3.0 STORM DRAINAGE

3.1 INTRODUCTION

This chapter covers closed storm drainage systems including inlets, manholes, and storm drainpipes.

Storm drainage systems shall be designed using the City of Lincoln Standard Plans and Standard Specifications for Municipal Construction, Chapter 21. Such systems must be planned and properly engineered to provide for orderly urban growth, to reduce costs to the community, and to reduce/prevent loss of life and property damage.

Minor drainage systems are closed systems such as storm drains and related appurtenances such as inlets, curbs, and gutters. Minor drainage systems are designed for the 5-year and 10-year flood events (minor storms), depending upon the kind of land use and level of service of the street (street classification).

Note: For development projects, if downstream drainage facilities are not sized for the increased design flow from a development, a detention structure is required to reduce adverse impacts from flooding.

Major drainage systems are open systems such as streams, channels, and lakes. Streets are also considered part of the major drainage system and act as drainage systems during major storm events. Major drainage systems are designed for major storm events like the 50-year and 100-year flood events.

Note: Detention/retention ponds are critical elements in major drainage systems and are often necessary and required for development projects.

3.2 PAVEMENT DRAINAGE DESIGN FACTORS

This section relates to pavement design and how it relates to drainage. The major consideration for selecting a rainfall design frequency is roadway classification. Speed, hazards, and pedestrian traffic can also be taken into consideration.

3.2.1 Runoff Width (Spread) on Pavement

Allowable maximum encroachments are provided as follows:

- Allowable maximum encroachments for minor storms (**Table 3-1**)
- Allowable maximum encroachments for major storms (**Table 3-2**)
- Allowable cross-street flow (**Table 3-3**)

Storm drain inlets shall be located to avoid exceeding the maximum allowable encroachments for minor storm events (5-year and 10-year flood events, as appropriate). Street inundation shall not exceed maximum encroachment for the 100-year flood event.

3.2.2 Longitudinal Slope

Curb and gutter grades that are equal to pavement slopes shall not exceed 8 percent or fall below 1 percent without approval from the Director of Lincoln Transportation and Utilities. Flat gradients on uncurbed areas where vegetation can build up should be avoided as the increased vegetation will cause flow spread.

3.2.3 Cross Slope

Cross slopes are determined by the City's standard roadway sections. Standard pavement cross slopes for the City of Lincoln are 2.5 percent and 3.3 percent. See the City of Lincoln Standard Plans LSP 640 for cross slopes for different paving sections.

Drainage from medians should not cross travel lanes and median shoulders should generally be sloped to drain away from the pavement. Narrow raised medians are not subject to these provisions.

3.2.4 Curb and Gutter

All curb and gutter must be designed in accordance with current City of Lincoln Standard Plans LSP 640 and Standard Specifications for Municipal Construction, Chapter 4.

3.2.5 Roadside and Median Drainageways

Flow from large drainage areas that drain toward curbed highway pavements should be intercepted by channels and routed away from the highway pavement. Area tributaries and gutter sections on curbed highway sections should be kept to a minimum to reduce hazards from water on the pavement. Large median areas and inside roadway shoulders should be sloped to a center swale, preventing drainage from the median area from running across the pavement. This is critical for high-speed roadways and for roadways with more than two lanes of traffic in each direction.

3.2.6 Bridge Decks

Gutter flow from roadways should be intercepted and diverted before it reaches bridge decks. Providing and maintaining adequate bridge deck drainage systems is difficult because cross slopes are flatter, parapets collect large amounts of debris, and small drainage inlets on bridge-deck scuppers have a higher potential for being clogged by debris. Scuppers are recommended for deck drainage to reduce the problems of transporting a relatively large concentration of runoff in an area with a limited right-of-way. However, when traffic under the bridge or environmental concerns prevents the use of scuppers, grated bridge drains should be used. Drainage from bridge decks is to be designed to avoid erosion potential at abutments and/or under the bridge.

3.2.7 Median/Barriers

The City prefers that the drainage be designed to collect water into a subsurface drainage system connected to the main storm drain to minimize flow across traveled lanes.

3.2.8 Gutter Flows

This derivation of Manning's equation should be used to evaluate gutter flow hydraulics:

Equation 3.1 $$Q = [0.56 / n]\, S_x^{5/3} S^{1/2} T^{8/3}$$

Q = gutter flow rate (cfs)

n = Manning's roughness coefficient

S_x = pavement cross slope (ft/ft)

S = longitudinal slope (ft/ft)

T = width of flow or spread (ft)

Standard pavement cross slopes for the City of Lincoln are 2.5 percent and 3.3 percent. See City of Lincoln Standard Plans 640 for cross slopes for different paving sections.

