of flood storage volume is reached in the storage basin).

The water level on the downstream side of the device may exist in the form of a standing pool or backed-up water which submerges the outlet, or discharge may be made to the atmosphere (free discharge or unsubmerged outlet) in which case it is usually acceptable to take the water level at the crown (top) of the pipe as the outlet. In the case of free discharge from orifices, the head would be the centerline of the orifice if the opening was in a vertical plane, or to the entrance of the orifice if it is in a horizontal plane.

Fluid Flow Equations After determining the upstream and downstream water levels, a suitable fluid flow equation must be applied. The type and design of the outflow control device and the conditions it will be subjected to will dictate which equation is appropriate.

In the case of weirs and spillways, there are numerous variables involved, and a great number of discharge formulas have been developed. The reader is advised to consult the literature for equations suitable to his particular case. One recommended reference is Handbook of Hydraulics by King and Brater.

Similarly, equations and nomographs have been published for discharge rates from culverts based on different pipe shapes and materials, entrance shapes, exit conditions, etc. The reader may consult manufacturer's literature or a publication by the U.S. Department of Commerce, Bureau of Public Roads entitled Hydraulic Charts for the Selection of Highway Culverts (Hydraulic Engineering Circular No. 5), or similar publications available from state

highway agencies.

Discharge rates of orifices and simple pipes may be calculated by the use of rather simple formulas applicable to many cases. The sizing of these two types of outflow control devices is discussed herein.

Orifice Discharge An orifice is an opening having a regular form and closed perimeter. Note that if the perimeter is not closed at the top, or if an orifice opening is not flowing full, the device is, or behaves as, a weir, and the orifice formula presented below does not apply.

Common examples of outflow control devices which behave as orifices include circular or rectangular openings in retaining or manhole walls; holes in metal “orifice plates”; and holes in metal collars around roof drains. The general rule is that if the length of the opening is not more than twice or thrice its diameter, the orifice formula is suitable. Otherwise, friction in the barrel of the device comes into play, and the orifice formula will no longer apply. For the sake of simplicity, the MWRD has accepted use of the orifice formula in calculating discharge through restrictor pipes (if 2 feet in length or shorter) even if the length exceeds the diameter by more than a factor of two or three.

The orifice formula can be written as

$$(Eqn 1) \quad Q = C_d A \sqrt{2gh}$$

where Q is a discharge rate in ft³/sec
A is cross-sectional area of orifice, ft²
g is acceleration due to gravity, 32.2 ft/sec²
h is available head of water, ft
C_d is a discharge coefficient, dimensionless

The value of the discharge coefficient, C_d, primarily depends on the shape of the orifice rim (entrance). Rounded or beveled entrances allow greater flow and thus have larger C_d values than square edged entrances. Figure 1 shows various types of entrances and corresponding C_d values.

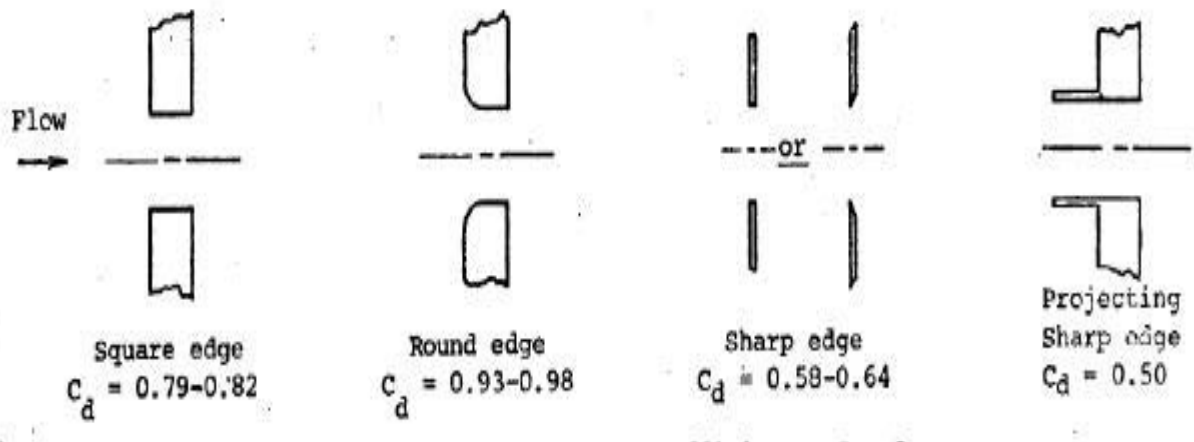


Figure 1. Discharge coefficients, C_d , for various entrance types

(Note: For required discharge coefficient values, C_d , for various entrance types to use for MWRDGC Sewer Permit Application Detention Designs, [Click Here](#).)

In cases where the downstream side of the orifice is submerged, the value of h in the formula will be the differential head, or difference between the water levels on the upstream and downstream sides.

Where discharge is made to the atmosphere (unsubmerged outlet), h is the head of water to the centerline of the orifice.

Example Problem 1.

