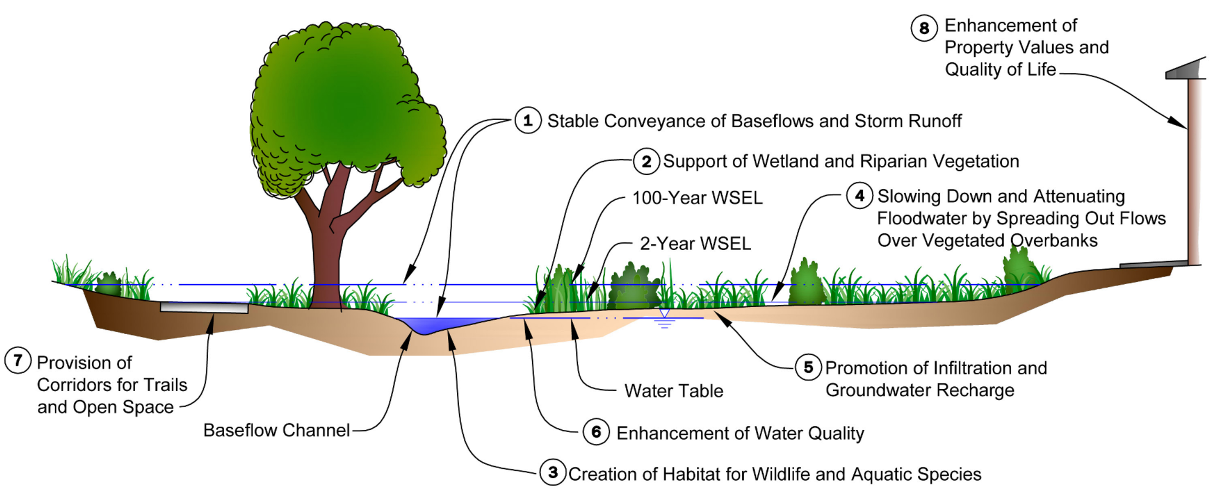
## 12.0 Introduction

This chapter summarizes the analysis and design methodology for drainageway improvements within the City. Definitions are provided for minor and major drainageways and design considerations for the preservation and stabilization of both drainageway classifications.

**12.0.1 Functions of Drainageways.** Healthy streams and floodplains provide a number of important functions and benefits. These are summarized below and illustrated in Figure 12-1.

1. Stable conveyance of baseflow and storm runoff.
2. Support of riparian and wetland vegetation.
3. Creation of habitat for wildlife and aquatic species.
4. Slowing down and attenuating floodwater by spreading out flows over vegetated overbanks.
5. Promotion of infiltration and groundwater recharge.
6. Enhancement of water quality.
7. Provision of corridors for trails and open space.
8. Enhancement of property values and quality of life.

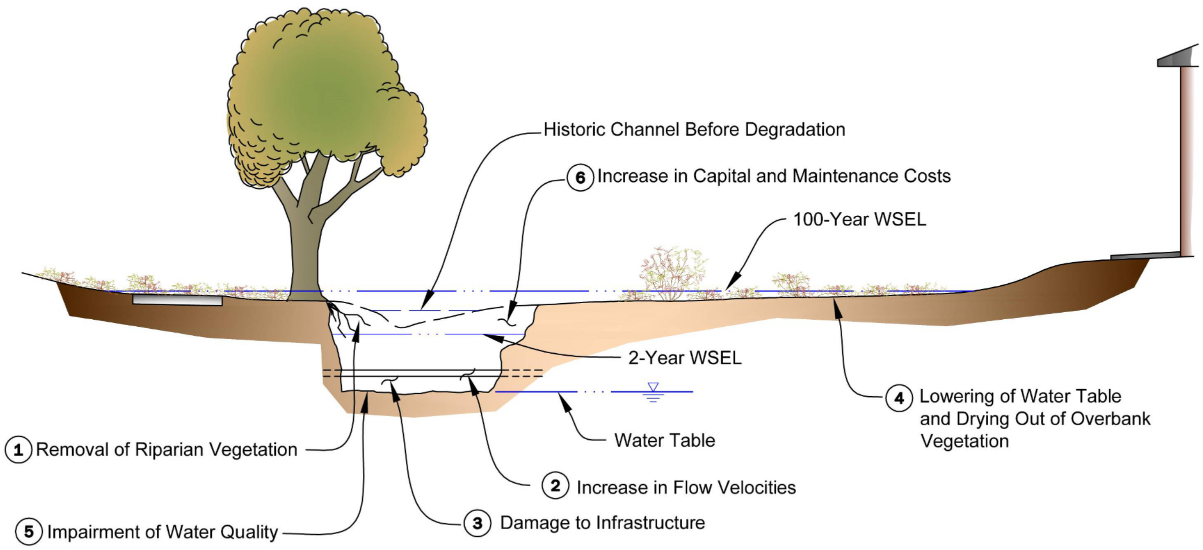
**FIGURE 12-1**
**FUNCTIONS AND BENEFITS OF HEALTHY STREAMS**




Natural stream systems are dynamic, responding to changes in flow, vegetation, geometry, and sediment supply that are imposed in developing urban environments. As a result, natural streams often face threats that can degrade the functions and values highlighted above.

