CHAPTER

2

CRITERIA FOR STORMWATER DESIGN

2.1 Integrated Site Design Approach

2.1.1 Introduction

This chapter represents the requirements, policies and other guidance for stormwater management design in Knox County. Included in this chapter are detailed design criteria to support Knox County's overall stormwater runoff quality and quantity management standards which are presented in Volume 2, Chapter 1. The design criteria presented herein address the key adverse impacts of stormwater runoff from a development site in Knox County. The purpose of the design criteria is to provide a framework for design of the site's stormwater management system in order to:

- remove stormwater runoff pollutants and improve water quality;
- prevent downstream streambank and channel erosion;
- reduce downstream overbank flooding; and
- safely pass or reduce the runoff from extreme storm events.

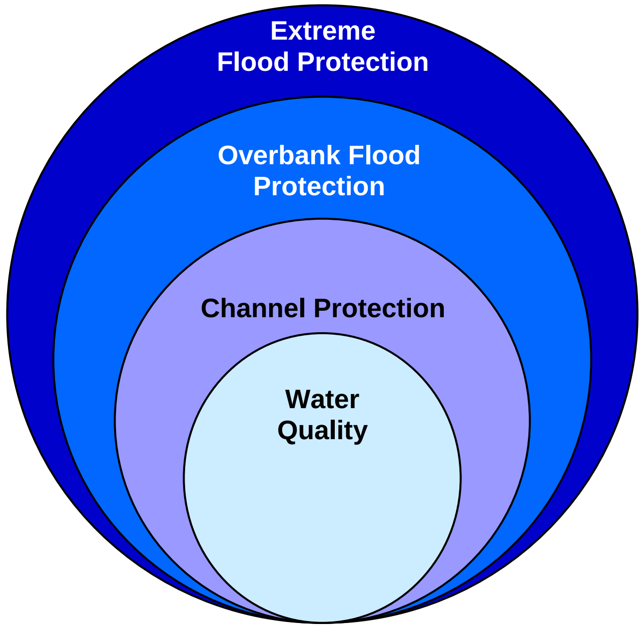
The Integrated Site Design (ISD) approach utilizes a set of design criteria that can be blended together, enabling the site engineer to size and design structural stormwater controls to address all of these objectives to achieve water quality and quantity goals. There are four criteria, one for each of the goals above, which are summarized in Table 2-1 below.

Table 2-1. Summary of Stormwater Criteria

Sizing Criteria	Description
Water Quality (WQv)	Treat the runoff from 85% of the rainfall events that occur in an average year to a load reduction goal of 80% average annual post-development total suspended solids (TSS).
Channel Protection (CPv)	The runoff volume from the 1-year frequency, 24-hour storm must be detained for no less than a 24-hour period in order to provide channel protection for channels and streambanks downstream from the new development.
Overbank Flood Protection (Qp_{25})	Provide peak discharge control of the 2, 10 and 25-year return frequency, 24-hour duration storm events such that the post-development peak rate does not exceed the pre-development rate.
Extreme Flood Protection (Qp_{100})	Provide peak discharge control of the 100-year return frequency, 24-hour duration storm event such that the post-development peak rate does not exceed the pre-development rate.

Each of the stormwater sizing criteria is intended to be designed in conjunction with the others to address the overall stormwater impacts from a development site. When used as a set, the criteria control the range of design events, from the smallest runoff producing rainfalls to the 100-year storm. Figure 2-1 graphically illustrates the relative volume requirements of each of the design criteria and demonstrates that the criteria are "stacked" within one another (i.e., the extreme flood protection volume requirement also contains the overbank flood protection volume, the channel protection volume and the water quality treatment volume).

Figure 2-1. Design Volume "Nesting" of Stormwater Criteria



2.1.2 General Design Policies and Guidance

The following general requirements and policies shall apply to the design of all stormwater control and conveyance facilities located in Knox County, including stormwater quality treatment facilities, stormwater quantity control facilities, pipe systems, culverts, open channels, bridges, and other stormwater conveyance system components.

1. Hydrologic and hydraulic computations shall be performed in accordance with NRCS (formerly known as the Soil Conservation Service or SCS) unit hydrograph procedures using AMC II curve numbers and Type II rainfall distribution, or other criteria that the Director of Engineering and Public Works or his designee (henceforth called "the Director") shall establish based on scientific and engineering information.
2. All post-development conditions must be routed at appropriately small time intervals through stormwater storage and drainage facilities using either hand calculations or computer models that are widely accepted among engineering professionals. Detailed information on accepted hydrologic and hydraulic calculation methods and procedures is presented in Volume 2, Chapter 3 of this manual.
3. Other hydrologic and hydraulic computation methods may be approved by the Director in the design of curb inlets and small pipe systems when the final result is verified by a SCS method analysis.
4. All hydrologic and hydraulic computations utilized in the design of stormwater facilities must be prepared by a registered engineer proficient in the field of hydrology and hydraulics and licensed to practice engineering in the State of Tennessee.

5. The Director has the authority to require additional water quantity control standards, including restrictions on peak velocity and/or runoff volumes or less frequent design events, in areas where the Director has determined, through stormwater master plans, engineering studies, other regulatory water quality requirements, a history of existing or documented flooding or erosion problems, or engineering judgment, that additional restrictions are needed to limit adverse impacts of the proposed development downstream or upstream of the site.
6. The Director may waive or modify any of the stormwater system design criteria if adequate water quality treatment, and/or channel protection, and/or overbank flooding, and/or extreme flooding is suitably provided by a downstream or shared off-site stormwater facility, or if engineering studies determine that installing the required stormwater facilities would not be in the best interest of Knox County.

2.2 Stormwater Quality Management

2.2.1 General Requirements and Policies

The Knox County Stormwater Management Ordinance requires that stormwater runoff discharging from new development or redevelopment sites be treated to remove pollutants prior to discharge from the site. Minimum Standard #1 (Chapter 1) states that stormwater management systems shall be designed to remove 80% of the 85th percentile storm total suspended solids (TSS) load and be able to meet any other additional watershed or site-specific water quality requirements. This standard is often referred to as “the 80% TSS removal standard”.

The Director has the authority to require additional treatment in specific areas of Knox County to conform to state and/or Federal regulatory requirements, and/or if (in the opinion of the Director) the development or redevelopment has the potential to generate higher than normal pollutant discharges.