Calculate the discharge from the circular orifices show in Figures 2a and 2b.

The outlet of the orifice shown in Figure 2a is not submerged, so h is to the centerline of the orifice; $698.00 - (695.30 + 0.5) = 2.20$ ft. $A = \pi D^2/4 = 0.785$ ft. $C_d = 0.79$ (from Figure 1; square edge entrance).

$$\text{Then } Q = CA\sqrt{2gh} = (0.79)(0.785) \sqrt{2(32.2)(2.2)} = 7.38 \text{ ft}^3/\text{s}$$

In Figure 2b, the outlet is submerged, hence h is the difference in water levels. $h = 698.00 - 697.00 = 1.00$.

$$\text{Then } Q = (0.79)(0.785) \sqrt{2(32.2)(1.00)} = 4.98 \text{ ft}^3/\text{s}.$$

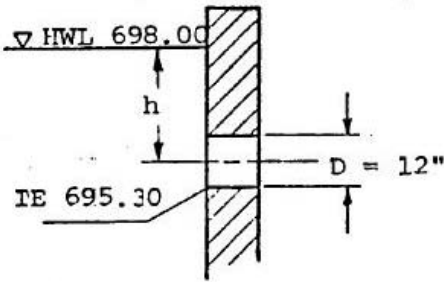


Figure 2a

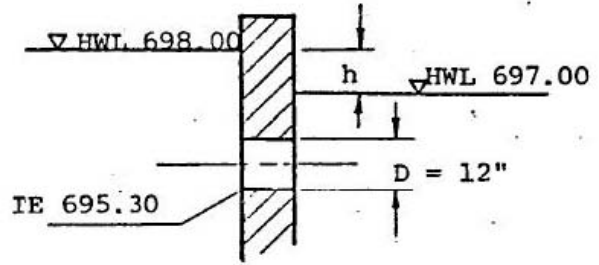


Figure 2b

Pipe Discharge Discharge rates of simple sewer pipes or short restrictor pipes can be calculated by use of an equation based on the Bernoulli equation:

$$(Eqn 2) \quad H = K_e \frac{v^2}{2g} + K_o \frac{v^2}{2g} + \frac{2.87 n^2 L v^2}{D^{4/3}}$$

Where

H	is available head of water, ft
v	is average velocity, ft/sec
g	is acceleration due to gravity, ft/sec ²
n	is roughness coefficient, dimensionless
L	is length of pipe, ft
D	is diameter of pipe, ft
K _e	is the entrance loss coefficient, dimensionless
K _o	is outlet loss coefficient, dimensionless

The first and second terms on the right-hand side of the equation express the head loss due to the entrance and exit conditions, respectively. Generally K_o equals 1.0, but K_e varies considerably and depends on the shape of the entrance. Table 1 gives K_e values for various entrance shapes.

The third term on the right-hand side of the equation represents the head loss due to friction of the pipe barrel. In this case the expression is based on Manning's formula for fluid flow, but other friction-flow formulas could be used as well (e.g. Darcy-Weisbach or Hazen-Williams formulas). Table 2 lists values of n, Manning's roughness coefficient, for various pipe materials.

To calculate the discharge rate from Eqn 2, the continuity equation (Q = vA) is used. After substitution and rearrangement, the following equation results

$$(Eqn 3) \quad Q = A \left[\frac{H}{\frac{K_e + K_o}{2g} + \frac{2.87n^2L}{D^{4/3}}} \right]^{1/2}$$

Where Q is discharge rate, ft³/sec
 A is cross-sectional area of pipe, ft²
 L is length of pipe, ft

If the pipe is relatively long and the head is relatively small, the contribution of the entrance and exit head loss terms may be negligible. Then Manning's formula may be used directly. Substituting the continuity equation into Manning's formula for circular pipes yields

$$(Eqn 4) \quad Q = \frac{0.464D^{8/3}}{n} (H/L)^{1/2}$$

The value of H is the difference in liquid level elevation at the entrance and the exit. If there is no standing water on the outlet side (i.e., unsubmerged outlet), the liquid level at the outlet can be assumed to be, in most cases, at or just below the crown of the pipe at the outlet.

Example Problem 2.

Calculate the discharge rates from the pipes shown in Figures 3a and 3b.

In figure 3a the pipe in its entirety is used to control the flow. In figure 3b a short restrictor pipe is used to control the flow. Since the head is large and the pipe is relatively short, use Equation 3.

For the problem, shown in Figure 3a, H equals the pond highwater elevation less the elevation of the water at the outlet, which can be taken as the elevation of the crown of the pipe because the outlet is unsubmerged. Hence, H = 664.30 - (654.05 + 0.50) = 9.75 ft. From Table 1, K_e = 0.43. From Table 2, n = 0.013 K_o is usually taken to equal 1.0. L = 20ft. D = 0.5 ft. A = D²/4 = (0.5)²/4 = 0.196 ft².

