MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 11

Drainage and Irrigation Design

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Contents

Chapter 11

Drainage and Irrigation Design

Chapter 11 presents principles and criteria for the design and consideration of drainage facilities in collaboration with the roadway design; including:

- culverts,
- special-purpose large culverts,
- storm drains,
- roadside drainage,
- miscellaneous drainage facilities,
- irrigation facilities, and
- encasement pipes.

For detailed hydraulic design methods and policies, the *MDT Hydraulics Manual* is available at the following link on the MDT website and should be referenced in conjunction with the information in this chapter.

MDT Hydraulics Manual

The MDT Permanent Erosion and Sediment Control (PESC) Design Guidelines should also be referenced for an understanding of erosion control measures required with the design and implementation of drainage facilities. This manual is available at the following link on the MDT website.

The *MDT Permanent Erosion and Sediment Control Best Management Practices Manual* provides additional information on erosion control, primarily with regard to temporary conditions.

MDT Permanent Erosion and Sediment Control (PESC) Design Guidelines

Drainage design details are provided in the *MDT Detailed Drawings*, which are provided at the following link on the MDT website:

MDT Detailed Drawings

11.1 DESIGN PRINCIPLES AND APPROACH

Extensive coordination with the MDT Hydraulics Section should occur throughout the drainage design process.

Drainage facilities carry water across the right-of-way and remove stormwater from the roadway. Drainage facilities include bridges, culverts, channels, curbs, gutters, inlets, and various types of drains.

Drainage design is an integral component in the design of roadways and must be closely coordinated with other roadway design elements. There are many aspects that fall under the general category of drainage design. This chapter focuses heavily on design requirements and considerations in relation to culverts but also addresses a number of other drainage topics to be accounted for by the design team.

Live loads are the weight of an object (most commonly a vehicle) passing over a pipe. Earth loads are the weight of the material resting on top of the pipe.

Pipes may be fabricated out of many different types of material, and each of these materials presents different structural properties in response to both live loads and earth loads. The hydraulics designer will provide information for the different pipe material options, including wall thickness, size of corrugations, and class of concrete for all culverts. It is MDT's practice to specify alternate or optional pipe materials where they can be used, with the basic bid item for optional pipe being steel.

Stormwater collection and conveyance occurs primarily through the use of storm drains and roadside drainage facilities. The detailed design of storm drains is prepared by the hydraulics designer. However, the design team is responsible for calculating the quantity of trunk line, granular bedding, and length of lateral lines and for checking for adequate cover over storm drain facilities. The storm drain design is an iterative process between Roadway Design Section and the hydraulics designer to establish a storm drain system that functions with the road grades, cross slopes, flow lines, and American with Disabilities Act (ADA) features.

For roadside drainage, the design team must ensure roadside drainage features are designed and constructed with consideration to the potential consequences of run-off-the-road vehicles. Refer to Chapter 9, Section 9.3.5 for detailed discussion on the design and safety considerations of roadside drainage features. Skewed pipes require special attention as the inside corners have the potential to be a roadside hazard.

Irrigation facilities must also be considered in the roadway design. Whenever possible, the design team should strive to locate longitudinal irrigation ditches outside of the right-of-way. The design team must coordinate with the hydraulics designer for all design details related to irrigation facilities.

This chapter also discusses several special-purpose large culverts and miscellaneous drainage features used for certain drainage design situations such as vehicular underpasses, stockpasses, and wildlife crossings. Additionally, coordination with the hydraulics designer may be required for special designs such as ditch blocks, interceptor ditches and dikes, streambank protection, detention basins, and retention basins.

11.2 CULVERTS

Nearly all drainage and irrigation facilities involve the use of some type of culvert. Culvert design requires a determination of:

- pipe material,
- design service life,
- pipe size and shape,
- pipe length,

- structural and installation requirements,
- pipe end treatments,
- pipe inlet and outlet edge protection, and
- pipe bedding/foundation.

11.2.1 Pipe Material

Pipes may be fabricated from concrete, steel, smooth steel casing (jacked and bored), aluminum, or plastic material. Pipe material selection will be based on an evaluation of the project location's soil and water corrosive characteristics. The hydraulics designer will provide recommendations for the different pipe material options including wall thickness, size of corrugations, coating, and class of concrete for all culverts.

