2.5 Stormwater Conveyance Design

2.5.1 General Criteria

The components of the stormwater conveyance system, excluding the treatment and flood control facilities discussed in the previous sections, include pipe systems, culverts, open channels, and bridges. Design criteria that are specific to each of these components are presented in the following sections. General design criteria that are applicable to all of these components are presented below.

1. The design of the stormwater system, excluding stormwater management facilities for water quality treatment, channel protection, and overbank, extreme, and downstream flood protection shall be based on the 25-year frequency storm event unless otherwise specified by the Director. This criterion shall be applied to both closed conduit and open channel components. Minor systems that discharge to sinkholes must be designed to safely carry the 100-year frequency storm event.

2. All drainage systems shall be designed to insure that no habitable finished floor elevations are flooded for the 100-year frequency storm, and that no structures are located within the vertical projection of the 10-year floodplain line (i.e. located within the 10-year floodplain). Pipes and culverts designed for a 100-year storm shall be constructed of reinforced concrete if such pipes or culverts lie in public lands or easements.

3. Off-site runoff must be taken into account in the design of stormwater components if such runoff could affect the street that the stormwater system is serving.

4. Pipes or culverts that carry public water under pavement surfaces, and any pipe, culvert, or drainage system dedicated to Knox County, a private individual or a Homeowners' Association, whether inside or outside the right-of-way, can be constructed of reinforced concrete, high-density polyethylene (HDPE) or corrugated metal, subject to the approval of the Director. It shall be the responsibility of the property owner to provide all necessary design, data, and installation details for construction to ensure failure will not occur, and prevent flooding or potential property damage on adjacent properties or rights-of-way.

2.5.2 Pipe Systems

Stormwater pipe systems, also called storm drains, are pipe conveyances that are designed to collect and transport surface stormwater through drainage inlets and convey that water through closed conduits to outfalls at structural stormwater BMPs and receiving waters. The conduit system is comprised of different lengths, material types, shapes, and sizes of storm drain pipes which are connected by appurtenant structures such as manholes, junction boxes, or other miscellaneous structures. Stormwater pipe systems are sometimes referred to as storm sewers. To some people, such terminology implies that the stormwater system is the same as the wastewater (i.e., sewage) system. It is important in Knox County not to confuse the two systems: the stormwater system collects and transports stormwater drainage only, while sewage is carried via a different closed conduit system.

To the degree feasible, Knox County encourages the use of natural drainageways and/or properly vegetated open channels for stormwater runoff conveyance. Prior to design of a new development or redevelopment site, the use of the better site design practices (and corresponding site design credits) that are discussed in Chapter 5 of this manual should be considered to reduce the overall length of a piped stormwater conveyance system. However, pipe drain systems are necessary in many areas to ensure the safe collection and conveyance of stormwater away from habitable structures and streets. Pipe systems are suitable mainly for medium to high-density residential and commercial/industrial development where the use of natural drainage ways and/or vegetated open channels is not feasible.

Piped stormwater systems should be designed to ensure that storms in excess of pipe design flows can be safely conveyed without damaging structures or flooding major roadways near to the system and downstream. This is often done through design of both a major and minor drainage system. The minor (piped) system carries the mid-frequency design flows while larger runoff events may flow across lots and along streets as long as it will not cause property damage or impact public safety.

Pipe systems for stormwater runoff must be designed and constructed in accordance with the criteria listed below. Guidance on the design of storm drain pipe systems is given in Volume 2, Chapter 7.

5. Pipe systems serving local, collector and arterial streets must keep one ten (10) foot lane of traffic open in each direction for the 25-year design storm, and the 100-year storm shall be contained within the right-of-way. In pipe systems serving local roads, a ten (10) foot lane is allowed at inlets.

6. The minimum easement width for public piped stormwater systems that are located less than twelve (12) feet below the ground surface shall be twenty (20) feet. For piped stormwater systems that are located twelve (12) feet or more below the ground surface, the minimum easement width shall be thirty (30) feet.

7. The minimum acceptable diameter for any public storm drain is fifteen (15) inches or equivalent arch pipe.

8. When connecting into an existing storm drain system, the existing storm drain systems shall be analyzed to determine available capacity.

9. New storm drains and manholes shall not be located under existing or future curb and gutter or sidewalk, whenever possible.

10. For ordinary conditions, storm drain pipes should be sized on the assumption that they will flow full or practically full under the design discharge but will not be placed under pressure head. The Manning Formula is recommended for capacity calculations.

