3.3.2.6 The major drainage system shall be designed to convey runoff from the 100-year recurrence interval flood to minimize health and life hazards, damage to structures, and interruption to traffic and services and shall be designed to discharge to an acceptable outfall per these DENVER CRITERIA.

3.3.2.7 The major drainage system shall be designed and sized without accounting for peak flow reductions from onsite or offsite detention unless otherwise approved by Denver. In cases where permanently dedicated, publicly maintained detention facilities are in place, Denver will provide credit for flow reduction.

3.3.2.8 Storm runoff shall be determined by the Colorado Urban Hydrograph Procedure (CUHP) Method or the Rational Method, depending on the catchment size and complexity, as determined by the criteria provided in Table 6.1.

3.3.2.9 Streets are an integral part of the urban drainage system and may be used for drainage in accordance with the limitations identified in Tables 7.1 through 7.3 of these DENVER CRITERIA. Streets shall not be used for drainage in a manner that unduly restricts the primary purpose of streets, which is for traffic.

3.3.3 Operation and Maintenance of Drainage Facilities

3.3.3.1 Storm drainage facilities, including channels, flood detention and water quality facilities, storm sewers, and related appurtenances, require on-going maintenance and periodic repair and restoration to ensure proper functioning. Maintenance and access requirements shall be considered during the planning and design of these facilities. Maintenance requirements and access provisions shall be clearly defined in the drainage plan, storm sewer construction plan and site plan submittals. Easement widths should be based on maintenance access needs and overflow widths, if any.

3.3.3.2 The land owner is responsible for maintenance of private drainage facilities located on their land, unless the facilities are designated as public facilities and are within dedicated public easements.

3.3.3.3 Maintenance access shall be provided for all storm drainage facilities. Easements for adequate maintenance shall be as defined in Table 3.2.

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Table 3.2. Required Maintenance Easements for Drainage Facilities

Facility Type	Easement Width
Single Pipe	$W = B_c + 2H + 3$ where B_c = outside span of pipe in feet H = depth from top of pipe to final surface elevation in feet W = easement width, which shall be rounded to the next highest 5-foot increment with a minimum width of 20 feet.
Multiple Pipe Installation	Width calculated on a case-by-case basis
Open Channels and Swales	Q_{100} less than 20 cfs: 20 ft Q_{100} less than 100 cfs: 25 ft Q_{100} greater than 100 cfs: See DISTRICT MANUAL
Detention Basin	Width as required to contain storage, freeboard and associated facilities plus no less than 10 feet for maintenance access around the perimeter. When multiple lots are involved, a dedicated tract of land is required.

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3.3.3.4 Drainage easements shall be shown on the corrected plats, drainage plan, and storm sewer construction plan and state that Denver has the right of access on the easements, which shall be kept clear of obstructions restricting flow and/or maintenance access.

3.3.3.5 In order to be eligible for maintenance by UDFCD, all drainage facilities shall be designed and constructed in accordance with the most current version of the District Maintenance Eligibility Guidelines (downloadable from www.udfcd.org).

3.3.4 Irrigation Conveyance and Storage

The criteria below define the relationship between irrigation ditches and storm drainage and identify dam safety issues and restrictions associated with irrigation storage facilities.

3.3.4.1 Irrigation facilities such as ditches and reservoirs shall not be used as drainage facilities, except where the requirements of Sections 3.3.4.3 through 3.3.4.6 are met.

3.3.4.2 Irrigation ditches shall not be used as basin boundaries when evaluating the interaction of irrigation ditches with a major drainageway for the purpose of basin delineation. Drainage analysis shall assume that irrigation ditches do not intercept storm runoff from the upper basin and that the upper basin is tributary to the basin area downstream of the ditch. During major storms, ditches will generally be flowing full, near full or sometimes overflowing; therefore, the tributary basin runoff would flow across the ditch.