**12.0.2 Drainageway Degradation.** Urbanization typically increases the frequency, duration, volume, and peak flow of stormwater runoff and, by stabilizing the ground with pavement and landscaping and installing water quality ponds can decrease the supply of watershed sediment. Urban drainageways tend to degrade and incise as the streams seek a new condition of equilibrium, producing a number of negative impacts to riparian environments and adjacent properties. These are illustrated in Figure 12-2 and described below.

**FIGURE 12-2**
**IMPACTS OF STREAM DEGRADATION**




1. Removal of Riparian Vegetation. Erosion typically strips natural vegetation from the bed and banks of drainageways. This disrupts habitat for aquatic and terrestrial species and leaves the channel exposed to further erosion damage.

2. Increase in Flow Velocities. An incised channel concentrates runoff and increases flow velocities. It is not unusual for channel velocities to more than double during high runoff in an incised condition, leading to further channel erosion.

3. Damage to Infrastructure. Channel erosion can threaten utility lines, bridge abutments, and other infrastructure. Utility pipelines that were originally constructed several feet below the bed of a creek often become exposed as the bed of a channel lowers. Damage to the utility lines can result as the force of that water and debris come to bear against the line. Channel degradation can expose the foundations of bridge abutments and piers, leading to increased risk of undermining and scour failure during flood events. Erosion and lateral movement of channel banks can cause significant damage to properties adjacent to drainageways, especially if structures are located close to the top of the bank.

4. Lowering of Water Table and Drying-out of Overbank Vegetation. In many cases, lowering of the channel thalweg and baseflow elevation leads to a corresponding lowering of the local water table. Besides the loss of storage volume, lowering the water table can “dry-out” the overbanks and can effect a transition from wetland and riparian species to weedy and upland species. This can have a striking effect on the ecology of overbank areas.

5. Impairment of Water Quality. The sediment associated with the erosion of an incised channel can lead to water quality impairment in downstream receiving waters. One mile of channel incision 5-feet deep and 15-feet wide would produce almost 15,000-cubic yards of sediment that could be deposited in downstream lakes and stream reaches. In the front range of Colorado, these sediments contain phosphorus, a nutrient that can lead to accelerated eutrophication of lakes and reservoirs. Also, channel incision impairs the “cleansing” function that natural floodplain overbanks can provide through settling, vegetative filtering, wetland treatment processes, and infiltration.

6. Increase in Capital and Maintenance Costs. Typical stabilization projects to repair eroded drainageways require significant capital investment; the more erosion, generally the higher the cost.

**12.0.3 Vision for Drainageways**. Drainageway modification is intended to reflect a natural stream character, attained by preserving and restoring existing natural drainageways and, when necessary, creating new drainageways with natural features. Natural planform and cross-sectional geometry, riparian vegetation, and natural grade control features are to be emulated wherever possible.

The vision is to go beyond just stabilizing a channel against erosion (which technically could be accomplished by lining the channel with concrete), and to implement *enhanced* stream stabilization. Enhanced stream stabilization has the goal of creating natural streams and well-vegetated floodplains that are physically and biologically healthy, with all of the attributes shown in Figure 12-1. This goal is just as important as improving the water quality of runoff flowing off a development site and into a receiving stream.

**12.0.4 Definition of Major and Minor Drainageways**. Criteria are presented for major drainageways and minor drainageways. Major drainageways consist of all streams or conveyance channels draining watershed areas greater than 130-acres. Major drainageways are intended to be preserved or, if degraded, to be restored to a natural condition, but not to be relocated or replaced with a pipe.

The remaining drainageway network, whether existing or constructed, are considered minor drainageways. In general, minor drainageways may be reconstructed, relocated, or replaced with a storm sewer in combination with flood conveyance in the street network. However, SEMSWA encourages the creation of vegetated surface channels wherever possible in the minor drainageway network.

**12.0.5 Jurisdictional Streams.** Streams designated by the Corps of Engineers as jurisdictional under Section 404 of the Clean Water Act are subject to specific protections established during the 404 permit process. The 404 permit may impose limits on the amount of disturbance of existing wetland and riparian vegetation, may require disturbed areas to be mitigated, and may influence the character of proposed stream improvements.