11. The minimum desirable physical slope should be 0.5% for concrete or smooth wall plastic (HDPE) and 1.0% for corrugated metal pipe (CMP), or the slope that will produce a velocity of 3.0 feet per second when the storm sewer is flowing full, whichever is greater.

12. The hydraulic grade line for the 25-year design storm for any piped stormwater system shall remain below the elevation of the ground surface.

2.5.3 Roadway Culverts

A culvert, sometimes called a cross drain, is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water. If designed properly, culverts may also be used to restrict flow and reduce downstream peak flows. On a development site, culverts are typically aligned with ditches, swales, and open channels which serve as primary drainageways that carry stormwater to more regional stormwater collection systems. In addition to the hydraulic function, a culvert must also support the embankment, roadway, or other structure under which it lies, and protect traffic and adjacent property owners from flood hazards.

Culvert design is influenced by purpose, hydraulic efficiency, site topography, effects on adjacent property, and cost. The most critical aspect of culvert design is the determination of stable and predictable performance of the culvert during all possible flows. This can be best determined when the type of flow (i.e., weir, orifice, or pipe) is known. The relationship between head and discharge can be determined using equations for weir flow, orifice flow or pipe flow.

Culverts must be designed and constructed in accordance with the criteria listed below. Further guidance on culvert design is contained in Volume 2, Chapter 7.

13. All culverts shall be designed for the 25-year design storm. The design engineer shall ensure that the culvert does not cause flooding of nearby structures in the 100-year design storm.

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14. All culverts shall be hydraulically designed to determine whether inlet and outlet control conditions govern for the design storm discharge(s).

15. Culverts shall be located and designed to present a minimum hazard to traffic, persons, and property. Projecting ends shall not be permitted for culverts intended to become public.

16. Survey and resource information should include topographic features, channel characteristics, aquatic life, riparian habitat, high-water information, existing structures, and other related site specific information, as applicable.

17. Roadway culverts shall be designed to accommodate debris or proper provisions shall be made for debris maintenance. Where practicable, some means shall be provided for personnel and equipment access to facilitate maintenance.

18. Material selection shall include consideration of service life, hydraulic efficiency, and maintenance and shall not be made using initial cost as the sole criteria.

19. Low water or at-grade, dip crossings of FEMA designated/mapped washes or other riverines are not permitted for public or private roadways which serve as the primary access to a development or single family residence.

20. Culvert or bridge crossings of FEMA designated/mapped washes shall be analyzed with HEC-2 Water Surface Profiles, HEC-RAS, or a pre-approved equal model. It must be demonstrated and certified by the engineer that there will be no increases on the base flood elevations(s) and/or limits upstream or downstream of the crossing.

21. Performance curves shall be developed for all public culverts for evaluating hydraulic capacity versus various headwater depths, outlet velocities, and scour depths.

22. The culvert length and slope shall be chosen to approximate existing topography, and to the degree practicable, the culvert shall be aligned with the channel bottom and the skew angle of the watercourse. Multiple barrel culvert crossings should fit onto the natural channel cross-section with minimal widening of the channel so as to avoid conveyance loss and sediment deposition.

23. Multiple barrel culverts shall be avoided where the approach velocity is high, particularly supercritical, to avoid adverse hydraulic jump effects.

24. The minimum velocity through a culvert should be three (3) feet per second when the culvert is flowing partially full.