11.2.1.1 Common Pipe Materials

The pipe materials listed in Exhibit 11-1 are commonly used by MDT. Pipe material selection for mainline culvert crossings, approach culverts, irrigation facilities, and storm drains is based on design criteria such as service life, site conditions, and its intended use. The pipe materials in Exhibit 11-1 are not intended to be all inclusive; therefore, a proper engineering analysis is required for all installations. For large installations, the analysis should include installation cost comparisons.

Exhibit 11-1
Pipe Materials

Pipe Material	Abbreviation	MDT Specification
Corrugated Steel Pipe*	CSP	709.02
Corrugated Steel Pipe Arch*	CSPA	709.02
Structural Steel Plate Pipe	SSPP	709.03
Structural Steel Plate Pipe Arch	SSPPA	709.03
Reinforced Concrete Pipe	RCP	708.01.2
Reinforced Concrete Pipe Arch	RCPA	708.01.3
Reinforced Concrete Box	RCB	Standard Special Provision 603-3
Corrugated Aluminum Pipe	CAP	709.07
Steel Casing Pipe	SCP	709.01.2 & Special Provision 603-1
Corrugated Polyethylene Pipe	HDPE	708.07
Solid Wall Polyethylene Pipe	HDPE	708.08.2
Large Diameter PVC Pipe (18”-48”)	PVC	708.05.3
Profile Wall PVC Pipe (4”–36”)	PVC	708.05.4
PSM PVC Pipe (15” or Less)	PVC	708.05.2
PVC Pressurized Pipe	PVC	708.06

* Acceptable coatings:	-Type II Aluminized	AASHTO M274	MDT 709.12
	-Pre-Coated Polymeric	AASHTO M245	MDT 709.05

For reconstruction projects where existing pipes can be used in place and require lengthening, the additional length of pipe usually will be constructed of the same material as the existing pipe. Pipes to be lengthened will be identified in the hydraulics designer recommendations.

11.2.1.2 Optional Pipe Materials (Basic Bid Item)

The hydraulic engineer determines which pipe materials are acceptable for each project based on service life, fill height, etc. The acceptable pipe materials are shown in the plans as optional pipe. During construction, the contractor may select which option to use.

The basic bid item for optional pipe is steel. If steel pipe is not an option in the design, then reinforced concrete pipe (RCP) will be the basic bid item. Only the basic bid items are shown in the plans and cross sections. The allowable optional pipe materials for the project are listed in the culvert summary frame.

11.2.1.3 Alternative/Optional Pipe Materials

Alternate bids will be used when the area of the opening is greater than a 10-ft diameter round pipe and the use of both materials is appropriate. Alternate bids can be provided for small structures if the design team elects to do so. All alternate bid items are shown in the plans, summaries, and cross sections. The hydraulic engineer will determine and document which materials are appropriate for a project.

11.2.2 Design Service Life

The hydraulics designer will use service life criteria in the Hydraulics Manual to determine the allowable pipe materials and the required wall thickness, type of coating, and any special requirements for new pipes.

For specific design service life criteria, see Section 11.6 of the MDT Hydraulics Manual "Pipe Material Selection & Structural Requirements".

11.2.3 Pipe Size

The minimum pipe size for new mainline drainage pipes is 24" in diameter. The minimum pipe size for irrigation pipes is 18" in diameter. Equivalent arch pipes may be used. If an approach pipe also carries irrigation water the hydraulics designer will determine the appropriate pipe size.

Pipes located underneath public road approaches must be at least 24" in diameter, while pipes located underneath private approaches and farm field approaches must be at least 18" in diameter. The hydraulics designer will provide the pipe sizes for approach culverts that convey significant flows, and the road design team will provide approach pipes at all other locations where necessary.

Locate the entire road approach pipe, including the end treatments, outside the clear zone where practical. Flared End Treatment Sections (FETS) will be provided for all approach culverts located outside the clear zone. Where it is not practical to place approach culverts outside the clear zone, specify the 6:1 Road Approach Culvert End Treatment Section (RACETS).

Occasionally, pipes may need to be oversized to account for environmental needs such as Aquatic Organism Passage (AOP), wildlife, or stock crossings based on the specific location. See Section 11.3 for discussion on special-purpose large culverts.

The hydraulics designer will provide pipe size and material type recommendations for all mainline drainage and irrigation crossings. The design team will design all culvert inlet, outlet ditches, and ensure roadside ditches maintain positive drainage. The design team should keep in mind that many pipes, especially larger diameter pipes, are typically embedded below the flowline.

