Chapter 3 - System Planning

Storm drainage is an integral component in highway and transportation networks. Drainage design for highway facilities strives to maintain compatibility and minimize interference with existing drainage patterns, control flooding of the roadway surface for design flood events, and minimize potential environmental impacts from highway-related stormwater runoff. To meet these goals, the planning and coordination of storm drainage systems begins in the early planning phases of transportation projects. Conducted before beginning design, successful system planning produces a final system design that evolves smoothly through the preliminary and final design stages of a transportation project.

3.1 Design Objectives

Highway storm drainage design aims to provide for safe and reliable passage of vehicles during the design storm event. The drainage system collects stormwater runoff from the roadway surface and right-of-way (ROW), conveys it along and through the ROW, and discharges it to an adequate receiving water body without causing adverse on- or off-site impacts.

Traffic safety relates directly to surface drainage. Rapid removal of stormwater from the pavement minimizes the conditions which can result in the hazards of hydroplaning. Surface drainage is a function of the hydrology, transverse and longitudinal pavement slope, pavement roughness and voids, inlet spacing, and inlet capacity.

Stormwater conveyance systems (storm drain piping, ditches, channels, pumps, etc.) provide an efficient mechanism for conveying design flows from inlet locations to the discharge point without surcharging inlets or otherwise causing surface flooding. Designers also consider erosion potential in the design of open channels and ditches used for stormwater conveyance.

Water collected from and conveyed through the roadway corridor discharges offsite to receiving waters or to other storm drainage systems. Federal, State, and local regulations often guide the quality and quantity of the discharge. (Chapter 2 describes certain relevant Federal statutes and regulations.) To meet these regulatory requirements, storm drainage systems often rely on detention or retention basins and other best management practices (BMPs) for the control of discharge quantity and quality.

3.2 Minor versus Major Systems

A complete storm drainage system design includes consideration of both minor and major drainage systems. This manual focuses on the minor system, which consists of the components typically considered part of the “storm drainage system.” Some designers refer to the minor system as the “convenience” or “primary” system. These components include curbs, gutters, ditches, inlets, access holes, pipes and other conduits, open channels, pumps, detention basins, water quality control facilities, etc. The minor system is typically designed to carry runoff from an intermediate design storm event such as the 0.1 annual exceedance probability (AEP) (10-year return period) event.

The major system provides natural or constructed overland relief for stormwater flows exceeding the capacity of the minor system and may be intentionally designed or unintentional. Some designers refer to the major system as the “secondary” system. The major system usually carries stormwater during larger, more infrequent storm events, such as the 0.04, 0.02, and 0.01 AEP storms. The major system provides pathways for runoff to flow to natural or constructed receiving channels such as streets, streams, creeks, rivers, and ditches. The designer considers (at least in a general sense) the flow pathways and related depths and velocities of the major system under less frequent or check storm conditions.

Typically, design effort focuses on components of the minor system. However, when infrastructure owners and designers also consider the functioning of the major storm drainage system, they can provide more resilient transportation infrastructure and associated drainage features when storms exceeding the design magnitude for the minor system inevitably occur. This is especially relevant today as the FHWA and others seek to ensure the transportation network is resilient and reliable for all users despite the risk associated with a changing climate. (USDOT 2021).

3.3 Design Approach

Storm drainage system design evolves as a part of the highway design process. Figure 3.1 summarizes the primary activities of the process: data collection, agency coordination, concept development, concept refinement and design, and final design documentation. The first two activities continue throughout the design process. The next three activities represent progressively comprehensive stages of the design process: concept development, hydrologic and hydraulic (H&H) design, and final design.