3.3.4.3 Development and redevelopment projects (as defined in Section 1.3) shall avoid discharging into irrigation canals and ditches, except as required by water rights, and shall instead direct runoff into historic and natural drainageways. As a general rule, the flat slopes,

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10.0 OPEN CHANNELS

10.1 Introduction

This chapter provides the minimum technical criteria for the hydraulic evaluation and design of open channels in Denver. In many instances, special design or evaluation techniques will be required. Design criteria in the Open Channels section of the MAJOR DRAINAGE chapter of the *Urban Storm Drainage Criteria Manual* (DISTRICT MANUAL) are hereby incorporated by reference. Except as modified herein, all open channel designs shall be in accordance with the DISTRICT MANUAL.

10.2 Channel Types

A variety of channel types occur in Denver. These include channels resulting from natural processes and artificial channels. Examples of natural channels include Bear Creek, the South Platte River, Cherry Creek and Sand Creek. Most natural channels within the older parts of Denver have been modified in the past. Artificial channels include large designated floodways, irrigation canals and flumes, roadside ditches, concrete or rock-lined channels, composite channels, bioengineered channels and grass-lined channels. An overview of channel types allowed in Denver under various conditions and associated design considerations is provided below, followed by specific design criteria in Section 10.4 through 10.6.

As previously discussed in Chapter 3, a major drainageway is defined as any drainage flow path with a tributary area of 130 acres or more. Minor drainageways convey flows from tributary areas less than 130 acres.

10.2.1 Natural Channels

If natural channels are to be used for carrying storm runoff from an urbanized area, the altered nature of the runoff peaks and volumes from urban development will inevitably cause erosion, which must be planned for and controlled based on detailed hydraulic analysis. Investigations necessary to assure that the natural channels will be adequate are different for every waterway. At a minimum, the engineer must prepare cross sections of the channel, define the water surface profile for the minor and major design flood, investigate the bed and bank material to determine erosion tendencies, and study the bank slope stability of the channel under future flow conditions. Supercritical flow does not normally occur in natural channels, but calculations must be made to assure that the results do not reflect supercritical flow. Typically, a variety of measures must be implemented to ensure channel stability that may include drop structures along with both hard (e.g., rip-rap, boulders) and soft (e.g., willows, revegetation, slope shaping) streambank stabilization measures. The natural floodplain along these channels should be preserved whenever practicable.

10.2.2 Grass-lined Channels

Denver requires grass-lined channels for major drainageways, except in cases of existing development where right-of-way (ROW) is restricted. Grass-lined channels provide many benefits such as channel

If extensive modification or disruption of existing areas is necessary, rehabilitate the channel corridor to conform to, or improve upon, predevelopment conditions. Channels should be natural-looking and/or be consistent with the surrounding land use. Techniques that can be used to achieve this goal include varying the slope and edge of channel, using river rock for riprap, replanting appropriately sized riparian vegetation, introducing meandering character on flat areas, and providing pools and rocks in steeper areas. A higher concentration of plant materials should be included where drainages intersect arterial streets, when feasible, to maintain and enhance visibility from roadways. The distance (buffer) on each side of any flowing or intermittent stream channel should be large enough to ensure its use for active and ecreation and as a visual amenity.

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To be eligible for UDFCD maintenance, the most current version of UDFCD's maintenance eligibility requirements (downloadable from www.udfcd.org) must be met.

10.6 Design Criteria for Channel Rundowns

A channel rundown is used to convey storm runoff from a higher elevation to a lower elevation (e.g., the bank of a channel to the invert of an open channel or drainageway). The purpose of the structure is to minimize channel bank erosion from concentrated overland flow. Denver's design criteria for channel rundowns are summarized in Table 10.1. See the Rundowns section of the HYDRAULIC STRUCTURES chapter of the DISTRICT MANUAL for rundown details and additional guidance for rundowns into storage facilities and wetland channels, as well as criteria for grouted riprap rundowns. An alternative to rundowns includes the use of storm sewers with drop manholes and low tailwater or impact basin energy dissipators at the outlet.