**12.0.6 Governing Criteria**. All open channel design criteria shall be in accordance with the Major Drainage Section in Volume 1 of the UDFCD Manual except as modified herein. The UDFCD Manual provides useful information for planning and designing open channel improvements and is referenced often in this chapter. The criteria described herein and in the UDFCD Manual represent minimum standards. Drainageway improvements will be reviewed on a case-by-case basis and in many instances, site-specific design or evaluation techniques will be required.

The criteria described herein and in Natural Channels in Volume 1 of the UDFCD Manual shall be used for major drainageways (certain features of Composite Channels and Bioengineered Channels have been incorporated into the Natural Channel criteria). Natural Channels, Composite Channels, or Grass-lined Channels shall be used for minor drainageways. The use of riprap-lined or concrete-lined channels is prohibited. Exceptions may be considered on a case-by-case basis for extreme cases in which hard-lined solutions are the only viable alternatives.

## 12.1 Drainageway Preservation and Stabilization

**12.1.1 Preservation of Natural Drainageways.** Natural drainageways and floodplains shall be preserved. SEMSWA will require that all major drainageways (upstream watershed area greater than 130 acres) be preserved. In addition, consideration shall be given to minor drainageways which may be considered to have a high resource value. Initial site planning documents shall accurately identify all existing drainageways, floodplains, and other site features that should be protected and preserved. The features that are proposed to be left in place and preserved or restored shall be clearly shown by shading these areas on the initial site planning documents. Areas shown to be protected will be subject to the review and acceptance of SEMSWA.

Although a development project can preserve additional areas, all drainageways that have one or more of the following features or characteristics, generally defined as major drainageways, shall be protected and preserved.

- Upstream watershed area greater than 130-acres.
- Presence of riparian vegetation such as cottonwood or willow trees, shrub willows, and wetland or transitional grasses.
- Presence of baseflows.
- Presence of protected habitat for threatened and endangered or other protected species.

- Presence of jurisdictional wetlands.
- Presence of bedrock outcroppings or unique landforms.
- Presence of historic, cultural, or archeological resources.

To properly identify whether or not the features listed above exist and need to be protected, information submitted in the initial planning documents shall include studies or reports regarding threatened and endangered species, wetland surveys, photographs of the drainageways, etc.

By respecting natural, historic drainage patterns in early planning, drainageways and floodplains can be preserved that provide adequate capacity during storm events, that are stable, cost-effective and of high environmental value, and that offer multiple use benefits to surrounding urban areas.

**12.1.2 Stabilization of Natural Drainageways**. SEMSWA will require the stabilization of drainageways as a condition of development approval. Because the increased runoff from urbanization typically leads to channel erosion (with all the associated impacts described in Section 12.0.2), it is not acceptable to simply "leave a stream alone", even when preserving drainageways as discussed in Section 12.1.1. Detention facilities do not fully mitigate impacts to the drainageways, as the adverse impacts are also related to increased runoff volumes and frequency of runoff events. Therefore natural drainageways shall be stabilized using one of the three approaches described below.

1. Preserving Streams not yet Impacted. Drainageways that have not yet experienced degradation from increased urban runoff or other forms of erosion shall be preserved by implementing the following improvements:

   - Grade control structures to limit degradation in the low flow channel, stabilize any existing headcutting, and to establish a flatter equilibrium slope than may have existed previously.
   - Bank stabilization at select locations where existing instability or the potential for future instability is evident.
   - The planting of supplemental vegetation to provide for the transition to species suited for "wetter" urban hydrology. Additional moisture can sustain wetland and riparian vegetation. These grasses, sedges and rushes, shrubs, and trees can help to stabilize the channel and provide a diverse habitat for wildlife.

2. Restoring Impacted Streams. Drainageways that have already experienced significant erosion and downcutting are to be addressed differently than streams that are not degraded. Restoration of these types of drainageways requires the following improvements:

   - Eroded, incised channels, if possible, shall not be stabilized in a manner that retains the incised geometry with steep side banks, but shall be restored by raising the channel invert up to its historic condition and encouraging high flows to spread out, avoiding deep, concentrated flood flows within the channel.

- Grade control structures to raise the channel invert and to establish a flatter equilibrium slope.
- Utilization of vegetated overbank benches adjacent to the base flow channel to allow high flows to spread out and dissipate energy (shown in Figure 12-1).
- Bank stabilization at select locations where existing instability exists or there is potential for future instability.

These elements are discussed further in Section 12.2. The goal of preservation or restoration improvements is to avoid disturbing existing drainageways more than what is necessary to provide a stable, sustainable stream system. However, the greater the extent of existing degradation, the more work and disturbance will be required.

3. Constructing New Natural Drainageways. Where it can be demonstrated that it is not feasible or practicable to preserve a natural drainageway (generally for minor drainageways that do not exhibit the characteristics described in Section 12.1.1), or if surface channels are desired in areas where no existing drainageways are evident, construction of a new natural drainageway may be accepted. It is the intent of SEMSWA that such constructed channels be designed to emulate natural drainageways with all of the attributes shown in Figure 12-1.