11.2.4 Pipe Length

FETS = Flared End Terminal Section

RACETS = Road Approach Culvert End Treatment Section

Safety End Section = Used on mainline culverts greater than 30" in diameter that cannot be extended beyond the clear zone.

The design team determines pipe length by measuring along the pipe flowline and including any end treatments. If the pipe installation is perpendicular or skewed less than 5 degrees to the roadway centerline, then the pipe length may be scaled directly from the roadway cross section. If the pipe is skewed more than 5 degrees, scale its length along the skewed line.

When end sections are specified (such as FETS, RACETS, step bevel or beveled ends), measure the pipe length, including the end sections, along the pipe flowline. Additional pipe length is not required for the end sections. However, if the end treatment is square to the skewed pipe, the pipe must be extended beyond the toe of the slope, and additional pipe length is required to ensure the fill slope catches at the inside corner of the concrete edge protection. Chapter 13 provides additional information on measuring and quantifying pipe lengths.

11.2.5 Structural Requirements for Pipes

Fill Height Tables are located in MDT Hydraulics Manual Chapter 11, Appendix A.

Pipes have different structural capabilities depending on the pipe size, both in terms of diameter and material thickness. In general, the smaller diameter the pipe and/or the thicker the pipe material the more load the pipe can withstand. The design team must be aware of these properties to ensure the fill heights fall within the maximum and minimum allowable ranges for the pipe material and size specified. See Section 11.6.3 of the MDT Hydraulics Manual for information on measuring fill heights and structural features of pipe material types.

11.2.6 Multiple Pipe Installations

It may be necessary to install two or more adjacent culverts at one location to provide adequate conveyance. Multiple pipe installations are identified as a "double" or a "triple" installation at the station representing the center of the installation. Typically, a single pipe crossing is preferred to multiple pipe installations.

The hydraulic designer will specify the spacing between culverts and the detail for the plans.

11.2.7 Culvert End Treatments

See the *MDT Detailed Drawings* for the standard culvert end treatments.

Pipe end treatments exist along the roadside and may result in a roadside hazard if not properly located and designed. The proper type of end treatment varies depending on the pipe size, shape, material, and orientation to the roadway. Inlet and outlet protection may also be specified at pipe ends to prevent erosion and maintain the integrity of the pipe and roadway.

Exhibit 11-2 provides criteria for determining the proper end treatments for cross drain structures based upon pipe type and size. These end treatment criteria apply to both single- and multiple-pipe installations. Refer to Chapter 9 of the Road Design Manual and Chapter 11 of the Hydraulics Manual for detailed information on the proper use and installation of culvert end treatments in relation to roadside safety best practices.

Exhibit 11-2
Culvert End Treatment Determination

Pipe Type and Size	End Treatment	Cutoff Walls	Inlet/Outlet Concrete Edge Protection
RCP ≤ 48"	FETS	No	No
RCP ≥ 54”	FETS	Yes	No
RCPA ≥ 65" x 40"	FETS	Yes	No
CMP ≤ 48”	FETS	No	No
CMP ≥ 54"	Step Bevel①	Yes	Yes
CSPA or SSPPA ≥ 54"	Bevel①	Yes	Yes
SCP ≤ 48”	FETS	No	No
SCP ≥ 54"	Square	Yes	Yes

CMP = Corrugated Metal Pipe (CSP or CAP)

FETS = Flared End Terminal Section

Notes:

① Type of bevel will be identified on the plans and culvert summary frame (e.g., 2:1 step bevel, 2:1 bevel).

② In special situations, square ends may be specified by the hydraulics designer. For square ends on culverts ≤ 48” or equivalent, the culvert length should be extended 2 feet beyond the toe of the fill slope. For square ends on culverts ≥ 54” or equivalent, add cutoff walls and concrete edge protection to the inlet and outlet.