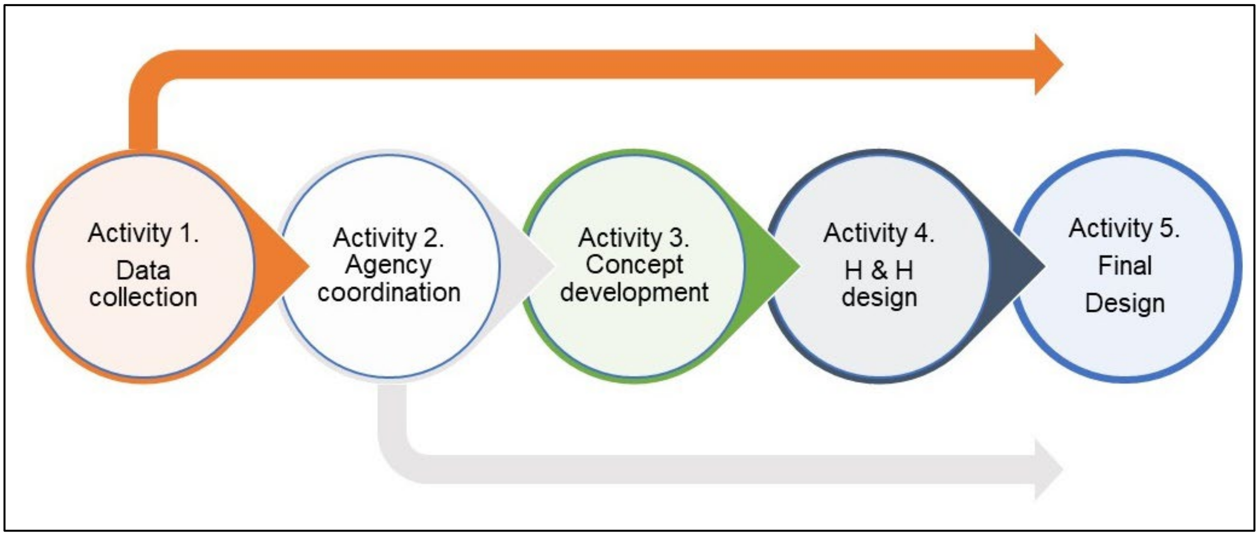

Figure 3.1. Drainage design process overview.

3.3.1 Data Collection

Initial data collection involves assembling and reviewing technical data and background information pertinent to the design. As the design progresses, the designer collects additional data needed for subsequent steps.

The design of storm drainage systems accumulates certain basic data discussed in the following paragraphs. The type of project, project drainage needs, and potential project risks inform the types and extent of supporting information needed.

- Watershed maps: These identify topographic features, watershed boundaries, existing drainage patterns, and ground cover. These maps are typically available from U.S. Geological Survey (USGS), local river authorities, drainage districts, or other planning agencies maps, field surveys, or aerial photography.
- Land use maps: These identify existing and potential future land uses. They are typically available from the internet and local zoning or planning agencies.

- Soils maps: These identify soil types and hydrologic soil groups. They are available in county soil surveys available online and from local U.S. Natural Resources Conservation Service (NRCS) offices.
- Flood histories and high-water marks: These may be available from local offices of the USGS, National Weather Service (NWS), Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers (USACE), local planning agencies, river authorities, and drainage districts. Residents or Department of Transportation (DOT) regional or district maintenance offices may also be able to provide this information.
- Descriptions of existing drainage facilities: These includes size, shape, material, invert information, age, condition, etc. As-built information for existing drainage facilities may be available from the local facility owner. If unavailable, the DOT can perform field surveys to obtain this information.
- Design and performance data for existing drainage systems: These may be available from the facility owner. If unavailable for the existing system, the designer can develop the needed information to determine how the existing system will function under the new loading.
- Utility plans and descriptions: These may be available from the utility owner. If unavailable, the DOT can perform field surveys to determine critical design information.
- Existing right-of-way information: These may be available from the appropriate highway agency ROW office or local tax maps.
- Federal, State, and local regulatory requirements: Typical regulatory authorities include USACE, U.S. Environmental Protection Agency (USEPA), State environmental regulatory agencies, and local governments. (Chapter 2 describes Federal statutes and regulations.)