SEMSWA requires that channel stabilization measures shall be implemented on all drainageways that are either contained within the development, or are adjacent to the property. The need for additional measures downstream of the site shall be determined on a case by case basis.

All development projects, including those which do not contain or are not adjacent to a drainageway may be required to provide or participate in channel stabilization improvements to address water quality concerns within the drainageway which are created by the impact of all development within the watershed.

**12.1.3 Design Considerations**. Section 2 of the Major Drainage section of the UDFCD Manual provides a thorough discussion of drainageway planning considerations. The designer is referred to this section for guidance on urban effects, route considerations, and drainageway layout within a site.

**12.1.4 Master Planning.** UDFCD Outfall Systems Planning and Major Drainageway Planning Studies commonly referred to as master plans, have been developed for many of the watersheds in the urbanized parts of the City. These studies typically provide standard channel cross-sections and details to depict the selected channel type and/or improvements for the specific reaches of the drainageway. It is recognized that many of the master plans were completed several years ago and may not have been updated to reflect current approaches and design details, technology, and philosophies regarding channel stabilization improvements. The master plans shall be used as a basis, where appropriate, for general stabilization concepts, but will be subject to re-evaluation with regard to the standards presented in this chapter.

**12.1.5 Design Flows.** The design flow for open channel improvements shall be the discharge for the 100-year event assuming a fully urbanized watershed. Future developed conditions shall be based on the estimated imperviousness of the upstream watershed, or actual imperviousness if the basin is fully developed. In addition to the 100-year event, the design must also consider baseflows and frequent storm events, including the 2-year flow and any other events the designer judges may produce a critical design condition. The 1.5-year to 2-year discharge is commonly referred to as the “bankfull” or “channel forming” discharge for natural streams and is considered to have morphologic significance because it typically represents the breakpoint between the processes of channel formation and floodplain formation (FISRWG, 2001).

Design flow rates have been calculated in master planning documents. Prior to the use of these, or other published flow rates, a check should be made to verify that the assumptions used in the determination of the flow rates are valid. If design flow rates are not available, the engineer shall be responsible for providing the appropriate analysis to determine the design flow rate. The final design flow rate shall be approved by SEMSWA and UDFCD.

**12.1.6 Permitting and Regulations.** Major drainage planning and design along existing natural channels are multi-jurisdictional processes, and therefore, must comply with regulations and requirements ranging from local criteria and regulations to Federal laws. Discussions with the relevant permitting authorities should be held early in the design process and throughout construction to ensure that all permitting and regulatory requirements are being met. The following are some of the permitting requirements, however, the Project Engineer is responsible for contacting the appropriate agencies to determine all of the permitting requirements for a specific project.

1. Floodplain Development Permit. A Floodplain Development Permit is required for all activities proposed within the Floodplain. Refer to Chapter 5, Floodplain Management for additional discussion regarding floodplain regulations and permit requirements.

2. USACE 404 Wetlands Permit. Construction along existing drainageways may require a Section 404 permit from the US Army Corps of Engineers (USACE). The USACE should always be contacted early in the design process to determine if the activities will require a 404 permit. Figure MD-4 of the UDFCD Manual provides guidance regarding 404 permitting.