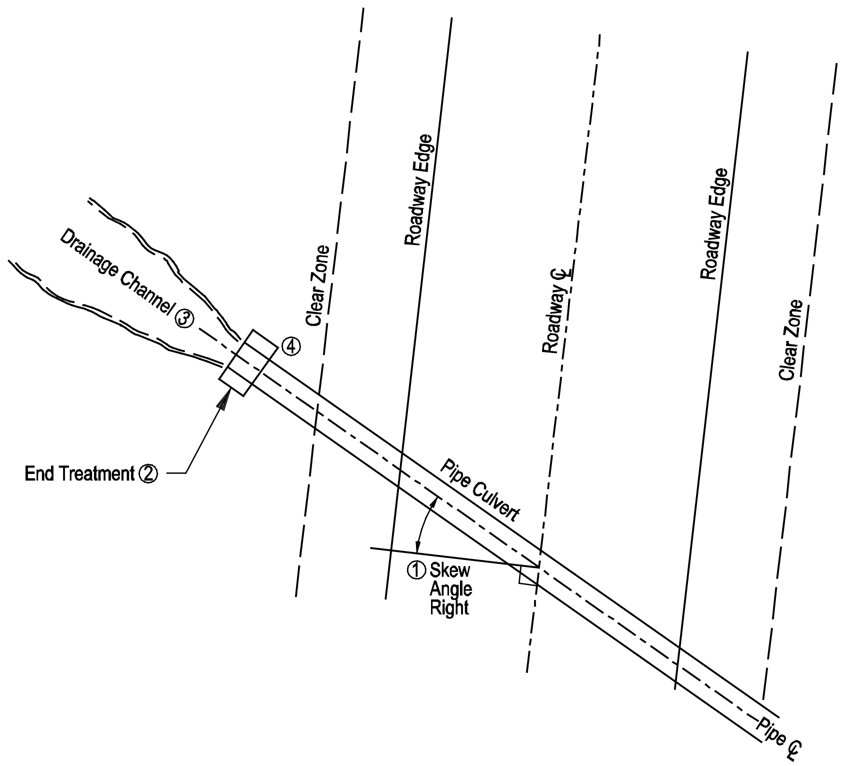
11.2.7.1 Skewed Pipe Installations

Concrete pipes are not beveled or skew-beveled.

The skew is defined as the angle measured left or right from a line which is perpendicular to the roadway centerline. See Exhibit 11-3 for a general illustration of pipe skew in relation to the roadway orientation.

See Section 11.4.6.1 of the MDT Hydraulics Manual for additional information on pipe skew.

Exhibit 11-3
Pipe Skew



① A skew angle right is one where the pipe centerline is to the right of a line extended perpendicular from the roadway centerline. A skew angle left is one where the pipe centerline is to the left of a line extended perpendicular from the roadway centerline.

Avoid skew angles greater than 35 degrees.

② End treatments for all single concrete pipe and corrugated steel pipe installations with diameters 48” or less will be installed perpendicular to the centerline of the pipe regardless of pipe skew, unless specified otherwise by the hydraulics designer.

The following will apply to installations of corrugated steel and structural steel plate pipe diameters 54” or greater:

- For skew angles 0° to 15°, the end treatment should be perpendicular to the centerline of the pipe.
- For skew angles 16° to 35° and fill height 10 feet or less, the end treatment should generally be skew-beveled. The design team should verify this with the hydraulics designer.
- For skew angles 16° to 35° and fill height greater than 10 feet, the end treatment should generally be perpendicular to the centerline of the pipe and the fill warped to the pipe ends. The design team should verify this with the hydraulics designer.
- Avoid skew angles greater than 15° for structural steel plate pipe culverts.

③ Consider channel realignment changes where appropriate, with consideration of potential environmental impacts, to limit pipe skew.

④ The pipe should be extended so that the near corner of the edge protection catches the fill slope beyond the clear zone.

11.2.7.2 Inlet and Outlet Edge Protection

The hydraulic characteristics of some drainage channels may require special protection for the roadway embankment at the inlets and outlets of pipe installations. The hydraulics designer will provide design information for special features.

If skew-bevels are used, concrete edge protection is required to strengthen the top arch on the pipe inlet and outlet. Bolting should follow the *MDT Detailed Drawings*.

If a culvert requiring edge protection is skewed, the design team should design the edge protection to match the roadway inslope and extend the culvert sufficiently to be adequately protected by the edge treatment.

For metal pipes 48″ or less in diameter, it is not necessary to provide special protection unless the hydraulics designer provides specific recommendations to do so. For metal pipes 54″ or larger in diameter, provide the protective measures described in the *MDT Detailed Drawings*, as applicable:

- Cutoff walls at both ends, and
- Concrete edge protection at inlet and outlet.

See the *MDT Detailed Drawings* and *MDT Hydraulics Standard Drawings* for estimated quantities for cutoff walls and inlet and outlet edge protection.

Concrete pipes 54″ or larger in diameter with FETS require cutoff walls at both ends. Concrete edge protection should not be used unless specified by the hydraulics designer. Riprap edge protection should not be used in conjunction with the standard end treatment for concrete pipe unless specified by the hydraulics designer.