3.3.2 Agency Coordination

Agency coordination includes consultation with regulatory agencies and other stakeholders and continues through the design process. Before designing a storm drainage system, it is good practice to coordinate with regulatory agencies or others that have interests in drainage matters. Regulatory agency involvement may come from any level of government (Federal, State, or local). These agencies are generally concerned with potential impacts resulting from highway drainage, and center on stormwater quantity and quality issues. Chapter 2 discusses the Federal regulatory context.

Others with interests in storm drainage systems include local municipalities and developers. Local municipalities may wish to use portions of the system to provide for new or better drainage, or to augment old municipal drainage systems. Local municipalities may be interested in developing cooperative projects where a mutual economic benefit may exist. Local municipalities may also be aware of proposed private development in the vicinity of the road project which may affect drainage design. These groups may wish to improve or change drainage patterns, redirect stormwater to the ROW, or propose joint projects which could affect the highway storm drainage system. Early planning and coordination help identify and facilitate cooperative projects that are beneficial to both the transportation agency and other stakeholders.

The concerns of local community members, for example, about drainage facility impacts on their home or business, are also important. Community member concerns typically include impacts of roadway interruption and redirection of existing drainage patterns, the potential for flow concentration and increased flooding, and water quality impacts to both surface water and groundwater. Local government entities and the public hearing process usually facilitate communication and coordination with local community members.

3.3.3 Concept Plan Development

A concept plan typically provides a preliminary layout for the proposed storm drainage system identifying the basic components of the intended design superimposed on a project base map. The base map identifies the watershed areas and subareas, land use and cover types, soil types, existing drainage patterns, and other topographic features. Underground utility locations (and elevations if available), a preliminary roadway plan and profile, and locations of existing and proposed structures supplement this base information.

The concept plan illustrates how stormwater will be collected, conveyed, and discharged through both the minor and major systems. The designer may include preliminary sizes of significant drainage features. The basic components in the concept plan generally include:

- Elements of the major drainage system.
- Outfalls for the minor drainage system.
- Primary underground pipes and surface channels and ditches.
- Inlets.
- Stormwater quantity controls.
- Stormwater quality BMPs.

As a part of the development of the conceptual storm drainage plan, designers consider several additional issues. Whenever possible, designers avoid deep cuts and utilities. Designers address maintenance of traffic and construction related impacts and, in some cases, provide temporary drainage and traffic bypasses and other traffic control related activities. Designers also consider construction sequencing as it relates to the constructability of laterals and storm mains. Some instances may dictate a trunk line on both sides of the roadway with very few laterals, while other instances may call for a single trunk line.

3.3.4 Hydrologic and Hydraulic (H&H) Design

Once the concept is approved, the drainage designer refines the H&H aspects of the design. Design changes in the overall project development process, including input from regulatory and review agencies, result in the need for system refinement. This stage generally proceeds in the following sequence:

1. Compute runoff parameters and quantities based on the concept layout (see Chapter 4).
2. Estimate pavement drainage conditions (see Chapter 5) and roadside and median channel conditions (see Chapter 6).
3. Refine inlet location and spacing (see Chapter 7).
4. Refine the storm drain system layout including access holes, connecting mains, outfall control structures, and any other system components (see Chapters 8 and 9).
5. Size pipes, channels, pump stations, discharge control structures, and other storm drain system components.
6. Compute and review the hydraulic grade line (see Chapter 9).
7. Revise plan and recompute design parameters, as necessary.

3.3.5 Final Design

The final design includes preparation of final design documentation and construction plans. The sponsoring agency or the applicable local or State DOT Drainage Design Manual typically describes final design documentation requirements, which can vary with project type and scope. The AASHTO Drainage Manual (AASHTO 2014) provides a general description of design documentation.

3.4 Stormwater Drainage System Components

Minor storm drainage systems collect stormwater runoff from the roadway surface and ROW, convey it along and through the ROW, and discharge it to a receiving body without causing adverse on- or off-site environmental impacts. Major storm drainage systems provide flood conveyance and discharge for floods exceeding minor storm system capacity. As described in Section 3.2, this function is typically provided by streets, surface swales, ditches, streams, and other flow conduits to provide a relief mechanism and flow path for flood waters. The following sections describe the components of the minor storm drainage system.