Typical Manning's *n* for gutters is shown in **Table 3-4.**

3.3 STORM DRAIN INLETS

3.3.1 Introduction

The main purpose of storm drain inlets is to capture and divert or channel water from the roadway and allow traffic to proceed. Storm drain inlets are placed at such points and at such intervals, for the appropriate design frequency, to intercept flows and control the spread of water flowing along the gutters or ponding at the sags. Storm drain design uses the Rational method formula (See Chapter 2).

Stormwater inlets are located to limit the depth or spread of water on traffic lanes to the allowable limit for the storm event they have been design for. Storm drain inlets at vertical curve sags in the roadway grade should be located to limit the spread to allowable limits.

Storm drain inlets should be located so that concentrated flow and heavy sheet flow will not cross traffic lanes and will be located just upgrade of pedestrian crossings and locations where the pavement slope reverses.

There are two classifications of storm drain inlets. A continuous grade storm drain inlet allows water from the street to enter from only one direction. A sump storm drain inlet is located at a low point in the street and allows water to enter from both directions.

Grate drain inlets are used to drain paved or unpaved surfaces. Grate inlets consists of an opening that is covered by one or more grates. They are not to be used on the public street system without approval of the Director. If grate inlets are approved and allowed, the grates will be designed to safely accommodate bicycle and pedestrian traffic as appropriate. Curb-opening inlets have vertical openings within the curb and are covered by a top slab.

3.3.2 Storm Drain Inlet Design Criteria

The design frequency for residential land use is the 5-year flood event. The design frequency for commercial or industrial land use, and for arterial roads is the 10-year flood event. If the land use is residential and other areas down gradient are of commercial or industrial use or are an arterial roadway that receives runoff from these areas, the design frequency will use the 10-year flood event.

The public street system will use 72-inch straight, canted, or armored inlets. Grate inlets are not to be used on the public street system but may be used for parking lot drains or area drains.

Flow in the gutter for the minor storm event should not exceed 5 inches in the first inlet and each subsequent inlet. Inlets should be placed at the low points in the street grade and at the upper end of all storm drain lines. Inlets should also be placed at the ends of radii and/or before crosswalks at intersections. If inlets are needed at locations other than at intersections, they shall be centered between lot lines. Multiple inlets may be necessary at some locations to pick up the contributing flow. Canted inlets shall not be placed along intersection radii, unless approved by the Director.

Concrete valley gutters may be used across roadways at intersections of local roadways if the calculated depth of flow for the minor storm system design flow in the curb and gutter section immediately upstream is less than 5 inches and if there is no existing or proposed storm drain conduit extended to the intersection. Pavement cross slope on the uphill lane of the minor storm system approach shall be reduced at a gradual rate from 3 percent to 1 percent to allow drainage of the uphill gutter flow line through the return. Valley gutters shall not be used across collector or arterial roadways.

Curb and gutter grades shall not exceed 8 percent or be less than 1 percent without approval from the Director. Inlets need to intercept flow before major arterial crossings and roundabouts. Contributing flow shall be based on the contributing area without attenuation, except for that provided by approved detention systems. See the City of Lincoln Standard Plans 640 for additional details.

At street slopes of 2 percent or less, it is recommended to use straight inlets because the efficiency of using canted inlets diminishes with flatter street slopes and the canted inlets have decreased life cycle costs because of vehicles running up against them (e.g., snowplows).

Armored inlets shall be used along commercial, industrial, and arterial roads.

3.3.3 Manholes

Manholes will be installed at the upper end of all storm drain lines and at all changes in grade, drain line size, or drain alignment. The maximum spacing allowed between manholes/inlets is 600 feet for storm drain lines that are 36 inches in diameter or less. Any greater spacing between manholes/inlets requires approval by the Director.

Laterals from a storm drain inlet to the main storm drain line may be tapped directly into the main storm drain line if the diameter of the lateral does not exceed one-half of the diameter of the pipe being tapped and the main storm drain is 36 inches in diameter or larger. If the diameter of the lateral exceeds one-half the diameter of the pipe being tapped, a storm drain manhole or inlet will be required. If the diameter of the main storm drain line is less than 36 inches, a manhole or inlet will be required.

The crowns of all storm drainpipes entering and leaving a junction shall be placed at the same elevation and the crowns of the lateral pipe shall match the crown of the main storm drainpipe. Construction must be in accordance with current City of Lincoln Standard Plans 141 and 142 and Standard Specifications for Municipal Construction, Chapter 21.