Table 10.1. Channel Rundown Design Criteria

Feature	Criteria
Cross Sections	Typical cross-sections for channel rundowns are presented in the HYDRAULIC STRUCTURES chapter of the DISTRICT MANUAL.
Design Flow	The channel rundown shall be designed to carry the full design flow or 1 cfs, whichever is greater.
Flow Depth	The maximum depth at the design flow shall be 12 inches. Due to the typical profile of a channel rundown beginning with a flat slope and then dropping steeply into the channel, the design depth shall be the critical depth for the design flow.
Outlet Configuration	The channel rundown outlet shall enter the drainageway at the trickle channel flow line. Erosion protection of the opposite channel bank shall be provided by a layer of B-24 grouted boulders in accordance with the MAJOR DRAINAGE chapter of the DISTRICT MANUAL. The width of this erosion protection shall be at least three times the channel rundown width or pipe diameter. Grouted boulder protection shall extend up the opposite bank to the minor storm flow depth in the drainageway or 2 feet, whichever is greater.
General	All designs must be in accordance with the DISTRICT MANUAL.

the tributary watershed. The designer should also be aware of the erosion potential created by constriction and poorly vegetated areas. An example is a bridge crossing over a grassed major drainage channel, where velocities increase as a result of the constriction created by the bridge, and bank cover is poor due to the inability of grass to grow in the shade of the bridge. In such a situation, structural stabilization, such as riprap, may be needed.

Another aspect of erosion control for major drainage channels is controlling erosion during and after construction of channel improvements. Construction of channel improvements during times in the year that are typically dryer can reduce the risk of erosion from storm runoff. Temporary stabilization measures including seeding and mulching and erosion controls such as installation and maintenance of silt fencing should be used during construction of major drainage improvements to minimize erosion.

3.2.7 Summary of Preliminary Design Guidance

Table MD-2 summarizes the guidance for the preliminary design of man-made channels discussed above. This guidance is for simple trapezoidal shapes to approximate alignment and geometry. Final design of man-made channels of a more complex nature will be discussed in Section 4.0.

Table MD-2—Trapezoidal Channel Design Guidance/Criteria

Design Item	Major Drainage Chapter Section	Criteria for Various Types of Channel Lining			
		Grass: Erosive Soils	Grass: Erosion Resistant Soils	Riprap	Concrete
Maximum 100-yr velocity	3.2.1	5.0 ft/sec	7.0 ft/sec	12.0 ft/sec	18.0 ft/sec
Minimum Manning's *n*—stability check	Table MD-3	0.03	0.03	0.03	0.011
Maximum Manning's *n*—capacity check	Table MD-3	0.035	0.035	0.04	0.013
Maximum Froude number	3.2.1	0.5	0.8	0.8	N/A
Maximum depth outside low-flow zone	3.2.2	5.0 ft	5.0 ft	n/a	N/A
Maximum channel longitudinal slope	3.2.3.1	0.6%	0.6%	1.0%	N/A
Maximum side slope	3.2.3.2	4H:1V	4H:1V	2.5H:1V	1.5H:1V [4]
Minimum centerline radius for a bend	3.2.4	2 x top width	2 x top width	2 x top width	2 x top width
Minimum freeboard [3]	3.2.5	1.0 ft [1]	1.0 ft [1]	2.0 ft [1]	2.0 ft [2]

[1] Suggested freeboard is 2.0 ft to the lowest adjacent habitable structure's lowest floor.

[2] For supercritical channels, use the freeboard recommended in Section 4.3.1.5 for final design.

[3] Add superelevation to the normal water surface to set freeboard at bends.

[4] Side slopes may be steeper if designed as a structurally reinforced wall to withstand soil and groundwater forces.

3.2.8 Maintenance Eligibility

The minimum design criteria requirements below must be satisfied as of June 2001 for a major drainage channel to be eligible for District maintenance assistance. Note that the District's *Maintenance Eligibility Guidelines* may change with time. The reader is directed to the District's Web site (www.UDFCD.org) for

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the latest version of the *Maintenance Elegibility Guidelines*.

3.2.8.1 Natural Channels (Open Floodplain Design)

When a developer chooses to stay out of the 100-year floodplain, the following requirements must be met:

1. If the total flow of the channel and floodplain is confined to an incised channel and erosion can be expected to endanger adjacent structures, 100-year check structures are required to control erosion and degradation of the channel area. See the HYDRAULIC STRUCTURES chapter of this *Manual* for more information. In addition, sufficient right-of-way shall be reserved to install the equivalent of a trapezoidal grass-lined channel that satisfies the velocity criteria specified in Table MD-2. Extra width shall be reserved where drop structures are needed, in which locations a 20-foot-wide maintenance access bench shall be provided along one side of the channel.