3.4.1 Collection

Collection components, including gutters, ditches, and inlets, concentrate water on the roadway or bridge and move it away from the traveled way. Roadside and median ditches intercept runoff and carry it to a storm drain or channel. Ditch design considers not only hydraulic capacity but also safety for vehicles that may leave the roadway. If necessary, the design provides channel linings to control erosion in ditches.

Gutters intercept pavement runoff and carry it along the roadway edge to an adequate storm drain inlet. Designers install curbs in combination with gutters where runoff from the pavement surface would erode fill slopes or where ROW requirements or topographic conditions will not permit the development of roadside ditches. Urban settings typically use curbed pavement sections. Some other areas use gutters without curbs.

Drainage inlets receive surface water collected in ditches and gutters and serve as the mechanism for surface water to enter storm drains. Along the edge of the roadway, designers size and locate storm drain inlets to limit the spread of surface water onto travel lanes. Inlets may be grated, curbed, slotted, etc.

Roadway geometry and the ability to control the spread of water on the roadway surface determine the location of drainage inlets. Generally, placing inlets at low points in the gutter grade, intersections, crosswalks, cross-slope reversals, and on side streets prevents the water from flowing onto the main road. Additionally, placing inlets up-gradient of bridges prevents drainage onto bridge decks; placing inlets down-gradient of bridges prevents the flow of water from the bridge onto the roadway surface. Chapter 7 discusses inlet design.

3.4.2 Conveyance

Upon reaching the main storm drainage system, storm drains connected by access holes or other structures convey stormwater along and through the ROW to its discharge point. Storm drains receive runoff from inlets and convey it to some point where it is discharged into a channel, waterbody, or other piped system. Storm drains can be closed conduit or open channel; they consist of one or more pipes or conveyance channels connecting two or more inlets.

Access holes, junction boxes, and inlets serve as access structures and alignment control points in storm drainage systems. Access structure spacing and storm drain deflection are critical design parameters related to these structures. Maintenance tasks often dictate spacing limits. In addition, these structures are located at the intersections of two or more storm drains, when there is a change in the pipe size, and at changes in alignment (horizontal or vertical). Chapter 9 describes the design of storm drains.

Where gravity drainage is impossible or not economically justifiable, designers can use stormwater pump stations. For example, stormwater pump stations may be the only alternative for draining depressed roadway sections. Chapter 12 introduces the design of stormwater pumping stations.

3.4.3 Discharge Controls

Prior to discharging stormwater offsite or to receiving waters, designers may need to employ discharge controls to reduce the quantity (peak or volume) and improve the quality of discharge. For example, such controls may be required by Federal and state laws including Federal laws described in Chapter 2 such as the Clean Water Act. Detention and retention facilities control the quantity of runoff discharged to receiving waters. Runoff quantity can be reduced by storing runoff in detention/retention basins, storm drainage pipes, swales and channels, or other storage facilities. Outlet controls on these facilities reduce the rate of stormwater discharge. These controls can be useful where existing downstream receiving channels are inadequate to handle peak flow rates from the highway project, where highway development would contribute to increased peak flow rates and aggravate downstream flooding problems, or as a technique to reduce the size and associated cost of outfalls from highway storm drainage facilities. Chapter 10 discusses the analysis and design of detention and retention facilities.

Water quality controls improve the quality of stormwater discharges from highway storm drainage systems and mitigate potential impacts on receiving waters. They include extended detention ponds, wet ponds, infiltration trenches, infiltration basins, porous pavements, sand filters, water quality inlets, vegetative practices, erosion control practices, and wetlands. Water quality constituents typically associated with highway runoff include suspended solids, heavy metals, nutrients, and organics. Chapter 11 describes tools and methods for analyzing urban stormwater quality.