11.2.8 Pipe Bedding/Foundation

Bedding is required for all pipe installations per the *MDT Detailed Drawings*. For pipes 48″ in diameter or less, bedding is paid for within the cost of the pipe and does not need to be shown in the culvert summary. For pipes 54″ or larger in diameter, granular bedding must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

When foundation material is specified, it will be placed below the granular bedding or bedding material. Foundation material must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

11.2.9 Riprap

The hydraulics designer will typically design embankment protection, outlet aprons, and other features requiring riprap. The hydraulics designer will work with the design team to calculate quantities and provide the necessary details. Show the riprap on the plans and cross sections and include the quantities in the appropriate summary.

The layout and quantities of riprap at bridge ends will be coordinated between the design team, the hydraulics designer, and the Bridge Bureau. Riprap will be shown on both the plan and profile, and the quantities will be included in the appropriate summary. Riprap details may need to be included in the plan set. Geotextile will be provided with all riprap installations unless otherwise specified.

11.2.10 Metal Culvert Extensions

Re-lay means to reinstall the existing culvert end treatment rather than installing a new end treatment.

The following will apply for metal culvert extensions:

- The hydraulics designer will evaluate the remaining service life of the pipe to determine if it should be extended or replaced. This determination is generally based on the condition of the in-place pipes.
- The length of extension includes the new end treatment section, unless the existing section will be removed and re-laid. Note this in the culvert summary.
- The design team is responsible for determining the length of pipe extensions. The hydraulics designer may recommend new end treatments on a case-by-case basis.
- If the existing pipe is a metric size, the diameter will be converted to US Customary units and rounded to the nearest inch (e.g., 600mm = 24 inches). The pipe extensions will be called out using the available US Customary size for the pipe.
- The thickness of the extension pipe should match the existing pipe thickness (e.g., a 0.064″ thick pipe extension should not be connected to an existing pipe that is 0.079″ thick).
- When the material or configuration of the existing pipe cannot be matched, a concrete collar will be needed to connect the extension to the existing pipe. Metal bands can be used to connect CSP to SSPP where the connection is beyond the edge of the surfacing section. This connection will require a special detail, and a CSP Verification special provision will typically be included, requiring the contractor to verify the existing CSP pipe dimensions prior to lengthening.
- Fill height for pipe extensions will be measured at the point of connection to the existing pipe unless otherwise specified.

11.2.11 Reinforced Concrete Pipe Extensions

The required minimum length of extension for reinforced concrete pipe is as follows (length is measured from the end of the existing pipe barrel minus the existing end treatment or any damaged pipe sections.):

- Diameter ≤ 30″: 10 feet, including 4 feet of new pipe and a 6-foot standard terminal section.
- 30″ < Diameter ≤ 72″: 12 feet, including 4 feet of new pipe and an 8-foot standard terminal section.
- Diameter > 72″: Contact the hydraulics designer.

- If extension of the barrel is not required, a FETS can be added without any additional length of pipe.
- Fill height for pipe extensions should be measured at the point of connection to the existing pipe.
- Connection to the existing RCP pipe can be made by matching the existing RCP joint, utilizing an RCP Adapter Ring in accordance with the *MDT Detailed Drawings,* or a Field Cast Concrete Connection in accordance with the *MDT Detailed Drawings*.

11.2.12 Culvert Cleaning

It may be desirable to include cleaning of existing culverts with design projects. The following guidelines should be followed to determine and document whether a culvert is eligible for cleaning on projects involving Federal-aid funds:

These guidelines on culvert cleaning apply only to projects involving Federal-aid funds.

- Except in special cases, such as difficult to reach culverts, only culverts larger than 48″ are eligible to be cleaned with Federal-aid funds. All culverts larger than 48″ will be evaluated for cleaning on a case-by-case basis. The decision should be based on the size, location, severity of the problem, and whether specialized equipment would be needed. If culvert cleaning will be addressed by a project, include the culvert locations in the plans and a cleaning special provision.
- Culvert cleaning should not normally be included in preventative maintenance projects such as pavement preservation projects.
- A list of smaller culverts (48″ and smaller), not eligible but in need of cleaning, can be sent to the appropriate MDT Maintenance Division to schedule cleaning activities.

11.2.13 Abandonment of Culverts

If the decision is made to abandon a culvert in place, rather than remove the culvert, three methods are allowed for the abandonment.