3.3.4 Grate Inlets

Grate inlets are not to be used on the public street system without the approval of the Director. Inlet capacity depends on the geometry and cross slope, the longitudinal slope, the total flow, the depth of flow, and pavement roughness. The interception capacity of the grate depends on the depth of water next to the curb.

- Note: Grates less than 2 feet long have low interception rates
- For grate inlet efficiency data, see the Hydraulic Engineering Circular No. 22 (FHA 2009) materials by grate manufacturers, or standard software

3.3.5 Curb Inlets

The curb inlet capacity for sump conditions is controlled by two flow conditions: weir flow and orifice flow. The equations for these two conditions are shown below:

Equation 3.2 $Q_w = 3.0\ Pd^{1.5}$ **(weir flow)**

Q_w = weir capacity (cfs)

P = perimeter (ft)

d = depth (ft)

Equation 3.3 $Q_o = 0.67\ A\ (2gd)^{0.5}$ **(orifice flow)**

Q_o = orifice capacity (cfs)

A = area (ft^2)

g = acceleration of gravity (32.2 ft/s^2)

d = depth (ft)

The curb inlet intersection capacity on a grade is the amount of flow intercepted by an inlet and is based on the cross slope, longitudinal slope, total gutter flow, and pavement roughness.

Equation 3.4 $Q_i = Q_g\ (1\text{-}(1\text{-}(E_L/(k\ Q_g^{0.42}\ S^{0.3}))\ (n\ S_e)^{0.6})^{1.8})$ **(FHA, Circular 22)**

Q_i = inlet capacity (cfs)

Q_g = flow in the gutter (cfs)

E_L = effective length of inlet (ft)

K = 0.6

s = pavement slope (ft/ft)

n = Manning's roughness coefficient

S_e = composite slope of cross-section (ft/ft)

Table 3-5 and **Table 3-6** present spreadsheets for designing inlets and pipe sizing, respectively. **Table 3-5** is for inlet design and **Table 3-6** is for pipe sizing.

3.4 STORM DRAIN SYSTEMS

3.4.1 Introduction

After the location and sizing of inlets has been determined based on the contributing drainage area for this part of the project, the rate of discharge for each section of pipe must be computed to determine the size and gradient of pipe needed to carry the discharge. Calculations should start at the most upstream inlet and proceed downstream as pipe size and gradient needs may change. Discharge rates are generally less than the sum of the inlet design discharge rates of all inlets above that section of pipe, which ensures that the full pipe capacity is used but will not be placed under pressure head. As the time of concentration grows larger, the rainfall intensity should be revised accordingly. As the time of concentration grows larger, the proper rainfall intensity to be used in the design grows smaller. Use Manning's equation for capacity calculations.

3.4.2 Design Criteria

When designing storm drain systems, certain design criteria must be adhered to. Maximum hydraulic gradients shall not produce a flow velocity exceeding 15 feet per second at the outlet. The hydraulic gradient shall not cause flooding or flows to exit the system at unacceptable locations. To determine the proper elevation along the HGL, keep the HGL 0.75 foot below the intake lip of any affected inlet, any manhole cover, or any entering nonpressurized system. Ensure the energy grade line shall not rise above the intake lip of any affected inlet, any manhole cover, or any entering nonpressurized system. Velocities of flow will not be less than 3.0 feet per second at design flow, and the minimum slope shall not be less than 0.5 percent. Shallow flow lines should be designed so that flow velocities will increase progressively throughout the length of the pipe system.

The location and alignment of storm drain systems is more than just aesthetic. For new subdivisions, the center of the street shall be used, which is reserved for the storm drain system. For older or developed areas, the location of the storm drain system is to be determined by the Lincoln Transportation and Utilities Department. Preference is for the center of the street, but this may not be possible or feasible in all cases.

No structures may be located over a public storm drain system or drainage easement. There shall be no vertical curves, horizontal curves, or abrupt changes in alignment. Changes in slope must be done via manhole or inlet. There are some exceptions to the no vertical and horizontal curves criteria. Horizontal curves can also be used on curved streets to stay in the center of the street. Horizontal curves can be used at the upstream end of the drainage system to allow the storm drain to curve horizontally from the upstream inlet to the center of the street.

Horizontal curves can also be used at the outfall of the drainage system to allow the storm drain to curve horizontally to provide for better pipe alignment at the outfall so that discharge is in the direction of the downstream channel flow.