2. If the floodplain is wide and the low-flow channel represents a small portion of the floodplain area, low-flow check structures are usually required, unless it can be demonstrated that the channel will remain stable as the watershed urbanizes.

3. Consult the applicable Urban Drainage and Flood Control District's master plan document for guidance on the design event and stable steam or waterway longitudinal slope.

4. For either of the above cases, a maintenance access trail shall be provided. It should be designed according to the guidelines for grass-lined channels in Section 3.2.8.3, below.

3.2.8.2 Open Floodway Design (Natural Channel With Floodplain Encroachment)

Although floodplain preservation is preferable, when the design involves preserving the floodway while filling and building on the fringe area, the developer must meet the requirements in Section 3.2.8.1, and the fill slopes must be adequately protected against erosion with:

1. Fill slopes of 4H:1V or flatter that are vegetated according to the criteria in the REVEGETATION chapter.

2. Fill slopes protected by rock (not broken concrete or asphalt) riprap meeting District criteria with up to 2.5H:1V slopes.

3. Retaining walls, no taller than 3.5 feet, with adequate foundation protection.

3.2.8.3 Grass-Lined Channel Design

The design for a grass-lined channel must meet the following criteria to be eligible for District maintenance:

1. Side slopes should be 4H:1V or flatter.

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2. Continuous maintenance access, such as with a trail, must be provided. The stabilized trail surface must be at least 8 feet wide with a clear width of 12 feet. It shall be located above the minor event water surface elevation (usually 2- to 10-year event, as directed by local government), but never less than 2-feet (3-feet for streams with perennial flow). Trail profiles need to be shown for all critical facilities such as roadway crossings, stream crossings and drop structures. All access trails shall connect to public streets. Maintenance trials need not be paved, but must be of all-weather construction such as aggregate base course, crusher fines, recycled concrete course or Aggregate Turf Reinforced Grass Pavement (RGP) described in Volume 3 of this *Manual* and capable of sustaining loads associated with large maintenance equipment. Paved trails are encouraged to allow for recreational use of the trails. When paved, pavement should be 5-inches minimum thickness of concrete (not asphalt). Maximum longitudinal slope for maintenance-only trails is 10%, but less than 5% when used as multi-purpose recreational trails to meet the requirements of the *Americans with Disabilities Act*. The District may accept adjacent public local streets or parking lots in lieu of a trail.

3. A low-flow or trickle channel is desirable. See Section 4.1.5 of this chapter for criteria.

4. Wetland bottom and bioengineered channels are acceptable when designed according to District wetland bottom channel criteria in Section 4.2 of this chapter.

5. The channel bottom minimum cross slope for dry bottom channels shall be 1%.

6. Tributary inflow points shall be protected all the way to the low-flow channel or trickle channel to prevent erosion. Inflow facilities to wetland bottom channels shall have their inverts at least 2 feet above the channel bottom to allow for the deposition of sediment and shall be protected with energy dissipaters.

7. All roadway crossings of wetland bottom channels shall incorporate a minimum of a stblized 2-foot drop from the outlet to the bottom of the downstream channel in order to preserve hydraulic capacity as sediment deposition occurs ovcer time in the channel.

8. All drop structures shall be designed in accordance with the HYDRAULIC STRUCTURES chapter of this *Manual*. Underdrain and storm sewer outlets located below the stilling basin's end sills are not acceptable. Construction plans shall utilize District standard details.

9. Storm sewer outlets shall be designed in accordance with the criteria in Sections 5.0, 6.0, and 7.0 of this chapter. Alternatively, conduit outlet sstructures, including low tailwater riprap basins design described in Section 3.0 of the HYDRAULIC STRUCTURES chapter of the *Manual* shall be used when appropriate.

10. Grouted boulder rundowns and similar features shall be designed in accordance with Section 7.0

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of the HYDRAULIC STRUCTURES chapter of the *Manual*.