Abandon. This should be used when a culvert is either filled with silt or is shown in the as-built plans but cannot be found. It should be noted in the plans, and since it does not require any additional work, no pay item is provided.

Plug Ends and Abandon. This should be used when a culvert is being abandoned but is small enough and in deep enough fill that it does not need to be filled throughout its length. The culvert will be filled for a distance of 10 feet from each end and the culvert ends will need to be capped to prevent material from infiltrating the abandoned culvert. Crushing the ends is an acceptable means of capping culverts.

Use the Plug Ends and Abandon treatment when both of the following criteria exist:

- The culvert diameter is 36” or less, and
- The culvert has at least 15 feet of cover.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be plugged and abandoned.

Fill and Abandon. Culverts must be filled and abandoned when they do not meet the criteria for Plug Ends and Abandon. As a general practice, fill and abandon all storm drains that are not removed.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be filled and abandoned.

11.3 SPECIAL-PURPOSE LARGE CULVERTS

Coordinate with the Right-of-Way Bureau for stockpass and vehicular underpass requirements.

Large culverts frequently may be used for purposes other than to accommodate drainage. They may serve as stockpasses, wildlife underpasses, vehicular underpasses with surfacing, or pedestrian/bicycle underpasses. The following criteria present guidance for special-purpose large culverts.

11.3.1 Stockpasses

Record stockpass culverts in a separate summary frame. Include associated paving in the additional surfacing frame.

A standard metal pipe may be designed to serve as a stockpass by using the treatment shown in the *MDT Detailed Drawings*. It should be specified only when justified by right-of-way negotiations. The primary purpose of this structure is to serve as a stockpass. However, stockpasses may also act as cross drains. Where possible, stockpasses should be separated from drainages and the stockpass invert elevation should be set to avoid water flow. Adjacent, lower-elevation culverts may also be provided for drainage when necessary. The design team should attempt to minimize the stockpass length whenever practical. A perpendicular crossing is preferred; however, if a skew is necessary, it should not exceed 15°.

The same bedding and fill height requirements for drainage culverts also apply to stockpasses. The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.2 Wildlife Underpasses

The location and size of the culvert should be coordinated with the Environmental Resources Section.

Wildlife underpasses are intended to provide connectivity across highways while reducing collisions between vehicles and animals. The size and structure type will vary in accordance with the size and type of animal species to be accommodated and potentially by the crossing length. When a culvert is used, it is typically sunk and backfilled with natural soil and used in conjunction with wildlife exclusionary fencing. The design team should coordinate with the hydraulics designer as the culvert will often function as both a wildlife crossing and a drainage culvert.

11.3.3 Vehicular Underpasses

Specify a circular structural steel plate pipe vehicular underpass unless directed otherwise by the Hydraulics or Geotechnical Sections. Construction personnel and the design team should review the installation for special construction requirements when staged construction is specified. Granular bedding material should be specified for all large culverts.

The *MDT Detailed Drawings* show the backfill retainer and cutoff wall requirements as well as the floor surfacing criteria for the underpass. The concrete collar shown in the *MDT Detailed Drawings* will be provided for vehicular underpasses.

The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.4 Pedestrian/Bicycle Underpasses

Pedestrian and bicycle underpasses are typically designed using a 10′ x 10′ equivalent opening. These structures may include lighting, special grouting, or paving to meet ADA guidelines. All pedestrian and bicycle underpasses should be ADA-compliant up to and through the underpass from both directions. A curb to direct drainage/snowmelt around the top of the pipe should be considered.

11.4 STORM DRAINS

The detailed design of storm drains will be prepared by the hydraulics designer. The design will include the size, type, and location of the trunk line, manholes, lateral lines, and drop inlets. Refer to the *MDT Detailed Drawings* for storm drain trench and bedding details.

MDT Hydraulics Manual Chapter 14 Storm Drain Systems has additional information on storm drain design.

The design team will coordinate with the hydraulics designer to establish the locations and finished grade elevations at manholes and drop inlets, ensure that the trunk line and laterals have adequate cover, and identify conflicts with in-place utilities. The hydraulics designer will coordinate with the Utilities Section regarding utilities crossing the proposed storm drain. A SUE Phase II survey may be required to identify and avoid utility conflicts.

11.4.1 Storm Drain Inlets

The hydraulics designer will recommend the types and locations of storm drain inlets. Details for storm drain inlets are provided in the *MDT Detailed Drawings*. The roadway designer will verify the inlet locations are located at low points of sag curves and will also check the inlet locations for conflicts with curb ramps, in-place utilities, approaches, or other features. This is an iterative process and will require coordination with the Hydraulics and Utilities Sections.