Broken back storm drain systems can be used at discharge points into open drainages on a case-by-case basis if they are designed to reduce energy, if they are approved by the Director, and if they follow general guidelines. Vertical deflections must use the City of Lincoln Standard Specifications, Chapter 21 and a reinforced concrete elbow (see Lincoln Standard Plan 150). Storm drainpipes need to be accessible and have a diameter of 42 inches or greater wherever vertical deflections are allowed. Any break in pipe must occur within a short distance of the outfall and no double broken back pipes will be allowed. Any request for a broken back drain system must be submitted along with calculations, demonstrating the need for energy dissipation for approval by the Director. Atypical situations may be permitted if they are approved by the Director, with the understanding that all storm drains are still required to meet the minimum allowable pipe deflection angle of the pipe manufacturer.

Drainage system design criteria prefer to run drainage systems along the center of the street; however, this is not always possible. Drainage systems are to be offset from the center of the street to avoid street monuments. These offsets will avoid wheel tracks and be less than 5 feet off the center of the street. Drainage systems may be offset to meet separation requirements from existing or proposed watermains. These storm drainpipes may run diagonally at intersections so they can be routed in a more efficient manner from inlet to inlet.

- This is allowed only at the upper end of the storm drains system for pipes with diameters of 24 inches or less, and only if the length of storm drainpipe run is 150 feet or less.

The depth of cover protects pipelines from environmental scour, freeze/thaw cycles, and is governed by local, state, and federal regulations. Depth of cover should be 2 to 3 feet, with 1.5 feet being the minimum at inlet locations. For new construction, the minimum depth of cover shall be the pavement thickness plus the depth of subgrade preparation, but not less than 1.5 feet. Depth of cover depth should be no greater than 3 feet to avoid any conflicts with sanitary sewer service lines connecting to main sanitary sewer lines.

Reinforced concrete storm drainpipes must conform to City of Lincoln Standard Specifications, Chapter 21. Any exceptions must be approved by the Director.

Open pipe inlets from an open drainageway into a closed pipe storm drain shall be designed and constructed with flared end sections and with a bar grate and must conform to City of Lincoln Standard Plan 161 (bar grate for flared end section). No bar grates on the end section of pipe outlets entering into an open channel are permitted unless approved by the Director.

Maintenance should be notified of any bar grates that are installed as they create a potential blockage point in the future.

Taps are permitted only if the storm drainpipe that are tapping into is 36 inches in diameter or larger and if the pipe being tapped into is twice the diameter of the incoming storm drainpipe or larger. The Maintenance Operating Division of the Lincoln Transportation and Utilities Department must be informed prior to any tap installation and must inspect the work. A right-of-way permit is required if the work is in a public right-of-way. Lincoln Transportation and Utilities Department approval is required if the work is outside public right-of-way.

In case of conflicts with other utilities (i.e., water and wastewater lines), Ten-State Standards should be followed.

3.4.3 Design Procedures

Design procedures require the submission of supporting documentation with all development plans. Once the inlet location and spacing has been determined, the plan layout can be prepared. The plan layout should include the location of storm drains, the direction of flow, the location of manholes and the location of existing facilities such as water, wastewater, gas, or underground cables. Drainage areas are determined by computing runoff using the Rational method and by computing hydraulic capacity using Manning's equation (**Equation 3.5**). The preliminary system design computations shall be summarized and HGL computations shall be completed to ensure they meet the design criteria in this section.

3.4.4 Capacity

Storm drain capacity for drainage systems, including reinforced concrete pipe and open channels, can be determined using Manning's equation as expressed by the following equation:

Equation 3.5 $Q = [1.486\ A\ R^{2/3}\ S^{1/2}]/n$

V = rate of flow (cfs)

A = cross-sectional area of flow (ft^2)

R = hydraulic radius (ft), where $R = A/W_p$

W_p = Wetted perimeter (ft)

S = slope of HGL (ft/ft)

n = Manning's roughness coefficient

Street rights-of-way and overland swales convey the portion of the runoff that exceeds pipe capacity (i.e., rainfall events above the design event for minor systems). Pipe capacities plus street conveyance need to be calculated to ensure that the major system can handle up to the 100-year rainfall event within the right-of-way without damaging public or private property, or infrastructure and that injury or loss of life is prevented. Street right-of-way or overland swale capacity is determined using Manning's equation for open channel flow conditions:

Equation 3.6 **$Q = K S^{1/2}$**

$K = 1.486/n \; A \; R^{2/3}$

<u>For residential</u>	<u>For overland swales</u>
$A = 21.662\ ft^2$	$A = 22.5\ ft^2$
$R = 0.360$ ft	$R = 0.149$ ft
$n = 0.026$	$n = 0.032$

Q = Flow, S = Slope, K = Constant

The following information gives the conveyance constants (K) for residential, commercial, and major two-lane streets and a 30-foot-wide swale with 10:1 side slopes:

Residential, K = 620

Commercial with parking, K = 970

Commercial without parking, K = 790

Major two-lane street, K = 1,100

30-foot swale, K = 780

The above conveyance constant K assumes for residential areas that $A = 21.662\ ft^2$, R = 0.360 ft and weighted n = 0.026, and for overland swales that $A = 22.5\ ft^2$, R = 0.149 ft and n = 0.32.