It is presumed that a stormwater management system complies with the 80% TSS removal standard if appropriate structural best management practices (BMPs) are selected, designed, constructed and maintained in accordance with the design criteria specified in this manual. Only those BMPs that are published in the Knox County Stormwater Management Manual are permitted for use as a water quality treatment practice in Knox County. Other BMPs are prohibited, unless approved by the Director.

2.2.2 Percent TSS Removal Values for Structural BMPs

The structural stormwater BMPs deemed acceptable for use in Knox County to attain the 80% TSS removal standard are listed in Table 2-2. The table presents the % TSS removal value assigned to each BMP. This value must be used to calculate the total weighted % TSS removal for the development site. The % TSS removal values assigned to each BMP are conservative median pollutant reduction percentages for design purposes that have been derived from existing sampling data, modeling and professional judgment. A structural BMP design may be capable of exceeding these performances; however, the values in the table are median values that can be achieved over time when the structural BMP is sized, designed, constructed and maintained in accordance with required specifications in this manual. The actual % TSS removal value for a BMP in any single storm event may be higher or lower, depending upon a number of factors, including the inflow pollutant concentration, type of storm event, and maintenance condition of the BMP.

The structural BMPs listed in Table 2-2 fall into two categories (general application or limited application) based upon the BMP’s ability to meet stormwater management goals and/or its maintenance requirements. Further discussion of these categories and detailed guidance on BMP selection, design, construction, and maintenance are presented in Volume 2, Chapter 4 for each BMP listed in Table 2-2.

2.2.2.1 Policies for New or Proprietary BMPs

There are many commercially available BMPs that provide water quality or quantity treatment (e.g., Stormceptor, Vortechnics, etc.). Typically, such "proprietary" controls have high installation and maintenance costs and requirements. Therefore, they are best suited for non-residential developments or redevelopments that have limited space for water quality or quantity treatment using standard BMPs. This section describes the requirements that must be met for proprietary BMPs to be approved for a given site.

Table 2-2. TSS Removal % for Structural BMPs

Structural BMP	TSS Removal %
General Application BMPs	
Wet Pond	80
Wet Extended Detention	80
Micropool Extended Detention Pond	80
Multiple Pond System	80
Dry Extended Detention Pond	60
Conventional Dry Detention Basins	10
Shallow Wetland	75
Extended Detention Shallow Wetland	75
Pond/Wetland System	75
Pocket Wetland	75
Bioretention Area	85
Sand Filters (Surface and Perimeter)	80
Infiltration Trench	90
WQ Dry Swales	90
Wet Swales	75
Filter Strip	50
Grass Channel[1]	30
Gravity (oil-grit) Separator	30
Modular Porous Paver Systems[2]	*
Porous Pavement/Concrete[2]	*
Limited Application BMPs	
Organic Filter	80
Underground Sand Filter	80
Submerged Gravel Wetland	75
Alum Treatment System	90
Proprietary Treatment Controls	10[3]
Underground Detention	10

1 – Refers to open channel practice not designed for water quality.
2 – These practices are not treatment BMPs but are source control BMPs, so they are not assigned a pollutant removal.
3 – Provisional % TSS Removal value pending third party information.

Proprietary BMPs, new BMPs, or technologies that are not included in this manual may be approved by the Director on a case-by-case basis for the treatment of stormwater quality. A TSS removal percentage of 10% shall be used for such BMPs (if approved), or a higher percentage may be approved provided that the three conditions listed below are met. Judgments of the below three conditions shall be made by the Director after review of applicable information submitted by the site designer. A poor performance record, high failure rate or unacceptably high maintenance requirements are all valid justifications for not allowing the use of a proprietary system or device. It is the responsibility of the developer to provide the Director with sufficient information to allow modification of the % TSS removal value for any proprietary BMPs. TSS removal rates greater than 10% can be granted when the following conditions are met.

1. The BMP or technology, as applied to the development or redevelopment on which it will be used, meets the minimum standards and design criteria published in the Knox County Stormwater Management Manual. The performance ability of the BMP must be verified by an independent third party, in accordance with the monitoring criteria presented below. If the performance ability of the BMP cannot be verified, the BMP will not be approved for purposes of stormwater quality treatment.
2. The BMP or technology must have a proven record of operational longevity under hydrologic conditions similar to what would be encountered in Knox County (rainfall, slope, soil types, etc.).
3. The BMP or technology must have documented procedures for inspection and maintenance, including the collection and removal of pollutants or debris. BMPs that have unacceptably high maintenance requirements may not be installed within public rights-of way or on public property.

The following monitoring criteria should be met for research/studies to support the three acceptance conditions stated above:

- Water quality treatment performance must be monitored for a minimum of fifteen (15) storm events.
- Water quality treatment performance research/monitoring must be conducted in the field, as opposed to laboratory testing.
- Field monitoring must be conducted using standard protocols which require proportional sampling both upstream and downstream of the device. For guidance on testing protocols, see "Stormwater Best Management Practices Demonstration Tier II Protocol for Interstate Reciprocity" as developed under the Environmental Council of States (ECOS) and Technology Acceptance and Reciprocity Partnership (TARP, 2001).
- Pollutant concentrations reported in the study must be flow-weighted.
- The proprietary system or device must have been utilized in place for at least one year prior to the time of monitoring.
- Although local data is preferred, data from other areas can be accepted as long as the design accounts for the local hydrologic conditions.

2.2.3 Calculation of WQv and % TSS Removal

Compliance with the % TSS removal standard requires the calculation of the WQv and % TSS removed for the entire development site. To obtain the lowest WQv for the site, this calculation should be performed <u>*after*</u> better site design practices that may be envisioned for the site have been considered and are included in design plans.

The WQv shall be calculated using Equation 2-1, as follows:

Equation 2-1

$$WQv = \frac{P \times Rv \times A}{12}$$

where:

WQv = water quality volume of the site (acre-feet);
P = rainfall depth for the 85% storm event (1.1 inches);
Rv = runoff coefficient; and,
A = site area (acres).

The runoff coefficient (Rv) shall be calculated using Equation 2-2.

Equation 2-2

$$Rv = 0.015 + 0.0092 \times I$$

where:

I = percent impervious area of the site (see Equation 2-5 below).

2.2.4 Calculation of % TSS Removal for BMPs in Parallel

The percent TSS removal (%TSS) that is achieved on a site can be calculated using Equation 2-3. Equation 2-3 is an area-weighted TSS reduction equation which accounts for the TSS reduction that is contributed from BMPs that area treating separate areas and not being used in series.