A SUE Phase II survey involves identifying and locating underground utilities via evacuation of material to determine and record the utility depths and invert elevations.

11.4.2 Manholes

The size and location of manholes will be specified by the hydraulics designer. The roadway designer will check the locations for conflicts with in-place utilities. Existing manholes can be adjusted up to a maximum of one foot through the use of adjusting rings to match new grades. All manholes requiring adjustment should be identified on the plans with notes added identifying specific items required by owners (e.g., concrete collars). Manholes that have been previously adjusted, need to be lowered, or requiring adjustments greater than one foot will require additional investigation and may result in substantial modification or replacement.

11.4.3 Curb Bulb-Outs

Where curb bulb-outs are used on urban routes with curb and gutter sections, the design team should check bulb-out locations and gutter grades to determine if the bulb-outs will block the gutter flow or interfere with storm drain inlets. The hydraulics designer will determine if existing storm drain inlets should be relocated or if new inlets or other drainage features are required to maintain roadway drainage.

11.5 ROADSIDE DRAINAGE

Effective roadside drainage is one of the most critical elements in the design of a roadway. Drainage features should be designed and constructed considering the potential consequences of run-off-the-road vehicles. See Chapter 9, Section 9.3.5 for additional safety considerations and information on roadside drainage features.

Additional information on maintenance of Existing Drainage Features can be found in the *MDT PESC Design Guidelines*.

The design team should also strive to minimize interference with existing roadside drainage patterns to the extent possible. Care should be taken to maintain existing drainage patterns throughout the project and to tie into existing ditches at the project ends. If the redirection of existing flows is unavoidable, this should be discussed with the hydraulics designer, and careful attention and consideration should be given to the impacts the redirection may have on adjacent properties, flooding, and erosion.

In some cases, the existing condition intermixes roadside drainage and irrigation water and, on occasion, both may utilize the same pipes and ditches. Where practical, MDT prefers to separate the drainage and irrigation water and to move irrigation ditches and structures to outside of the right-of-way.

Under some circumstances, it is difficult or infeasible to separate the irrigation and drainage. Separating roadside drainage and irrigation may not be feasible after years of current operational patterns, and/or the additional right-of-way requirements necessary for separation may be prohibitive. If unable to separate the irrigation and drainage, replicate the existing conditions to the extent practical. Whenever the roadside ditch is used for any irrigation purpose, the design team should coordinate with the hydraulics designer.

Hydraulically designed ditches are discussed further in MDT Hydraulics Manual Chapter 10 Channel Design.

MDT does not typically perform a hydraulic design for standard roadside ditches except for erosion protection; however, a hydraulic design should be considered for the following:

- Roadside ditches that collect significant drainage,
- Storm drain outlet channels (for riprap design and drainage),
- Relocated/realigned stream channels, and
- Lined ditches and chutes.

11.5.1 Cut Sections

Roadside ditches generally use a 10-foot, 20:1-bottom configuration, and the grade of roadside ditches typically matches the profile grade of the roadway. However, more detailed ditch design needs to be considered for the following situations:

- Ditches on sustained grades may carry relatively high volumes of runoff that can result in erosion to the ditch and the cut-to-fill transition. When sustained grades are encountered, the design team needs to consider the use of erosion control features discussed in the *MDT PESC Design Guidelines.*
- Extremely flat ditches also need additional design. Separate ditch grades need to be considered for 50 feet on each side of the crest if the grades along the curve are 0.30-percent or less. Separate ditch grades may also be necessary along a superelevated section where the profile grade is 0.5-percent or less.

11.5.2 Fill Sections

Drainage considerations in fill sections generally involve the following features:

- The location of minimum size (24”) culverts is often overlooked. The design team should review as-built plans to determine the location of existing culverts. When a project involves modification to the existing vertical alignment, the design team must also review the new profile grade to ensure that cross drains are provided in low spots where water would otherwise be trapped.
- Many older sections of roadway were constructed using side borrow, which resulted in substantial roadside ditches adjacent to the roadway embankment. New, wider roadway templates often fill these ditches, leaving no clear drainage path and often pushing runoff onto adjacent landowners. The design team should review these areas to ensure drainage is conveyed at the toe of the slopes. Additional ditch grading or cross drains may alleviate the problem. Construction of a drainage ditch at the toe of fill may be needed to convey runoff to a natural drainage.