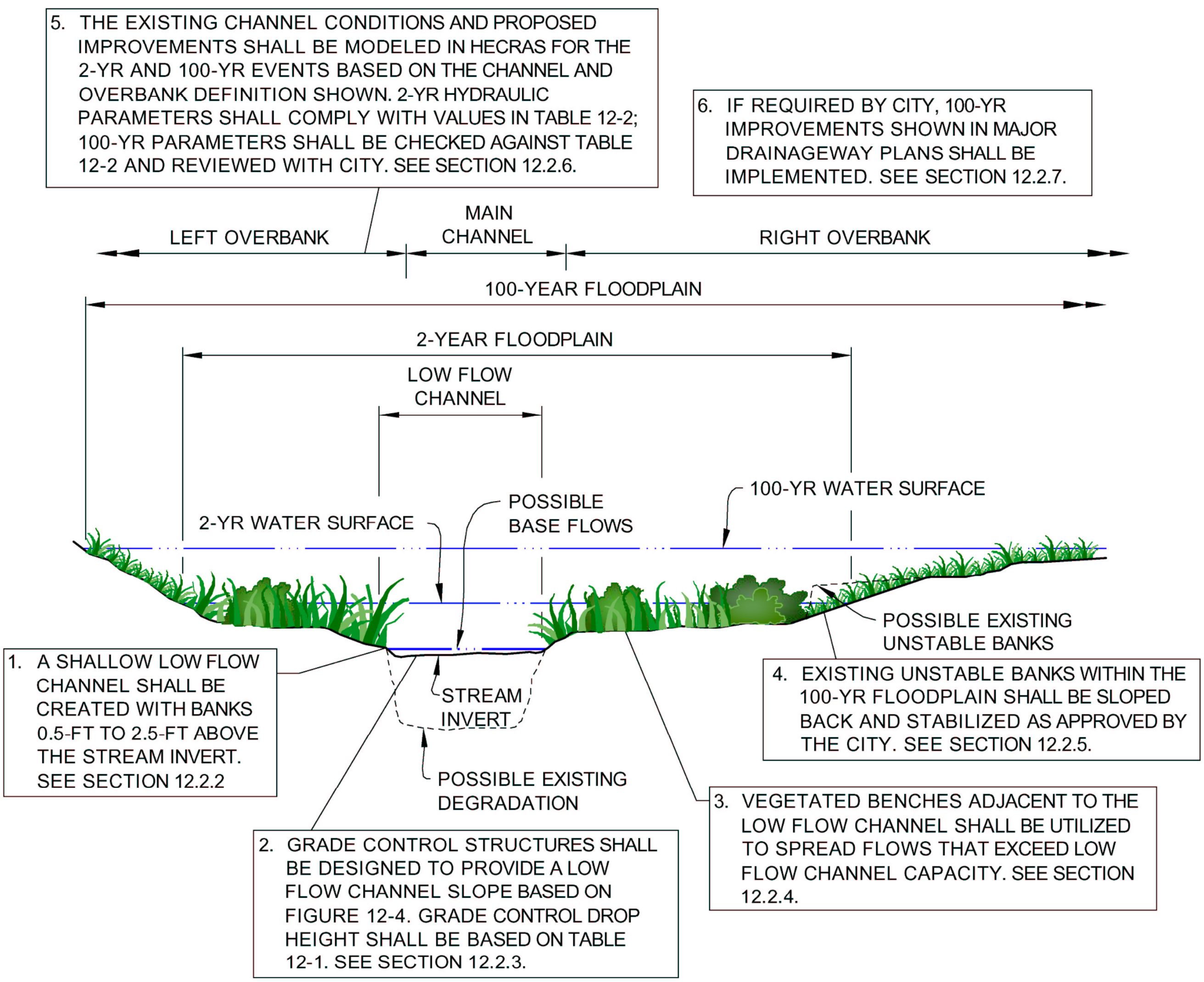
3. Threatened and Endangered Species Act. Construction of improvements along drainageways may also be subject to the federal Threatened and Endangered Species Act.

## 12.2 Design Criteria for Major Drainageways

**12.2.1 Natural Channel Approach.** Figure 12-3 illustrates six design elements associated with major drainageway design, summarized below.

1. Create shallow base flow channel.
2. Establish longitudinal slope using grade control structures.
3. Utilize vegetated benches to convey overbank flow.
4. Slope back and stabilize eroding banks.
5. Analyze floodplain hydraulics.
6. Undertake major drainageway plan improvements if required by SEMSWA.

**FIGURE 12-3**
**DESIGN ELEMENTS ASSOCIATED WITH MAJOR DRAINAGEWAY STABILIZATION**



These six steps are discussed in the following sections and comprise the recommended design approach for preserving, restoring, or constructing natural, healthy drainageways. Designers shall address these six elements and submit their proposed approach for drainageway stabilization to SEMSWA for review and approval.

12.2.2 **Create Shallow Base Flow Channel**. One of the primary design tasks is to preserve or establish a base flow channel that is appropriately sized in relation to the adjacent overbank geometry. In general, shallow baseflow channels with adjacent, well-vegetated overbank benches function best to spread out and dissipate the energy associated with flood flows. The top of baseflow channel banks shall be established in the range of 0.5-feet to 2.5-feet above the channel invert. This may require filling degraded, incised channels, excavating overbank benches adjacent to the base flow channel, or some combination of the two. Usually, filling a degraded channel is the option that results in the least disturbance to existing floodplain vegetation.

Sometimes, it may be difficult to raise up the invert of a degraded channel. Existing storm sewer outfalls may have been installed near the bottom of the incised channel and constrain how much the channel bed can be raised. It may be necessary to remove the downstream end of low storm sewer outfalls and reconstruct them at a higher elevation. Raising the invert may cause a rise in a critical floodplain elevation if the regulatory floodplain was based on the degraded channel condition (it is recommended that floodplains be determined for restored, not degraded channel conditions, as discussed in Section 12.2.6). There may be a need for compensatory excavation in another portion of the floodplain of offset any rise in the floodplain caused by filling in the eroded base flow channel.

The width of the base flow channel shall approximate the existing base flow channel width in the design reach or in stable reference reaches upstream or downstream, as approved by SEMSWA. It is normal that a baseflow channel exhibit a degree of meandering and sinuosity in natural channels. Constructed channels shall feature a meander pattern typical of natural channels.