Equation 2-3

$$TSS_{Site} = \frac{\sum_1^n (TSS_1 A_1 + TSS_2 A_2 + ... + TSS_n A_n)}{\sum_1^n (A_1 + A_2 + ... + A_n)}$$

where:

TSS_n = TSS removal for each structural BMP located on-site (%);
A_n = the area draining to each BMP (acres).

Where BMPs are used in series, the total % TSS removal for the combination of two or more BMPs shall be used for TSS_n in Equation 2-3. Calculation of this value is discussed in the next section.

2.2.5 Calculation of % TSS Removal for BMPs in Series

It will often be the case that the site designer will want to use two or more BMPs (structural and/or non-structural) in series, where stormwater treated in one BMP is discharged into another BMP for further treatment. Such BMP combinations are also called treatment trains. How and why BMPs might be used in treatment trains is discussed in Volume 2, Chapter 4 of this manual. This section presents the calculation of the total % TSS removal for treatment trains.

To calculate the total % TSS removal for a treatment train comprised of two or more structural BMPs, Equation 2-4 shall be used.

Equation 2-4

$$TSS_{train} = TSS_A + TSS_B - \frac{(TSS_A \times TSS_B)}{100}$$

where:

TSS_{train} = total TSS removal for treatment train (%);
TSS_A = % TSS removal of the first (upstream) BMP, from Table 2-2 (%)
TSS_B = % TSS removal of the second (downstream) BMP, from Table 2-2 (%).

For development sites where the treatment train provides the only stormwater treatment on the site, TSS_{train} must be greater than or equal to 80%. For development sites that have other structural BMPs for stormwater treatment that are not included in the treatment train, TSS_{train} must be included in Equation 2-3 in the calculation of the overall % TSS removal for the site. An example application of the latter situation is presented below.

Example 2-1. Calculation of %TSS when Treatment Trains are Used

A stormwater management system located on a 30 acre development site consists of a dry extended detention pond, a water quality dry swale, and a shallow wetland. The extended detention pond and dry swale are located in series, with the pond as the upstream control. The treatment train treats stormwater runoff from 20 acres of the site. The shallow wetland treats 10 acres. All three facilities are designed in accordance with the Knox County Stormwater Management Manual. What is the % TSS removal rate for the site?

The % TSS removal value for each BMP located on the site is determined from Table 2-2, as follows:

Control A (dry extended detention pond) = 60% TSS removal
Control B (water quality dry swale) = 90% TSS removal
Control C (shallow wetland) = 75% TSS removal

Step 1: Calculate TSS_{train}:

$TSS_{train} = TSS_A + TSS_B - (TSS_A \times TSS_B)/100 = 60 + 90 - (60 \times 90)/100 = 96\%$ removal

Step 2: Calculate % TSS removal for the site:

$\%TSS = ((TSS_{train} \times 20 \text{ acres}) + (\%TSS_{wetland} \times 10 \text{ acres})) \div 30 \text{ acres}$

$\%TSS = ((96\% \times 20 \text{ acres}) + (75\% \times 10 \text{ acres})) \div 30 \text{ acres} = 89\%$

Therefore, the % TSS removal for the site is 89%, which exceeds the minimum standard of 80% TSS removal. No other BMPs need to be constructed at the site.

2.2.6 Calculation of % TSS Removal for Flow-through Situations

BMPs within a treatment train may sometimes be separated by a contributing drainage area. In this case, equation 2-4 cannot be used, since some of the flow entering the downstream BMP has not been treated by the upstream BMP. This section presents the calculation of the total % TSS removal for flow-through situations.

To calculate the total % TSS removal for a treatment train separated by a contributing drainage area, Equation 2-5 shall be used.

Equation 2-5

$$TSS_{train} = \frac{TSS_A A_A + TSS_B A_B + \dfrac{TSS_B A_A (100 - TSS_A)}{100}}{A_A + A_B}$$

where:

TSS_{train} = total TSS removal for treatment train (%);
TSS_A = % TSS removal of the first (upstream) BMP, from Table 2-2 (%)
TSS_B = % TSS removal of the second (downstream) BMP, from Table 2-2 (%)
A_A = Area draining to BMP A
A_B = Area draining to BMP B.

For development sites where the treatment train provides the only stormwater treatment on the site, TSS_{train} must be greater than or equal to 80%. An example application of Equation 2-5 is shown below.

Example 2-2. Calculation of %TSS in a Flow-through Situation

A stormwater management system located on a 9 acre development site consists of a dry extended detention pond, and a bioretention cell. Five acres drain to the bioretention cell, which then drains to a pipe system. The pipe system also drains an additional 4 acres that have not been treated for water quality. The pipe system leads to a dry extended detention pond, that is used for final treatment. Both facilities are designed in accordance with the Knox County Stormwater Management Manual. What is the % TSS removal rate for the site?

The % TSS removal value for each BMP located on the site is determined from Table 2-2, as follows:

Control A (bioretention cell) = 85% TSS removal
Control B (dry extended detention pond) = 60% TSS removal

Step 1: Calculate TSS_{train}:

$$TSS_{train} = \frac{TSS_A A_A + TSS_B A_B + \dfrac{TSS_B A_A (100 - TSS_A)}{100}}{A_A + A_B}$$

$$TSS_{train} = \frac{85*5 + 60*4 + \dfrac{60*5(100-85)}{100}}{5+4}$$

$$TSS_{train} = 78.9\%$$

The % TSS removal for the site is 78.9%, which is below the minimum standard of 80% TSS removal. The conversion of the stormwater pipe system to a grass swale would add additional pollutant removal and help the site meet the 80% criteria.

2.2.7 The Measurement and Calculation of Percent Imperviousness

The percent impervious area (I) that is used to determine WQv is calculated using Equation 2-5.

Equation 2-5

$$I = \frac{I_A}{A} \times 100\%$$

where:

I_A = cumulative area of all impervious surfaces on the site (acres);
A = site area (acres).

Impervious areas are defined in the Knox County Stormwater Management Ordinance as impermeable surfaces which prevent the percolation of water into the soil including, but not limited to, paved surfaces such as walkways, sidewalks, patios, parking areas and driveways, packed gravel or soil, and rooftops. Other examples of impervious areas are paved recreation areas including pool houses and pool decks intended for use as a private (multi-family) or public recreation area, paved athletic courts (e.g., basketball, tennis), and storage buildings.