Table 3-1. Allowable Maximum Encroachment for Minor Storms.

Street Classification	Maximum Encroachment
Local	No curb overtopping (5 in)
Collector	No curb overtopping (5 in)
Arterial	No curb overtopping (5 in). Flow spread must leave at least one lane free of water in each direction.

Table 3-2. Allowable Maximum Encroachment for Major Storms.

Street Classification	Maximum Encroachment
Local and Collector	The depth of water over the gutter flowline shall not exceed the right-of-way width.
Arterial	The depth of water at the street crown shall not exceed 6 inches.

Table 3-3. Allowable Cross Street Flow.

Street Classification	Minor Storm Design Runoff	Major Storm Design Runoff
Local	Flow equivalent to 5 inches in depth in upstream curb and gutter system.	Depth of water over the gutter flowline shall not exceed the right-of way width.
Collector	Where cross pans are allowed, depth of flow shall not exceed 6 inches.	Depth of water over the gutter flowline shall not exceed the right-of-way width.
Arterial	None	The depth of water at the street crown shall not exceed 6 inches.

Table 3-4. Manning's *n* Values for Street and Pavement Gutters.

Type of Gutter or Pavement	Range of Manning's *n*	
Concrete gutter:	Troweled finish	0.012
Asphalt pavement:	Smooth texture	0.013
	Rough texture	0.016
Concrete gutter with asphalt pavement:	Smooth	0.013
	Rough	0.015
Concrete pavement:	Float finish	0.014
	Broom finish	0.016

Note: For gutters with small slopes (i.e., less than or equal to 1 percent) where sediment may accumulate, increase above values of n to 0.020.

Table 3-5. Inlet Design.

INLET DESIGN													
Q=CIA Minor Storm Return Frequency ______													
Location	**Area, A**	**Runoff Coefficient, C**	**Time of Concentration, T_c**	**Intensity, I**	**Runoff, Q**	**Bypassed, Q_b**	**Cross over, Qc**	**Total Flow, Q**	**Paving Slope, S**	**Depth-of-Curb Flow**	**Inlet Type**	**Intercepted, Q_i**	**Bypassed, Q_b**
	acres	constant	minutes	inches/ hour	cfs	cfs	cfs	cfs	ft/ft	inches		cfs	cfs

Table 3-6. Pipe Sizing.

Preliminary pipe sizing calculations will consist of a table with both minor and major storm system conveyance analysis:

Minor storm system analysis includes the following:

Minor storm return frequency of a 5- or 10-year frequency as appropriate.

Column 1:	Location
Column 2:	Area, A (acres)
Column 3:	Coefficient, C (constant)
Column 4:	A C column 2 x column 3
Column 5:	Sum of A C
Column 6:	Time of Concentration, T_c (minutes)
Column 7:	Intensity, I (inches/hour) Rainfall Intensity (see Chapter 2.4.2)
Column 8:	Runoff, Qr (cfs) Qr = CIA
Column 9:	Pipe Slope, S (ft/ft)
Column 10:	Pipe Length, L (feet)
Column 11:	Pipe Diameter, D (inches)
Column 12:	Pipe Capacity, Qp (cfs) Manning’s equation (see Chapter 3.4.4)
Column 13:	Pipe Velocity, Vp (ft/sec) Vp = Qp/A
Column 14:	Time in Section, Tp (minutes) L/(60 Vp)

Major storm return frequency for 100-year event:

Column 15:	Intensity, I (inches/hour for 100-year event) Rainfall Intensity (see Chapter 2.4.2)
Column 16:	Flow, Q (cfs for 100-year event) $Q_{100} = C\ I_{100}\ A$
Column 17:	Overflow Route Slope, S_{ov} (ft/ft)
Column 18:	Street/Overland Swale Width, W_{st} (feet)
Column 19:	Street/Overland Swale Capacity, Q_{st} (cfs) Street Right-of-Way and Overland Swale Capacity, (see Chapter 3.4.4)
Column 20:	Overflow plus Pipe Capacity, Q (cfs) Column 12 x column 20
Column 21:	Comments section (typically downstream outlet location)