Besides indicating width, depth and sideslope information for the base flow channel, the designer shall estimate the capacity of the baseflow channel as a percentage of the 100-year event. Typically, the brimful capacity of the base flow channel will be less than 1.0-percent of the 100-year discharge for large streams systems such as Cherry Creek upstream of the reservoir and up to approximately 3- to 4-percent of the 100-year flow for drainageways just over 130 acres.

The base flow channel is typically unvegetated if a constant base flow or frequent ephemeral flow is present, or vegetated with riparian or wetland species if baseflows are less frequent.

**12.2.3 Establish Longitudinal Slope Using Grade Control Structures.** If the expected long-term equilibrium slope of the baseflow channel is less than the longitudinal slope of the adjacent overbanks, grade control structures are required to enable the baseflow channel to adopt a “stairstep” profile without exceeding the baseflow channel depths discussed above. The maximum drop height of grade control structures shall conform to Table 12-1. The design of grade control structures is covered further in Section 12.4.

**TABLE 12.1**
**GRADE CONTROL DROP HEIGHT CRITERIA**

| Capacity of Grade Control Structure | Maximum Drop Height (feet) |
|---|---|
| Less than 2-year future discharge | 1.5 |
| Between 2-year and 100-year | 2.5 |
| 100-year and greater | 4.0 |

An examination of natural streams in the Denver metropolitan area reveals a typical range of stable, long-term equilibrium slopes for various urban watershed sizes and flow rates. This information was used to develop the envelop curve illustrated in Figure 12-4. Unless otherwise approved by SEMSWA, grade control structures shall be laid out assuming the baseflow channel slope shown in Figure 12-4. The specified slope shall extend from the crest elevation of a downstream grade control structure to the downstream invert of the stilling basin for the next grade control structure upstream.

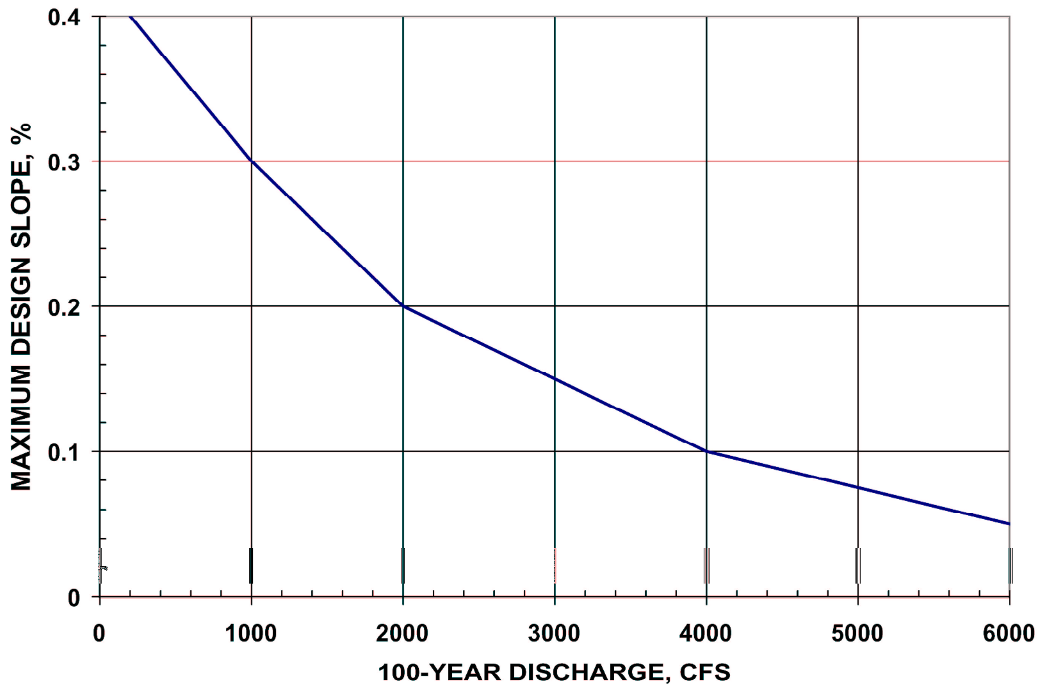
It is possible that channels may exhibit a steeper slope for periods of time, especially if a drainageway is subject to a high sediment load. This may lead to a partial or complete burying of grade control structures as channels aggrade from the design slope based on Figure 12-4. However, if slopes flatten over time in response to lower sediment loads, as is usually the case, this approach reduces the likelihood that drops will be undermined in the future. The designer shall be cognizant of the effects on the channel of steeper equilibrium slopes in the near term. Designers are encouraged to estimate equilibrium slopes using the following methods.