The determination of the impervious area (I_A) in order to calculate WQv shall be performed in the following manner:

1. For residential subdivisions that will be served by one or more shared stormwater facilities, I_A may be determined using percent (%) impervious values that were developed by the Soil Conservation Service (SCS)[1]. Where the average lot size of a subdivision or a drainage area within the subdivision falls between the lot size categories shown in Table 2-3, the site designer may interpolate the % impervious value based on Table 2-3.

   The values shown in Table 2-3 shall be utilized only for the portion of the subdivision that is covered by individual residential lots and streets. Other areas, such as common areas for recreation or meeting facilities, shall be added separately in the calculation of I_A. The calculation of the % impervious value for a residential subdivision having a common area is presented in Example 2-2.

   If lot sizes within a single subdivision fall into more than one of the lot size ranges listed in Table 2-3, the site designer shall consider the total amount of imperviousness in each lot range separately in the determination of the percent impervious value. Example 2-2 includes the calculation of the % impervious value for a residential subdivision having variable lot sizes.

Table 2-3. % Impervious Area Values for Subdivisions

Residential Lot Size Range[1]	% Impervious
⅛ acre or less	65
¼ acre	38
⅓ acre	30
½ acre	25
¾ acre	22.5[2]
1 acre	20
2 acres and greater	15

1 – Includes lots and streets. Common areas must be measured separately.
2 – The % impervious value is interpolated from SCS data.

2. For planned unit developments where the building and paving footprints are known, as well as all nonresidential developments, I_A shall be determined from the measured impervious footprints for all impervious areas as defined above. It is required that the footprint for all impervious surfaces in the proposed development and the calculation of I_A be shown in the stormwater management plan.

After the development and/or redevelopment of the property is complete, property improvement activities that do not require the submittal of a stormwater management plan will not require recalculation of the impervious percentage and WQv.

Example 2-2. Calculation of Percent Impervious Area (I)

A site design engineer is preparing a stormwater management plan for a proposed residential development in Knox County. The subdivision has a total area of 31 acres, and will include 52 residential lots ranging in area from approximately ¼ acre to no greater than 1 acre (as shown in the

[1] The Soil Conservation Service is now known as the Natural Resource Conservation Service.

table below). Three (3) acres will be preserved as an undisturbed forested water quality buffer located along a stream that crosses the property, and therefore, there is no impervious coverage within these three acres. Another three (3) acres will be utilized for a recreational common area which includes a community pool, tennis courts and an associated parking lot. Due to local topography on the site, the subdivision drains to two separate stormwater facilities, herein called Facility A and Facility B, both of which provide stormwater quality treatment. Twelve acres, including the 3 acre water quality buffer and 3 acre common area, drain to Facility A. The other 19 acres drain to Facility B. The table below provides lot size, area and impervious data for the proposed subdivision. What is the % impervious area for the site?

A	**B**	**C**	**D**
Lot Size	**Number of Lots in Size Range**	**Sub-total Area of Lots in Size Range**	**% Impervious (from Table 2-3)**
DRAINAGE AREA A (AREA DRAINING TO FACILITY A)			
approx. ⅓ acre	0	0 acres	30
approx. ½ acre	0	0 acres	25
approx. ¾ acre	2	1.3 acres	22.5
approx. 1 acre	5	4.7 acres	20
Area A Totals	7 lots	6.0 acres	--
DRAINAGE AREA B (AREA DRAINING TO FACILITY B)			
approx. ⅓ acre	21	6.6 acres	30
approx. ½ acre	16	7.3 acres	25
approx. ¾ acre	7	4.3 acres	22.5
approx. 1 acre	1	0.8 acres	20
Area B Totals	45 lots	19.0 acres	--

Since the site will be served by two separate detention facilities, it is best to determine the impervious area for each drainage area, rather than the overall impervious area for the site.

Step 1: Determine the total impervious area for the portion of each drainage area that is covered by residential lots and associated subdivision roads ($I_{\text{residential areas}}$):

This is calculated by multiplying the sub-total area of each lot size range (column C from the above table) by the corresponding % impervious in that lot size range (column D from the above table). Results of this calculation are shown in the table below.

A	**B**	**C**	**D**
Lot Size	**Sub-total Area of Lots in Size Range**	**% Impervious (from Table 2-3)**	**Sub-total Impervious Area**
DRAINAGE AREA A (AREA DRAINING TO FACILITY A)			
approx. ⅓ acre	0 acres	30	0 x 0.30 = 0 ac
approx. ½ acre	0 acres	25	0 x 0.25 = 0 ac
approx. ¾ acre	1.3 acres	22.5	1.3 x 0.225 = 0.29 ac
approx. 1 acre	4.7 acres	20	4.7 x 0.20 = 0.94 ac
Area A Totals	6.0 acres	--	1.23 acres
DRAINAGE AREA B (AREA DRAINING TO FACILITY B)			
approx. ⅓ acre	6.6 acres	30	6.6 x 0.30 = 1.93 ac
approx. ½ acre	7.3 acres	25	7.5 x 0.25 = 1.88 ac
approx. ¾ acre	4.3 acres	22.5	4.3 x 0.225 = 0.97 ac

A Lot Size	B Sub-total Area of Lots in Size Range	C % Impervious (from Table 2-3)	D Sub-total Impervious Area
approx. 1 acre	0.8 acres	20	0.8 x 0.20 = 0.16 ac
Area B Totals	19.0 acres	--	4.94 acres

Thus, the portions of the site where residential lots are located are covered by impervious surfaces as follows:

$I_{A\ residential\ areas}$ = 1.23 acres

$I_{B\ residential\ areas}$ = 4.94 acres

Step 2: Measure the area of impervious footprints in the common areas that are located in Area A ($I_{A\ common\ areas}$):

The following table presents the measurements of the impervious areas located in the common area.

Area Description	Impervious Area
Community pool (includes pool deck, maintenance building and sidewalk from parking lot)	0.8 acres
Tennis court (includes two courts, surrounding paved areas, and sidewalk from parking lot)	1.2 acres
Common area driveway and parking lot	0.7 acres
Total impervious areas	2.7 acres

Thus, 2.7 acres of the 3 acre common area, located in Area A, is covered by impervious surfaces. $I_{A\ common\ areas}$ = 2.7 acres

Step 3: Calculate the % impervious area (I) for each drainage area of the site using Equation 2-5. Because the water quality buffer is entirely undisturbed, and therefore entirely pervious, it is not considered in the calculation.

