CITY UTILITIES
DESIGN STANDARDS MANUAL

Book 2
Stormwater (SW)
SW9 Open Channels

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SW9.01 Purpose

This Chapter provides information for the design of open channels for the conveyance of stormwater in the City of Fort Wayne. By definition an open channel is a conduit for the conveyance of liquids. Flow in an open channel is open to the atmosphere and driven by gravity. Open channels for the conveyance of stormwater can be natural or constructed.

1. Natural Channels

   Natural channels include rivers, streams, and natural intermittent drainage courses. Investigation and analysis of the capacity of existing natural channels using the United States Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) is complex and time consuming. Alteration of a natural channel is also regulated and can require permits from the United States Army Corps of Engineers (USACOE), Indiana Department of Natural Resources (IDNR), and Indiana Department of Environmental Management (IDEM). Natural channels shall be regarded as receiving waters. Storm drainage design shall include detention for control of developed stormwater runoff peak flows thus avoiding the necessity of altering existing natural channels.

2. Constructed Channels

   This chapter will consider the design of constructed open channels. Constructed channels include drainage ditches, roadside ditches, swales, bioswales and water quality treatment channels. New constructed channels can be excavated or existing constructed channels can be reconstructed as part of a new or altered storm drainage system. Alteration of existing constructed channels might require permits from Allen County Drainage Board, Allen County Department of Planning Services, USACOE, IDNR or IDEM.

SW9.02 Channel Geometrics

1. V-Shaped Channels

   V-shaped open channels are used for roadside ditches or swales. V-shaped channels are not efficient for conveyance of high flows and are generally designed for collection of intermittent surface sheet flow.

2. Swales

   Swales are shallow channels with relatively flat side slopes frequently used in maintained yard areas or fields. Flow in swales is generally intermittent, collecting runoff during and immediately following rainfall events. Swales can also be used as overland flow routes for protection of property if storm sewer or detention facilities fail or overflow. Swales are not necessarily V-shaped channels. Swales can have uniform or variable width bottoms.

3. Trapezoidal Channels

A trapezoid is defined as a quadrilateral figure with two parallel sides. In the case of an open channel the channel bottom and top of water are regarded as parallel. Channels with rounded bottoms shall be treated as trapezoidal. The sides of an excavated trapezoidal channel are sloped to provide stability; channel slopes generally do not exceed 1.5 horizontal to 1 vertical (1.5:1). Three to one (3:1) slopes are recommended for grass lined channels.

Channels can have uniform or variable bottom widths and side slopes. In developed or agricultural areas where land is premium, storm drainage channels are generally designed to be uniform and functional with minimum use of land.

Two-stage open channels are designed with a low flow channel and at a higher elevation a wider second stage channel. Two-stage channels provide in channel storage and reduce flow velocity at higher flow rates.

4. Composite Channel

Composite channels are designed with a low flow channel in combination with additional natural channel features. Composite channels can be utilized as stormwater quality best management practices, detention facilities, wildlife habitat, attractive landscape feature or a combination of the above.

Composite channels may incorporate a low flow, meandering, variable width channel through constructed wetlands or open pools. The low flow channel may meander through a wider valley which can flood during higher flows. Composite channels can be used with a water control structure or multiple control structures which reduce flow velocity and provide storage during periods of high flow.

Low flow channel and valley side slopes and bottom widths may vary to provide the appearance of a natural topography. Riparian vegetation may be planted for water quality treatment and to provide a naturally appearing landscape. Upland slopes can be planted with prairie grass mixes and native woody species.

SW9.03 Channel Side Slopes

Channel side slope design is dependent on several factors including soil stability, available land area for top of bank width, ease of maintenance and safety. Grass lined slopes shall not exceed 3 feet horizontal to 1 foot vertical (3:1). Slopes maintained by mowing should not exceed 4:1. Yard swale side slopes should not exceed 6:1 for ease of maintenance. Where side slopes are steeper than 3:1 armor or stabilization lining is required.