1. Reference Reach Concept. This is a qualitative fluvial geomorphology method that correlates equilibrium longitudinal slopes from similar drainageways that have undergone adjustments in channel slope in response to urban development. Reference reaches have similar geomorphic characteristics as project reach such as watershed size, watershed imperviousness, soil type, sediment loading, etc. In addition, the reference reach must be in equilibrium conditions and not unduly influenced by unstable upstream conditions (i.e., high sediment loads from eroding tributary). Reference reach evaluations should only be done by a designer that has expertise in geomorphology and river mechanics.

2. Sediment Transport Evaluation. This is a quantitative methodology that looks at the balance between sediment supply and transport capacity. This method is most applicable in alluvial sand bed channels such as Cherry

Creek that have high sediment loads. Results are very sensitive to the assumptions used for sediment supply. An approximate methodology is provided in the "Design Guidelines and Criteria for Channels and Hydraulic Structures on Sandy Soil" (UDFCD, June 1981). Several computer models also exist that model sediment transport such as HEC-6, SAM, and GSTARS. This method should only be used by design engineers that have significant experience and expertise in geomorphology and river mechanics.

**FIGURE 12-4**
**BASE FLOW CHANNEL SLOPE CRITERIA**




**12.2.4 Utilize Vegetated Benches to Convey Overbank Flow.** Overbank areas adjacent to the baseflow channel are ideally wide, flat, well-vegetated, and not excessively steep with respect to longitudinal slope. Generally, the wider, the flatter, and the more vegetation, the better.

For existing natural channels, vegetated benches often exist just above the tops of the eroded base flow channel. Raising the invert of degraded channels as discussed in Section 12.2.2 usually establishes a favorable overbank geometry. If necessary, benches can be excavated adjacent to the baseflow channel, especially if impacts to existing vegetation are minimal.

It may be necessary to re-establish or supplement vegetation on the overbanks to build up a sturdy, durable cover to help retard flood flows and resist erosion.

**12.2.5 Slope Back and Stabilize Eroding Banks**. Steep unstable banks existing within the 100-year floodplain shall be sloped back and stabilized as approved by

SEMSWA. Designers shall indicate on a plan-view topographic map the location, height and existing slope of any unvegetated, steep, or otherwise unstable banks within the 100-year floodplain, along with the proposed approach for stabilizing the banks.

The engineer shall consider the existing bank conditions and angle of attack, the estimated potential for future erosion, and the proximity of infrastructure that could be impacted by the bank erosion as a basis for determining the appropriate method for bank stabilization. Other channel characteristics such as channel geometry, longitudinal slope, existing vegetation, underlying soils, available right-of-way and expected flow conditions shall be considered and analyzed with respect to the various potential improvements.

Unstable banks shall be protected using one of the following approaches.

1. Sloping Back Banks. Steep, unstable banks shall be sloped back to a flatter slope and revegetated. Slopes of 4 to 1 are desirable; any slopes up to 3 to 1 require approval of SEMSWA and need to be blanketed in accordance with SEMSWA's Grading, Erosion, and Sediment Control (GESC) program. If the toe of these banks are subject to frequent inundation of runoff, riprap bank protection or bioengineered bank protection (described below) shall be used up to a height approved by SEMSWA (normally up to the 2-year elevation).

2. Riprap Bank Protection. Riprap bank protection is widely used in the City to stabilize channel banks along the outside of existing channel bends and along steep banks that cannot be graded back at a 4:1 slope due to right-of-way constraints, or where overbank grades are too steep. The riprap may extend all the way up to the top of the bank or, with SEMSWA approval, part way up the bank to an approved elevation. Riprap bank protection shall be designed in accordance with the Riprap-lined Channel section of the Major Drainage Section of the UDFCD Manual. All riprap bank protection shall consist of soil riprap that is buried with 6-inches of topsoil and revegetated.

2. Bioengineered Bank Protection. Experience is growing in the Colorado Front Range with the application of bioengineering techniques to protect channel banks. Bioengineering techniques are discussed in Section 4.5 of the Major Drainage Section in Volume 2 of the UDFCD Manual.

**12.2.6 Analyze Floodplain Hydraulics.** The floodplain associated with the existing, unimproved natural channel and the proposed improved condition shall be analyzed using HEC-RAS to evaluate flow conditions and velocities for at least the 2-year and 100-year flood events for the purpose of assessing drainageway stability. For constructed drainageways designed to emulate natural channels, the parameters in Table 12-2 shall be achieved for both the 2-year and the 100-year event. For existing natural channels, design conditions shall be adjusted to achieve the hydraulic conditions shown in Table 12-2 for the 2-year event. Hydraulic parameters for the 100-year event shall be compared against the values in Table 12-2 and reviewed with SEMSWA to determine what, if any, additional improvements are required. All hydraulic modeling shall be based on the channel and overbank definition shown in Figure 12-3 and on the roughness information identified in Table 12-4 at the end of this chapter and discussed below.