For Area A:

$I_A = ((I_{A\ residential\ areas} + I_{A\ common\ areas}) \div 12\text{ acres}) \times 100\%$

$I_A = ((1.23\text{ acres} + 2.7\text{ acres}) \div 12\text{ acres}) \times 100\%$

$I_A = (3.9\text{ acres} \div 12\text{ acres}) \times 100\%$

$I_A = 32.8\%$

For Area B:

$I_B = (I_{B\ residential\ areas} \div 19\text{ acres}) \times 100\%$

$I_B = (4.94\text{ acres} \div 19\text{ acres}) \times 100\%$

$I_B = 26.0\%$

Therefore, the % impervious area for Area A (I_A) for the site is 32.8%. The % impervious area for Area B (I_B) is 26.0%. These values are utilized in Equation 2-2 to determine the values of Rv which will then be used in Equation 2-1 to find the WQv for each stormwater quality treatment BMP on the site.

2.2.8 Reducing the WQv

One of the key points to remember when calculating WQv is that it is proportional to impervious area, such that the amount of stormwater runoff required for treatment increases as impervious area increases. In other words, the more you pave, the more you treat. Therefore, to reduce the amount of stormwater runoff that must be treated, the developer must find ways to reduce site imperviousness. Reductions in imperviousness are beneficial from a stormwater management standpoint. Decreases in impervious area equate to less runoff, lower post-development peak discharges, and typically lower pollutant discharges. This can result in lower stormwater management costs, as structural BMPs, channel protection, and flooding protection controls can be smaller in size.

In order to reduce the WQv for a development site, Knox County encourages the use of better site design practices. Better site design can be defined as a combination of non-structural design approaches intended to reduce the impacts of stormwater runoff from development through the conservation of natural areas, reduction of impervious areas, and integration of stormwater treatment BMPs. Such practices are often referred to as "non-structural practices or BMPs". By implementing a combination of these non-structural approaches, it is possible to reduce the amount of runoff and pollutants that are generated from a site and provide for some non-structural on-site treatment and control of runoff.

Knox County does not require the use of better site design practices on a development or redevelopment site to attain the 80% TSS removal standard. However, in accordance with Minimum Standard #2 (Chapter 1), a strong incentive for the use of such practices is provided via the WQv method and through WQv credits. The basic premise of the credit system is to recognize the water quality benefits of certain site design practices by allowing for a reduction in the WQv. The WQv credits that are available in Knox County are listed in Table 2-4. Detailed policies and design requirements for credits and better site design practices are presented in Volume 2, Chapter 5 of this manual.

Table 2-4. Summary of WQv Credits

Credit	Description
Credit 1: Natural area preservation	Undisturbed natural areas are conserved, thereby retaining the pre-development hydrologic and water quality characteristics.
Credit 2: Managed area preservation	Managed areas of open space are preserved, reducing total site runoff and retaining near pre-development hydrologic and water quality characteristics.
Credit 3: Stream and vegetated buffers	Stormwater runoff is treated by directing runoff through a naturally vegetated or forested buffer as overland flow.
Credit 4: Vegetated channels	Vegetated channels are used to provide stormwater treatment.
Credit 5: Impervious area disconnection	Overland flow filtration/infiltration zones are incorporated into the site design to receive runoff from rooftops and other small impervious areas.
Credit 6: Environmentally sensitive large lot neighborhood	A group of site design techniques are applied to low and very low density residential development.

2.3 Channel Protection (CPv)

2.3.1 Background

The increase in the frequency, velocity, and duration of bankfull flow conditions in stream channels after a rainfall event is the primary cause of streambank erosion. Such erosion is common in Knox County, usually in channels and streams where the cumulative effect of development has caused lengthy, increased post-rainfall discharges. The sediment released as a result of streambank erosion is a likely major source of sediment pollutant loads in Knox County streams. Excessive sediment can impact a stream's ability to remain ecologically viable and provide a healthy habitat for aquatic species.

Streambank erosion can cause damaging hydraulic changes in a stream, including excessive widening, deepening, and undercutting. Figure 2-2 presents an example of this problem located on a tributary to Ten Mile Creek in west Knox County. Such changes can be detrimental to the ability of the stream to remain hydraulically stable in the long-term. Moreover, streambank erosion is a common source of complaints from citizens that experience property damage due to fallen trees or outbuildings, or property loss due to widening streams.

Figure 2-2. Example of Significant Streambank Erosion

2.3.2 Design Criteria and Policies

Knox County requires all developments and redevelopments to adhere to channel protection criteria (Minimum Standard #3), herein called the channel protection volume (CPv). This standard requires that the runoff volume from the 1-year frequency, 24-hour storm be detained for no less than a 24-hour period. In the design of the channel protection control, the 24-hour detention period shall be measured from the approximate center-of-mass of inflow to the approximate center-of-mass of outflow.

Downstream channel protection provided by an alternative approach may be considered in lieu of controlling the CPv, provided that sufficient hydrologic and hydraulic analysis shows that the alternative approach will offer adequate channel protection from erosion. Downstream channel protection provided by an alternative approach must be approved by the Director.

2.4 Stormwater Quantity Management

This section addresses the design criteria and policies associated with Knox County's requirements for overbank protection and extreme flood protection. This section also presents justification, policies and requirements for the downstream impact analysis.

2.4.1 Overbank Flood Protection Criteria (Qp_{25})

Minimum Stormwater Management Standard #4 establishes overbank flood protection design criteria (Qp_{25}). The purpose of Qp_{25} is to prevent an increase in the frequency and magnitude of damaging out-of-bank flooding (i.e., flow events that exceed the capacity of the channel and enter the floodplain). It is intended to protect downstream properties from flooding during and after middle-frequency storm events.

The Qp_{25} criteria requires that the calculated peak discharge of stormwater runoff resulting from the 2-year, 10-year, and 25-year return frequency, 24-hour duration storm events be no greater after development or redevelopment of the site than that which would result from the same 2-year, 10-year, and 25-year return frequency, 24-hour duration storms on the same site prior to development or redevelopment. Hydrologic calculation methods for Qp_{25} are provided in Volume 2, Chapter 3.