SW9.04 Channel Slope

Channel slope is the channel bottom gradient or profile grade defined as the ratio of elevation change over length. Channel slope is expressed as a percentage or a decimal.

Channel slopes vary due to existing topography and the design requirements of each storm drainage system.

The desirable minimum slope for open channels is 0.5 percent (.005 ft/ft). In areas of flat topography, the desirable 0.5 percent minimum slope is not always possible to achieve.

The desirable minimum slope for yard swales is 1.0 percent. Yard swales with slopes less than 1.0 percent should be constructed with subsurface drains. Bio swales with wetland vegetation should not be served by a subsurface drain.

Historically, design criteria for channel bottom slope considered minimum flow velocity to prevent sedimentation within the channel, however maintaining a minimum flow velocity may not always be possible or desirable. Channels and swales may be used as best management practices (BMPs) for stormwater quality. As a best management practice sedimentation is encouraged within the channel. Channel design for BMP's does not comply with minimum design slope or flow velocity.

SW9.05 Channel Linings

Open channel bottoms and side slopes require stabilization measures to prevent scour and erosion. At minimum the peak flow rate from a 10 year storm shall be used to design armored linings for all channels. Acceptable methods of lining include grass or riparian vegetation, riprap or rock, concrete, or manufactured linings.

As site conditions allow, a vegetated filter strip of appropriate width shall be maintained along unvegetated swales and ditches.

1. Grass Lined Channels

   Grass is the most common method of channel stabilization in areas of flat topography. Grass or vegetation lining is permitted in channel bottoms with slopes not exceeding 3.0 percent or flows not exceeding 5 feet per second. Grass is permitted on channel side slopes not exceeding 3:1.

   Armor might be required in areas of grass lined channels where scour or erosion might occur. Areas which might require riprap or rock armor include storm sewer outlets, changes in bottom slope grade, bends in channel alignment, or areas where gullies might be formed in side slopes by concentrated flow entering a channel over the bank.

2. Riprap or Rock Lined Channels

   Riprap shall comply with Indiana Department of Transportation (INDOT) Revetment Riprap. INDOT Class 1 or class 2 Riprap may be used for energy dissipators.

   Riprap or rock lined channels are required where flow velocity might result in bottom or side slope erosion. Armor lining is required where channel bottom slope exceeds 3.0 percent or flow velocity exceeds 5 feet per second. Maximum slope for riprap lined channels shall not exceed 10.0 percent.

Channel side slopes between 1.5:1 and 3:1 shall be riprap lined.

3. Concrete Lined Channels

Concrete lined channels are permitted only in areas where limited space due to existing development prohibits the construction of grass or riprap lined channels. Concrete lining shall also be used where channel bottom slope exceeds 10 percent or flow velocity exceeds 15 feet per second.

Side slopes 1.5:1 or steeper shall have a concrete lining and the concrete lining shall be designed as a structural retaining wall. Concrete channel bottom and slopes shall be constructed with expansion and contraction joints to control cracking. Weepholes shall be installed along all channels with paved side slopes or retaining walls to relieve hydrostatic pressure from ground water.

Concrete channel lining shall be steel reinforced INDOT Class A concrete with a minimum thickness of 5 inches.

Concrete channel lining shall be designed with lugs where bottom slope exceeds 3 percent. INDOT Paved Side Ditch Cut-Off Wall and Lug Standard drawings are available on the Indiana Department of Transportation website: http://www.in.gov/dot/div/contracts/standards/drawings/sep12/e/sep600.htm

Minimize use of concrete channels to greatest extent possible.

4. Manufactured Linings

Manufactured channel linings include concrete revetment, gabions and Reno mattresses, or turf reinforcement mats. Manufactured linings shall be designed and constructed according to the manufacturer's specifications.

SW9.06 Easements

Drainage easements shall be provided for the maintenance or reconstruction of all public open channels. The minimum easement width shall be 40 feet from the top of channel bank.

SW9.07 Public Safety

Safety should be considered where an open channel presents a potentially dangerous situation to pedestrians or vehicular traffic. Guardrail or fencing may be required for the protection of the public.