2.5.4 Open Channels

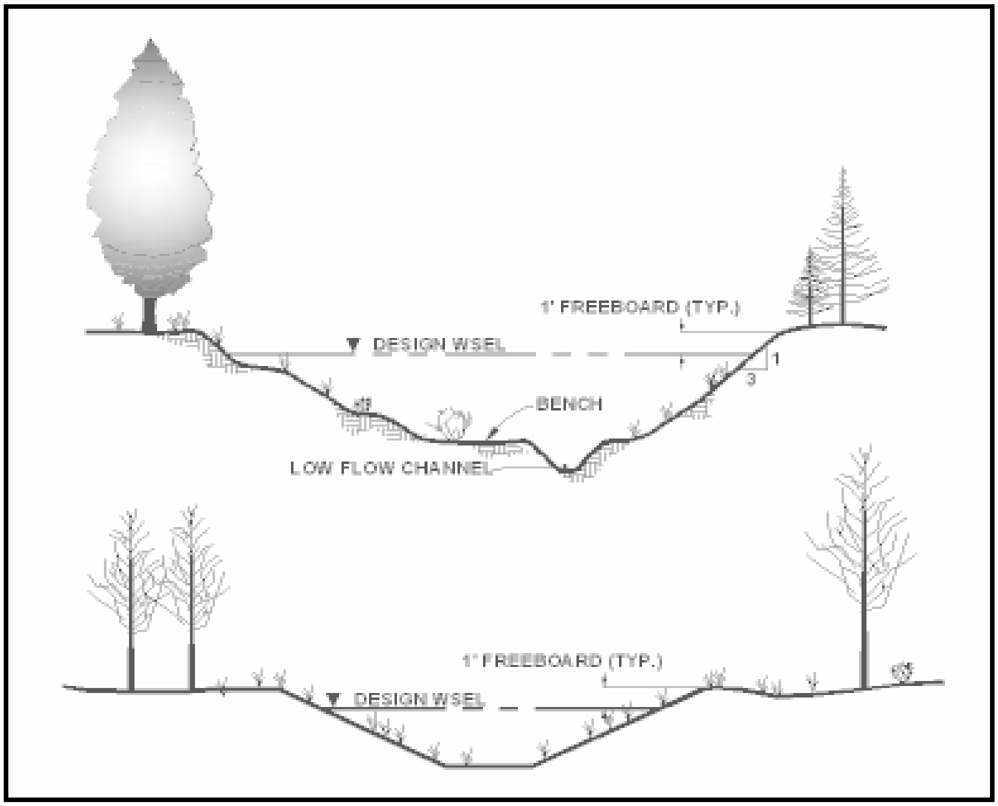
The design of open channel systems, particularly for development sites utilizing better site design, is an integral part of an overall drainage plan. An open channel is defined as a conveyance in which water flows with a free surface. Open channels can be either natural or artificial. Natural channels will typically consist of a compound cross section comprised of a low flow channel and the adjacent overbank floodplain. Artificial channels typically include roadside channels, irrigation ditches, and swales which have a general geometric cross section and can be either lined or unlined. An example of a typical compound cross-section channel and a typical trapezoidal channel is presented in Figure 2-5.

The three main classifications of open channel types according to channel linings are vegetated, flexible and rigid.

2.5.4.1 Vegetated Linings

Vegetated linings include grass with mulch, sod and lapped sod, and wetland channels. Vegetation, where practical, is the most desirable lining for an artificial channel because it can provide stability for the channel body, consolidate the soil mass of the bed, prevent erosion from the channel surface, and provide habitat and water quality benefits. Chapters 4 and 5 of Volume 2 of this manual provide guidance for the design of enhanced swales and grass channels for water quality treatment purposes. This section provides guidance solely for the purpose of stormwater conveyance.

Figure 2-5. Typical Channel Sections
(top - compound x-section, bottom- trapezoidal x-section)



Conditions under which the use of vegetated linings may not be acceptable include, but are not limited to areas where:

- high flow velocities are anticipated;
- a permanent or semi-permanent standing pool of water is anticipated;
- water will flow continuously (e.g., a conveyance channel that also serves as a landscaped waterway for a continuously flowing waterfall or pond);
- regular, necessary maintenance to prevent the growth of undesirable vegetation will not be available;
- there is a lack of nutrients and/or inadequate topsoil to properly sustain the vegetated lining; or
- there is excessive shade

Proper seeding, mulching and soil preparation are required during construction to assure establishment of healthy vegetation. Long-term regular maintenance is necessary to ensure the long-term proper operation and stability of the channel.

2.5.4.2 Flexible Linings

Rock riprap, including rubble, is the most common type of flexible lining for channels. It presents a rough surface that can dissipate energy and mitigate increases in erosive velocity. These linings are usually less expensive than rigid linings and have self-healing qualities that reduce maintenance. However, they may require the use of a filter fabric depending on the underlying soils, and the growth of grass and weeds may present maintenance problems.

2.5.4.3 Rigid Linings

Rigid linings are generally constructed of concrete and used where high flow capacity is required. Higher velocities, however, create the potential for scour at channel lining transitions and channel headcutting.

2.5.4.4 Design Criteria

The principles of open channel flow are the same regardless of the channel type. Flow classifications are generally categorized as steady or unsteady, uniform or varied, and subcritical or supercritical. Open channels must be designed and constructed in accordance with the criteria listed below. Further guidance on open channel design is contained in Volume 2, Chapter 7.