Typically, peak discharge control is achieved through detention of runoff for the design events; however, Knox County does not mandate the use of detention facilities. It should be noted that the smaller design events (e.g., 2-year and 10-year) are often effectively controlled through the combination of the required channel protection (CPv) control (i.e., extended detention of the 1-year event) and the control of the 25-year frequency event.

2.4.2 Extreme Flood Protection (Qp_{100})

The intents of Minimum Standard #5, also called the extreme flood protection design criteria (Qp_{100}), are to:

- prevent flood damage from infrequent, but large, storm events;
- maintain the boundaries of the mapped 100-year floodplain; and,
- protect the physical integrity of the structural stormwater BMPs as well as downstream stormwater and flood control facilities.

The Qp_{100} criteria requires that the calculated peak discharge of stormwater runoff resulting from a 100-year frequency, 24-hour duration storm be no greater after development or redevelopment of the site than that which would result from a 100-year frequency, 24-hour duration storm on the same site prior to development or redevelopment. In addition, all drainage systems shall be designed to insure that no habitable finished floor elevations are flooded for the 100-year frequency storm. 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.

Design of stormwater systems that will include extreme flood protection controls must route the Qp_{100} through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, and downstream areas. Emergency spillways of structural BMPs must be designed appropriately to safely pass the Qp_{100}.

Further guidance on hydrologic analysis and design for the Qp_{100} criteria is provided in Volume 2, Chapter 3.

2.4.3 Downstream Impact Analysis

2.4.3.1 Background

The Qp_{25} and Qp_{100} flood protection criteria require the design to control peak discharges at the outlet of a site, such that the post-development peak discharge does not exceed the pre-development peak discharge. Typically, this peak discharge control is achieved through construction of one or more on-site detention facilities. However, stormwater master plans developed for a number of Knox County watersheds indicate that peak discharge control does not always provide effective water quantity control from the site, and may actually exacerbate flooding problems downstream of the site. Moreover, master plans have shown that a development site's location within a watershed may preclude the requirement for overbank flood control from a particular site.

A major reason for negative impacts due to detention involves the timing of the peak discharge from the site in relation to the peak discharges in the receiving stream and/or its tributaries. If detention structures are indiscriminately placed in a watershed without consideration of the relative timing of downstream peak discharges, the structural control may actually increase the peak discharge downstream. An example of this situation is presented in Figure 2-3, which shows a comparison of the total downstream flow on a receiving stream (after development) with and without detention controls. In Figure 2-3, the smaller dashed-dot and solid lines denote the runoff hydrograph for a development site with and without detention, respectively. These runoff hydrographs will combine with a larger runoff hydrograph of the receiving stream (not shown). The combined discharges from the site and receiving stream are shown in the larger solid and dashed lines.

Figure 2-3 conveys a possible consequence of detention. The post-development flow from the site is reduced as required by flood protection design criteria to result in the detained flow (the smaller dashed-dot hydrograph). However, the timing of the peak discharge for the detained post-development flow, while reduced in magnitude, corresponds more closely with the timing of the peak discharge of the receiving stream (not shown) than the peak discharge of the post-development flow that was not detained. Therefore, the combination of the detained flow with the flow in the receiving stream is actually higher than would occur if no detention were required, as shown in the larger dashed hydrograph. Hence, there is a peak flow increase that is caused by detention.

Poor peak discharge timing can have an even greater impact when one considers all the developments located in a watershed and the cumulative effects of increases in runoff volume and the duration of high volume runoff in the channel, as well as peak discharge timing. Even if peak discharges are handled effectively at the site level and immediately downstream, the longer duration of higher flows due to the increased volume from many developments located on or near a stream may combine with downstream tributaries and receiving streams to dramatically increase the downstream peak flows.

Figure 2-4 illustrates this concept. The figure shows the pre- and post-development hydrographs at the confluence of two tributaries. Development occurs, meets the local flood protection criteria (i.e., the post-development peak flow is equal to the pre-development peak flow at the outlet from the site), and discharges to Tributary 1. When the post-development detained flow from Tributary 1 combines with the first downstream tributary (Tributary 2), it causes a peak flow increase when compared to the pre-development combined flow. This is due to the increased volume and timing of runoff from Tributary 1, relative to the peak flow and timing in Tributary 2. In this case, the detention volumes on Tributary 1 would have to have been increased to account for the downstream timing of the combined hydrographs to mitigate the impact of the increased runoff volume.

Figure 2-3. Potential Effect of On-Site Detention on Receiving Streams

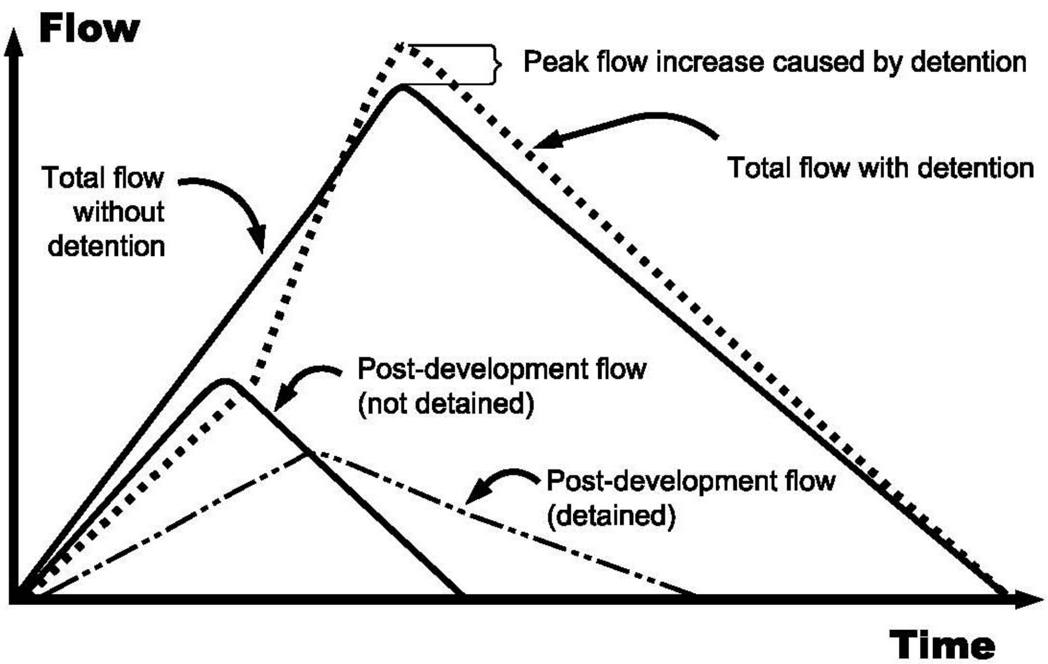
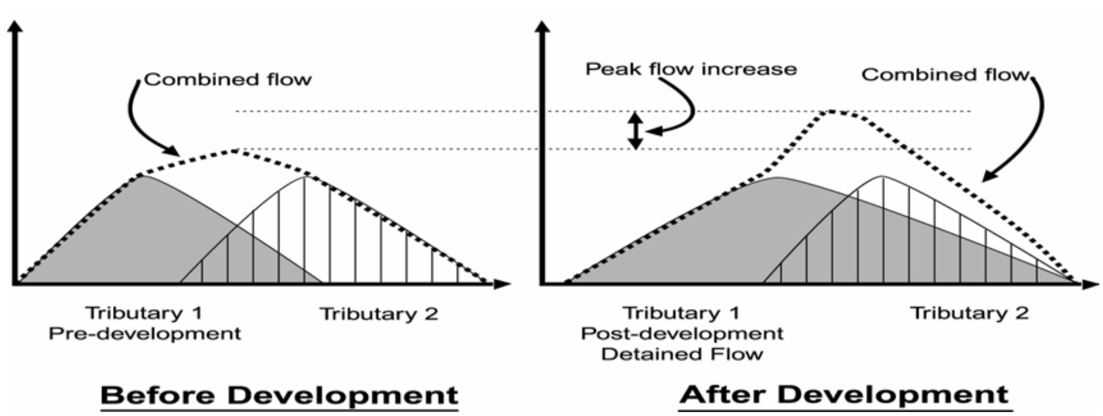