SW9.08 General Design Requirements

1. Design Storm

   Open channels and swales serving storm sewers and tributary flows from upstream watersheds shall be designed to convey runoff from a 100 year rainfall event.

2. Channel Lining and Stability

   Open channels shall convey the 100 year event with 2 feet of freeboard to the top of the channel bank.

   Channel lining shall be incorporated in the design to prevent scour and erosion and to assure stability of the channel. At minimum the peak flow from a 10 year design storm shall be used to design channel linings criteria for determining required channel lining type and design criteria are set forth in Figure SW9-1.

3. Channel Slope (Gradient)

   The minimum desirable gradient for open channels is 0.5 percent (.005 ft/ft) swales with gradient less than 1.0 percent shall be served by an underdrain.

Figure SW9-1 Open Channel Parameters

Channel Lining	Maximum Channel Gradient		Maximum Flow Velocity (ft/sec)	Maximum Side Slope Hor:Vert
	Percent	ft/ft		
Grass	3.0	0.03	5	3:1
Riprap	10.0	0.10	15	1.5:1
Concrete	-	-	-	≤1.5:1
Manufactured Lining	*	*	*	*

**Per manufacturer's specifications*

SW9.09 Hydraulic Design

1. Uniform Steady Flow Equations

   For the purposes of open channel design, flow is usually considered steady and uniform. Given steady, uniform flow or a reasonable approximate condition, Manning's equation can be used to calculate the capacity of a channel. Using this equation for gradually varied or rapidly varied flow will result in errors.

$$Q = (1.49/n)\ AR_h^{2/3} S_f^{1/2}$$

Where:

Q = flow rate (cfs)

n = Manning's Roughness Coefficient, [Exhibit SW6-1]

A = flow area (ft^2)

R_h = hydraulic radius (ft), defined as flow area, A, in square feet divided by wetted perimeter, (P_w) in feet

S_f = friction slope (equal to storm sewer slope for uniform flow) (ft/ft)

2. Flow Regime

A more detailed analysis of an open channel design might be required by City Utilities Engineering if there is concern regarding the flow regime. Flow regime describes the state of flow in an open channel. Critical flow represents the minimum specific energy for a given discharge. The flow depth at critical flow is considered critical depth. Designers must calculate critical depth to classify design flows in the open channel as supercritical or subcritical. To distinguish supercritical and subcritical flow, the Froude number (F_r), which represents the ratio of inertial forces to gravitational forces, is defined by the following equation:

$$F_r = \frac{v}{\left(\frac{g * A}{T}\right)^{0.5}}$$

Where:
F_r = Froude number
v = Mean velocity (ft/s)
g = Acceleration of gravity (32.2 ft/s^2)
A = Cross-sectional area of flow (ft)
T = Top width of flow (ft)

For flows near critical depth (F_r=1), small disturbances can cause changes in flow state and unexpected hydraulic jumps. Flow with a Froude number between 0.8 and 1.2 are unstable and must be avoided. Designers should seek to create open channels with subcritical flow. When flow in open channels is subcritical it is relatively easier to handle through bends and flow transitions. Supercritical flow has higher erosive power and hydraulic losses. Due to erosion potential, curves in an open channel with supercritical flow are not practical. A description of each flow regime is provided in Figure SW9-2.

Figure SW9-2 Flow Regime Classification

Flow Regime	Characteristics
$F_r > 1$ = Supercritical flow	Flow depth controlled by upstream influence usually critical depth. Characterized as shallow with high velocities and steeper slopes. Higher potential for erosion.
$F_r < 1$ = Subcritical flow	Flow depth controlled by downstream influence, usually a ponded area or larger downstream channel. Flow characterized as deep with lower velocities and mild slopes. This flow regime produces most stable open channels.
$F_r = 1$ = Critical flow	Minimum specific energy for a given discharge.

SW9.10 Permitting

Open channels are frequently constructed through low lying areas which may contain wetlands. Permitting may be required if wetlands are affected by construction. Refer to Chapter GR4 – Contracts, Fees, and Permits for additional information.