Design teams also need to conduct on-site reviews (Alignment and Grade, Plan-In-Hand) to determine the location of minor natural drainages.

11.6 MISCELLANEOUS DRAINAGE FACILITIES

11.6.1 Embankment Protectors

Embankment protectors, as shown in the *MDT Detailed Drawings*, should be installed at the corners of bridges and on high fills to control runoff unless their elimination can be justified (e.g., corners on the high side of a superelevated cross section). When the installation of embankment protectors is impractical (e.g., an embankment protector pipe would be located where it may become plugged with sediment, debris, or ice), the use of drain chutes may be considered, however, for stability, riprap drain chute slopes must be 4:1 or flatter. Do not install embankment protectors for bridges having rail configurations without curb (e.g., T101 rail)

Where drainage flows toward the structure, place embankment protectors as near to the structure as practical. On long, continuous sections of high fill, locate embankment protectors based on spread width calculated by the hydraulics designer.

11.6.2 Drainage Chutes

The drainage chutes described in the *MDT Detailed Drawings* may be used for backslope protection where the backslope intercepts a natural drainage coulee or where embankment protectors are not practical.

11.6.3 Median Inlets

Three types of median inlets are available. Each type is shown in the *MDT Detailed Drawings.* The hydraulics designer will determine the type of inlet and spacing to be used. Specify the type clearly on the plans. Tables on the applicable *MDT Detailed Drawings* present estimated quantities of materials.

11.6.4 Underdrains

The Geotechnical Section should be consulted for all subsurface recommendations. Unusual subsurface water conditions frequently are encountered during field locations and soils surveys. Some form of underdrain will be recommended by the Geotechnical Section to alleviate such conditions.

For each underdrain, the details should clearly define the location, the type, the depth of placement, and the drain aggregate and geotextile to be installed with the pipe. Outlet designs and cleanouts should also be included. On urban projects with new or existing storm drains, it can be evaluated on a case-by-case basis whether the underdrains may outlet directly into drop inlets.

11.6.5 Sidewalk Drains

Sidewalk drains may be required to drain low areas behind the sidewalk or to perpetuate drainage across sidewalks from rain gutter down pipes. Sidewalk drains may also be used to perpetuate drainage through sidewalk bulb-outs.

11.6.6 Other Facilities

Coordination with the hydraulics designer may be required for special designs such as ditch blocks, interceptor ditches, streambank protection, and detention and retention basin design. The design team will review locations and ensure that the design details are included in the plans.

11.7 IRRIGATION FACILITIES

11.7.1 Irrigation Pipe

Irrigation facilities will require water-tight pipe. In the culvert summary and the culvert summary recap, record these pipes separately and identify them as "Irrigation" or "Siphon." The hydraulics designer will provide flowline and pipe invert elevations for all irrigation installations. These elevations are critical to effective operation of the irrigation system. Irrigation pipe material will be selected by the hydraulics designer.

11.7.2 Irrigation Siphon Pipe

Some irrigation pipes will be "siphons," where the pipes are angled down under the roadway ditches with the inlet and outlet elevations higher than the pipe under the roadway centerline. The hydraulics designer will design siphons and provide the Siphon Detail Sheet.

11.7.3 Division Boxes

The hydraulics designer will provide the design and details for concrete division boxes. Some types of division boxes are shown in the *MDT Detailed Drawings*.

11.7.4 Irrigation Ditch Relocations

The hydraulics designer will provide recommendations for ditch relocations and linings, if required. Relocate longitudinal irrigation ditches outside of the right-of-way line where feasible. To avoid irrigation ditch maintenance within the roadway right-of-way, irrigation pipes 30″ in diameter and less should be extended 24″ beyond the right-of-way line where practical. The right-of-way fence may be winged into the pipe ends for irrigation pipes larger than 30″ in diameter to minimize the cost of pipe extension.

11.7.5 Inlet and Outlet Headwalls

The hydraulics designer will provide recommendations and design details for concrete headwalls. Some headwall details are included in the *MDT Detailed Drawings*.

11.8 ENCASEMENT PIPES

The request for an encasement pipe generally comes in the form of a landowner request or possibly from a municipality for a future water or sanitary sewer line. The hydraulics designer will provide a recommendation on the encasement pipe location and material type. Section 11.4.11 of the MDT Hydraulics Manual has additional information on encasement pipes

11.9 REFERENCES

1. AASHTO. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing.* AASHTO, Washington, D.C., 2013.