Figure 2-4. Potential Effect of Cumulative Detention Ponds



Potential problems such as those described above are quite common, but can be avoided through the use of a stormwater master plan and/or downstream analysis of the effects of a planned development. Studies have shown that if a developer is required to assess the impacts of a development downstream to the point where the developed property is 10% of the total drainage area, and there are no adverse impacts (i.e., stream peak discharge increases), then it is very unlikely that there will be significant increases in flooding problems further downstream. For example, for a 10-acre site, the assessment would have to take place down to a point where the total accumulated drainage area is 100 acres.

While this assessment does require some additional labor on the part of the design engineer, it allows smart stormwater management within a watershed. The assessment provides the developer, Knox County and downstream property owners with a better understanding (and corresponding documentation) of the potential downstream impacts of development. In turn, this information identifies those developments for which waivers or reductions in the flood protection requirements may prove beneficial.

2.4.3.2 Regulations and Policies

Regulations and policies pertaining to the downstream impact analysis are listed below.

1. In accordance with Minimum Standard #6 (Chapter 1), downstream impact analysis shall be required for all developments and redevelopments for which a stormwater management plan is required. The analysis shall determine if the proposed development or redevelopment causes an increase in peak discharge as compared to pre-development runoff rates for the same site, or has the potential to cause downstream channel and streambank erosion. This analysis must be done for the 2-year, 10-year, 25-year and 100-year return frequency, 24-hour duration storm events, at the outfall(s) of the site, and at each downstream tributary junction and each public or major private downstream stormwater conveyance structure to the point(s) in the stormwater system where the area of the portion of the site draining into the system is less than or equal to 10% of the total drainage area above that point.
2. If the downstream impact analysis shows that the development or redevelopment causes an increase in peak discharges, downstream flood protection shall be provided such that the calculated peak discharges for the 2-year, 10-year, 25-year and 100-year return frequency, 24-hour duration storm events after development of the site are not greater than that which would result from the same duration storms in the same downstream analysis area prior to development or redevelopment. These criteria must be applied throughout the 10% downstream analysis area
3. Downstream flood protection can be provided by downstream conveyance improvements and/or purchase of flow easements in lieu of peak discharge controls subject to prior approval by the Director and satisfaction of the following requirements:

   (1) Sufficient hydrologic and hydraulic analysis must be presented that shows that the alternative approach will offer adequate protection from downstream flooding for all potentially affected downstream property owners.

   (2) The applicant is responsible for providing to the County sufficient technical material for submittal and approval of any necessary CLOMR prior to construction, and a LOMR upon completion of construction. The applicant is also responsible for payment of any expenses or fees associated with preparation of such technical material and with submittal and approval of a CLOMR and/or LOMR.

   (3) The applicant is responsible for all State and Federal permits that may be applicable to the site including TDEC NPDES and ARAP permits, US Army Corps of Engineers Section 404 permits, and TVA Section 26A permits.
4. Developments and redevelopments that do not cause an increase in peak discharges are not exempt from conformance with the minimum standards for water quality treatment (WQv) and channel protection (CPv), presented earlier in this chapter.
5. The downstream analysis should be performed after any WQv credits for better site design practices have been taken into consideration in the calculation of peak discharges leaving the site. While there are no credits for flood protection criteria, the use of better site design practices will inherently reduce runoff volumes and potentially reduce post-development peak discharges, both on-site and downstream of the site.
6. The data and results of the downstream analysis must be presented to Knox County Engineering as part of the stormwater management plan.

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 area 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.

1. 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.
2. 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.
3. The minimum acceptable diameter for any public storm drain is fifteen (15) inches or equivalent arch pipe.
4. When connecting into an existing storm drain system, the existing storm drain system shall be analyzed to determine available capacity.
5. New storm drains and manholes shall not be located under existing or future curb and gutter or sidewalk, whenever possible.
6. 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.
7. 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.
8. 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. Culverts may also be designed 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.

1. 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.
2. All culverts shall be hydraulically designed to determine whether inlet and outlet control conditions govern for the design storm discharge(s).
3. 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.
4. 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.
5. 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.
6. Material selection shall include consideration of service life, hydraulic efficiency, and maintenance and shall not be made using initial cost as the sole criteria.
7. 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.
8. 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.
9. Performance curves shall be developed for all public culverts for evaluating hydraulic capacity versus various headwater depths, outlet velocities, and scour depths.
10. 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.
11. Multiple barrel culverts shall be avoided, if practical, where the approach velocity is high, particularly supercritical, to avoid adverse hydraulic jump effects.
12. The minimum velocity through a culvert should be three (3) feet per second for the 1-year storm.