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25. Open channels shall be designed to follow natural drainage alignments whenever possible.
26. All channels which are to be maintained by Knox County must be dedicated to the County either in fee title or granted as a drainage easement. Vegetated channels that are eligible to gain water quality volume (WQv) credits for stormwater treatment must be granted to the County as a water quality easement.
27. Channels with bottom widths greater than 10 feet shall be designed with a minimum bottom cross slope of 12 to 1, or with compound cross sections.
28. Channel side slopes shall be physically stable throughout the entire length and side slope shall depend on the channel material. A maximum of 2:1 should be used for channel side slopes, unless otherwise justified by calculations. Roadside ditches should have a maximum side slope of 3:1.
29. Trapezoidal cross sections are preferred over triangular shapes for artificial channel designs.
30. The design of artificial channels shall consider the frequency and type of maintenance required and makes allowance for access of maintenance equipment.
31. For vegetative channels, flow velocities within the channel should not exceed the maximum permissible velocities stated in Chapter 7.
32. Channel banks shall be left in a stabilized condition upon completion of the project. No actively eroding, bare or unstable vertical banks shall remain unless the Director has determined there is no better alternative.
33. If relocation of a stream channel is unavoidable, the cross-sectional shape, meander, pattern, roughness, sediment transport, and slope should conform to the existing conditions to the extent practicable. Some means of energy dissipation may be necessary when existing conditions cannot be duplicated. Unless proper authorization is obtained from Knox County and the adjacent property owner(s), open channels must enter and exit a site where the channel historically flows. Knox County is not responsible for obtaining any State and/or Federal permits that may be applicable to channel relocation on a development or redevelopment site.

2.5.5 Outlet Protection

Storm system conveyance outlets, whether open channels or pipe systems, are critical locations of erosion potential. High exit velocities and flow expansion turbulence often result in local scour, channel degradation, and conduit failure. Often, the stormwater transported by man-made conveyances reaches velocities that exceed the capacity of the receiving channel or area to resist erosion. In order to prevent scour at stormwater outlets, protect the outlet structure and minimize the potential for downstream erosion, a flow transition structure (energy dissipater) is needed to absorb the initial impact of flow and reduce the speed of the flow to a non-erosive velocity. Often, such dissipaters are relatively inexpensive to install, such as a rip rap apron, a stilling basin or a baffled outlet.

Design guidance on energy dissipaters is presented in Volume 2, Chapter 7. Design criteria for outlet protection are as follows:

34. Energy dissipaters shall be utilized wherever the velocity of flows leaving a stormwater management facility exceed the erosion velocity of the downstream channel system. When utilized, such devices shall provide uniform redistribution (spreading out) of the flow without creating excessive turbulence in order to protect downstream areas from erosion.

35. Rip rap basins, stilling basins, or concrete energy dissipaters can be utilized to reduce high velocity outlet flows to within acceptable limits.

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2.5.6 Gutters & Inlets

The design of the roadway drainage system is essential to traffic safety and roadway level of service. Excess water on the roadway can be hazardous to not only vehicular traffic but pedestrians as well. Poor roadway drainage can increase the potential for hydroplaning, limit visibility due to excessive splashing and spray, and cause loss of steering control when puddles are encountered.

Street drainage requires consideration of surface drainage, gutter flow, and drainage inlet capacity. The design of these components is dependent upon the design frequency and the allowable spread of stormwater on the pavement surface. Surface drainage is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, and inlet capacity.

General design criteria for gutters and inlets are provided below. Design specifications are provided in greater detail in Volume 2, Chapter 7.

36. Street drainage and roadways shall be designed so as to maintain the natural drainage patterns existing prior to development, whenever possible.

37. The street section shall be designed to convey local runoff only and shall not be used as major stormwater carriers for contributing watersheds.

38. Drainage facilities shall be installed to convey runoff under streets or street grades shall be set so diversion of runoff or ponding will not occur on adjacent properties.

39. Street slopes (longitudinal and transverse) and curb heights shall not be increased to create more carrying capacity for runoff. Curb overtopping is not permitted for the specified design storm.

40. Drainage facilities shall be placed to intercept runoff from sources outside the street section to avoid significant concentrated flows onto and over sidewalks or curb and gutter.

41. In all cases, street drainage shall be confined to the public right-of-way. Runoff which leaves the right-of-way shall do so in a controlled manner and shall be contained in appropriate right-of-way or drainage easement.

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