Substituting into Equation 3.

$$Q = (0.196) \left[\frac{(9.75)}{\frac{(0.43) + (1.00)}{2(32.2)} + \frac{2.87(0.013)^2(20)}{(0.5)^{4/3}}} \right]^{1/2}$$

$$Q = 2.83 \text{ ft}^3/\text{sec}$$

Note that if Equation 4 were used, which does not take into account the entrance and exit head losses, the discharge rate would be calculated to be $Q = 3.92 \text{ ft}^3/\text{sec}$. Therefore, use of Equation 4 was warranted since the entrance and exit losses were appreciable.

In Figure 3b H will be the pond elevation minus the elevation of the crown of the 2-foot long restrictor at its outlet. $H = 664.30 - (654.25' - 2' (0.01) + 0.50') = 9.57 \text{ ft}$. $L = 2 \text{ ft}$. A, n and K_o are the same as in the previous problem. K_e for rounded lip entrance is 0.10 (from Table 1).

Substituting into Equation 3 we get

$$Q = (0.196) \left[\frac{(9.57)}{\frac{(0.10) + (1.00)}{2(32.2)} + \frac{2.87(0.013)^2(2)}{(0.5)^{4/3}}} \right]^{1/2}$$

$$Q = 4.34 \text{ ft}^3/\text{sec}$$

If Equation 4 were used, $Q = 12.29 \text{ ft}^3/\text{sec}$, which is a very high value since the entrance and exit head losses were not considered.

If the orifice formula were used $Q = 0.93 (0.196) \sqrt{2(32.2)(664.3 - (654.25 + 0.25))}$
 $= 4.57 \text{ cfs}$.

Table 1

*Values of Entrance Loss Coefficients K_e

	<u>K_e</u>
**Concrete pipe in headwall:	
Socket or bevel entrance	0.19
Rounded lip	0.10
Square edge	0.43
Concrete pipe projecting, square edge	0.46
Corrugated metal pipe in headwall, square edge	0.43

*Values shown are from Handbook of Concrete Culvert Pipe Hydraulics, Portland Cement Association, 1964

**No data available for cast iron, clay, or plastic pipes. Use of the concrete K_e values for other materials having similar entrance types will be acceptable until better information is obtained.

Table 2

Values of Manning's Roughness Coefficient (n) for Various Pipe Materials

<u>Material</u>	<u>n value</u>
Asbestos-Cement	0.012-0.013
Cast iron	0.012-0.013
Concrete	0.012-0.013
Corrugated metal pipe:	
plain	0.024
paved invert	0.020
Plastic pipe (ABS or PVC)	0.012

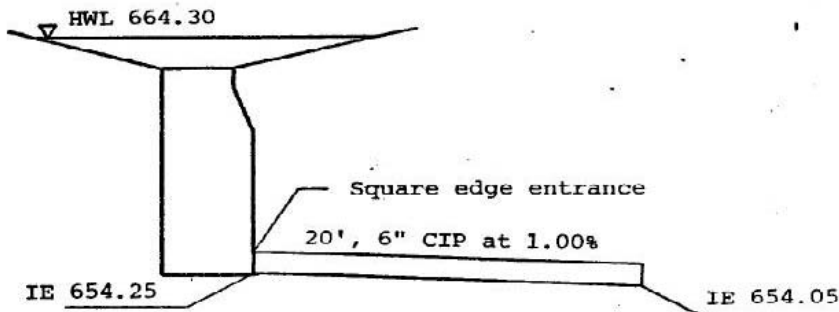


Figure 3a.

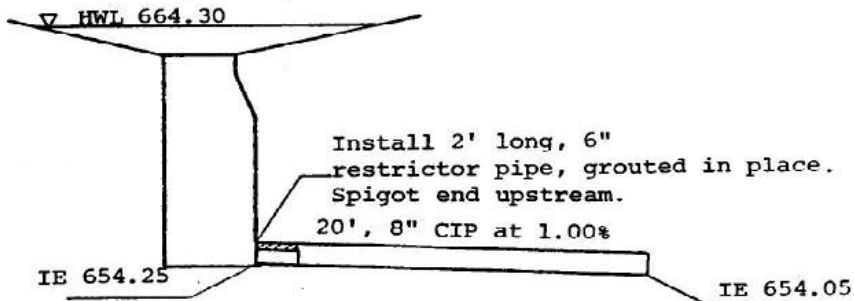


Figure 3b.

Fine-tuning Sometimes a value for actual discharge rate is arrived at which falls unacceptably in-between the discharge rate of pipes of nominal sizes. For example, given a hypothetical case, an 8 inch outlet pipe has a discharge rate that is slightly higher than the permissible discharge rate. But using a smaller pipe of the next nominal size - 6" - results in a release rate that is too low (extra flood storage volume would have to be provided, and the potential for clogging is larger). A 7" pipe would be almost perfect, but this size is not available.

One obvious design approach may be to lower the slope of the 8 inch pipe, but sometimes this is not possible. Another, less frequently used tactic is either to select a pipe entrance shape that causes a greater head loss, or use a pipe material which has a higher barrel roughness (e.g., use corrugated metal pipe instead of clay or cast iron).