2.5.4 Open Channels

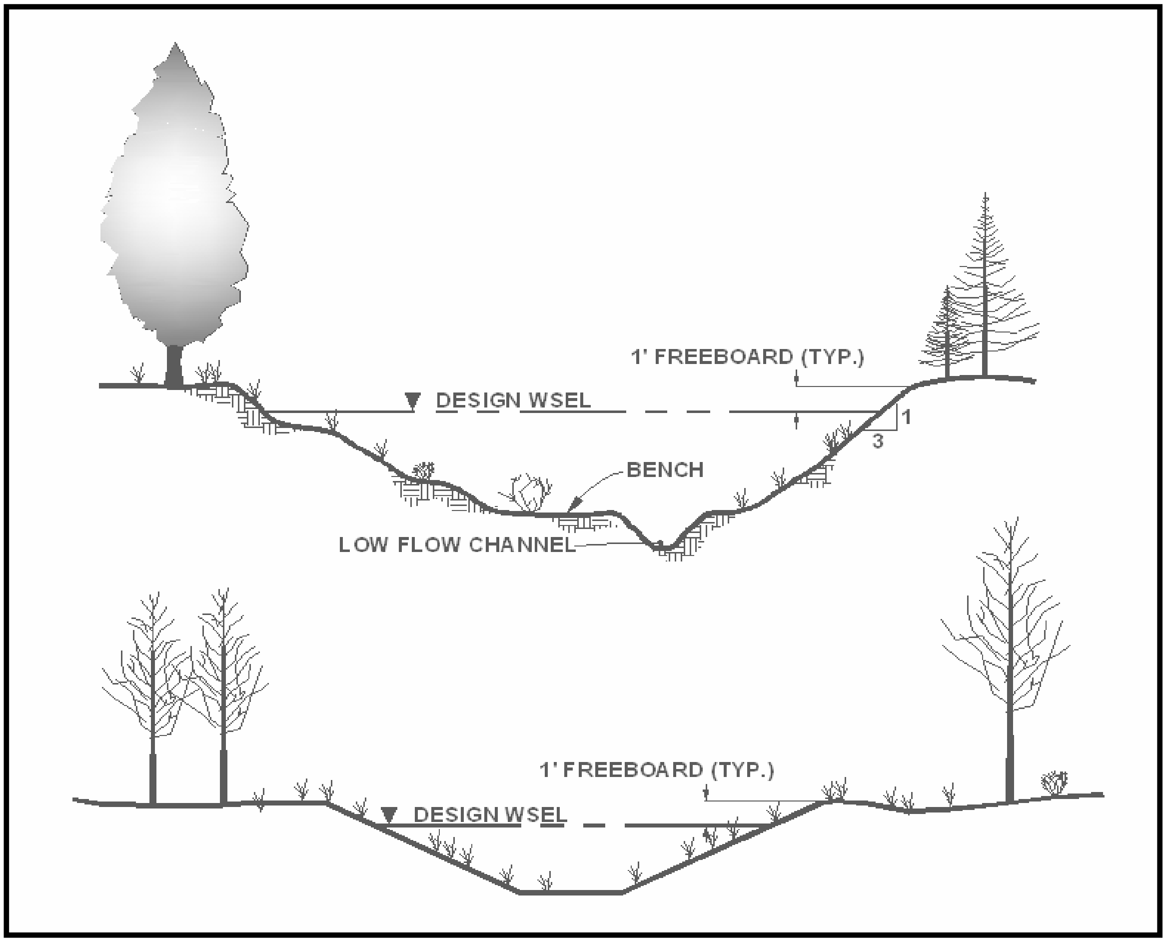
The design of open channel systems, particularly for development sites utilizing better site design, is an integral part of an overall drainage plan. An open channel is defined as a conveyance in which water flows with a free surface. Open channels can be either natural or artificial. Natural channels 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.

1. Open channels shall be designed to follow natural drainage alignments whenever possible.
2. 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.
3. 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.
4. 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.
5. Trapezoidal cross sections are preferred over triangular shapes for artificial channel designs.
6. The design of artificial channels shall consider the frequency and type of maintenance required and allow for access of maintenance equipment.
7. For vegetative channels, flow velocities within the channel should not exceed the maximum permissible velocities stated in Chapter 7.
8. Channel banks shall be left in a stabilized condition upon completion of the project. No actively eroding, bare or unstable banks shall remain unless the Director has determined there is no better alternative.
9. 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:

1. 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.
2. Riprap basins, stilling basins, or concrete energy dissipaters can be utilized to reduce high velocity outlet flows to within acceptable limits.

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.

1. Street drainage and roadways shall be designed so as to maintain the natural drainage patterns existing prior to development, whenever possible.
2. The street section shall be designed to convey local runoff only and shall not be used as major stormwater carriers for contributing watersheds.
3. 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.
4. 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.

5. 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.
6. 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.

2.6 Bridge Requirements

A bridge is defined as a structure that transports vehicular traffic over a watercourse or other obstruction, including the approach roadway over the floodplain and the relief openings. A bridge typically has a minimum span length of twenty (20) feet. Bridge hydraulics is very important in determining water surface profiles for use in flood studies, stream design, stream stability and scour evaluations. General design criteria for bridges are provided below. Design specifications are provided in greater detail in Volume 2, Chapter 7.

1. Bridge analysis, design and construction shall conform to the pertinent floodplain development regulations that are contained in the Knox County Stormwater Management Ordinance and the Knox County Flood Protection Ordinance.
2. The final design selection for any bridge shall consider the maximum backwater allowed by the Knox County floodplain regulations unless exceeding the limit can be justified by special hydraulic conditions. Backwater shall not increase flood damage to upstream property.
3. The final design shall not significantly alter the flow distribution in the floodplain and whenever possible, bridge structures should be designed so that there is little or no disturbance to the flow. Velocities through the structure shall not damage either the roadway facility or increase damages to adjacent property.
4. Degradation or aggregation of the watercourse as well as contraction and local scour shall be estimated, and appropriate positioning of the foundation, below the total scour depth if practicable, shall be included as part of the final design.
5. Bridges should be designed to minimize disruption of ecosystems and values unique to the floodplain and channel being crossed.

References

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Technology Acceptance and Reciprocity Partnership (TARP). *Protocol for Stormwater Best Management Practice Demonstrations*. 2001.

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