11. Grass seeding specifications provided by the District (see the REVEGETATION chapter of this *Manual*) are recommended unless irrigated blue grass is used. The District will not maintain irrigated blue grass (due to cost constraints), but other elements of such a channel (i.e., drop structures, trickle channel) can still qualify for maintenance eligibility.

3.3 Choice of Channel Type and Alignment

3.3.1 Types of Channels for Major Drainageways

The types of major drainage channels available to the designer are almost infinite, depending only upon good hydraulic practice, environmental design, sociological impact, and basic project requirements. However, from a practical standpoint, it is useful to identify general types of channels that can be used by the designer as starting points in the design process. The following types of channels may serve as major drainage channels for the 100-year runoff event in urban areas:

Natural Channels—Natural channels are drainageways carved or shaped by nature before urbanization occurs. They often, but not always, have mild slopes and are reasonably stable. As the channel's tributary watershed urbanizes, natural channels often experience erosion and degrade. As a result, they require grade control checks and stabilization measures. Photograph MD-5 shows a natural channel serving as a major drainageway for an urbanized area.

Photograph MD-5—Natural channel (open floodplain design) serving as a major drainageway. Note the preservation of riparian vegetation, absence of floodplain encroachment and the use of grade control structures to arrest thalweg downcutting (i.e., channel incising/degradation)

9.4 Mosquito Control

Weekly mosquito inspections with targeted treatments are frequently less costly and more effective than regular widespread application of insecticide.

Mosquito control may be necessary if the BMP is located in proximity to outdoor amenities. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections and treatment can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. The use of larvicidal briquettes or "dunks" is not recommended for ponds due to their size and configuration.

9.5 Sediment Removal from the Forebay

Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the pond. More frequent removal will benefit long-term maintenance practices. For dry forebays, sediment removal should occur once a year. Sediment removal in wet forebays should occur approximately once every four years or when build up of sediment results in excessive algae growth or mosquito production. Ensure that the sediment is disposed of properly and not placed elsewhere in the pond.

9.6 Sediment Removal from the Pond Bottom

Removal of sediment from the bottom of the pond may be required every 10 to 20 years to maintain volume and deter algae growth. This typically requires heavy equipment, designated corridors, and considerable expense. Harvesting of vegetation may also be desirable for nutrient removal. When removing vegetation from the pond, take care not to create or leave areas of disturbed soil susceptible to erosion. If removal of vegetation results in disturbed soils, implement proper erosion and sediment control BMPs until vegetative cover is reestablished.

For constructed wetland ponds, reestablish growth zone depths and replant if necessary.

10.0 Constructed Wetland Channels

10.1 Inspection

Inspect the channel at least annually. Look for signs of erosion.

10.2 Debris and Litter Removal

Remove debris and litter as needed.

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10.3 Aquatic Plant Harvesting

Harvesting plants will permanently remove nutrients from the system although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. For this reason, UDFCD does not recommend harvesting vegetation as routine maintenance. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

Photograph 6-4. This broom sweeper will only remove debris from the pavement surface. Broom sweepers are not designed to remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration through the wearing course.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

10.4 Sediment Removal

If the channel becomes overgrown with plants and sediment, it may need to be graded back to the original design and revegetated. The frequency of this activity is dependent on the site characteristics and should not be more than once every 10 to 20 years.

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11.0 Permeable Pavement Systems

The key maintenance objective for any permeable pavement system is to know when runoff is no longer rapidly infiltrating into the surface, which is typically due to void spaces becoming clogged and requiring sediment removal. This section identifies key maintenance considerations for various types of permeable pavement BMPs.

11.1 Inspection

Inspect pavement condition and observe infiltration at least annually, either during a rain event or with a garden hose to ensure that water infiltrates into the surface. Video, photographs, or notes can be helpful in measuring loss of infiltration over time. Systematic measurement of surface infiltration of pervious concrete, Permeable Interlocking Concrete Pavers (PICP), concrete grid pavement, and porous asphalt[1] can be accomplished using ASTM C1701 Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

[1] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.