**TABLE 12.2**
**HYDRAULIC DESIGN CRITERIA FOR NATURAL CHANNELS**

| Design Parameter | Upland Grass Vegetation | Wetland Grass (Dense Sod Forming Type) | Wetland Shrubs Trees (dense stand) |
|---|---|---|---|
| Maximum 2-year Velocity (ft/s) | 3.5 ft/s (2.5 ft/s) | 4.5 ft/s (3.0 ft/s) | 5.5 ft/s (3.0 ft/s) |
| Maximum 100-year Velocity | 6 ft/s (4.5 ft/s) | 7 ft/s (5 ft/s) | 8 ft/s (5 ft/s) |
| Froude No., 2-Year | 0.6 (0.5) | 0.6 (0.5) | 0.6 (0.5) |
| Froude No., 100-Year | 0.8 (0.5) | 0.8 (0.5) | 0.8 (0.5) |
| Maximum Tractive Force, 100-year | 0.60 lb/sf | 0.6 lb/sf | 1.00 lb/sf |

Values are shown for erosion-resistant soils (values in parentheses apply to erosive soils).

The other reason to analyze floodplain hydraulics is to accurately delineate the 100-year floodplain for the purposes of laying out a development project and setting lot and building elevations adjacent to the floodplain. It is important to keep in mind that compared to channel conditions existing at the time of development, floodplain elevations can rise over time due to the following:

- Increased baseflows and runoff from development can promote increased growth of wetland and riparian vegetation, making drainageways hydraulically rougher and leading to greater flow depths.
- Stream restoration work is intended to raise the bed of incised channels to levels that existed prior to degradation. This effort, plus modifying channel slopes to flatter or more stable grades increases water surface elevations.
- Upstream bank erosion or watershed erosion, flatter slopes, and increased channel vegetation can lead to sediment deposition and channel aggradation, raising streambed and floodplain elevations.

All of these conditions are generally healthy and positive, since they slow flow velocities, improve stream stability, and enhance water quality through sediment trapping. For these conditions to occur over time without jeopardizing properties during floods, floodplain determinations shall account for the three conditions discussed above, and the provision for ample freeboard is highly encouraged. A minimum of 2-ft of freeboard shall be provided between the 100-year base flood elevation and the lowest finished floor elevation of all structures (this includes basements). For facilities which are not structures (typically not requiring a building permit) such as roadways, utility cabinets, parks and trails improvements, etc., a minimum of 1 ft. of freeboard is acceptable. Where possible the required freeboard should be contained within the floodplain tract and/or easement.

Floodplain analyses shall be based on future-development flow rates, long-term channel roughness (considering potential increases in baseflows and riparian vegetation), and potential aggradation over time. Incised or eroded channels shall not be analyzed based on their existing geometry, but on the geometry representative of a restored Natural Channel, as described in Section 12.1 and illustrated in Figure 12-1. Otherwise, the floodplain may be inappropriately low, constraining future restoration efforts such as installing grade control structures that raise the channel bed back to earlier conditions.

**12.2.7 Undertake Major Drainageway Plan Improvements if Required by SEMSWA**. The previous five design elements associated with major drainageway stabilization are mandatory; undertaking further major drainageway plan improvements will be required by SEMSWA on a case-by-case basis. Section 3.4.4 provides additional guidance.

## 12.3 Design Criteria for Minor Drainageways

**12.3.1 Natural Channels**. Natural drainageways are the preferred channel type for minor drainageways, as well as for major drainageways. The natural channel criteria identified for major drainageways also apply to minor drainageways. It may be more common for natural channels to be constructed "from scratch" on minor drainageways than to be preserved or restored.

**12.3.2 Grass-Lined Channels.** Grass-lined channels are another alternative for minor drainageways, especially where the tributary area is relatively small and base flows are not expected. Sod-forming native grasses suited to wetter conditions are recommended for grass-lined channels. If irrigated bluegrass sod is proposed, a small low-flow channel (sized for approximately 1- to 3-percent of the 100-year discharge) shall be provided and vegetated with the wetter sod-forming native grasses. Hard-lined low flow channels are not desired in grass-lined channels in the City. Grade control structures or rock stabilization in the bottom of the channel may be necessary if the longitudinal slope exceeds the values in Table 12.3.

Design criteria for grass-lined channels are provided in Section 4.1 of the Major Drainage chapter of Volume 1 of the UDFCD Manual. Preliminary design guidance for grass-lined channels from Table MD-2 in the Major Drainage chapter of Volume 1 of the UDFCD Manual is reproduced below for reference:

**TABLE 12.3**
**HYDRAULIC DESIGN CRITERIA FOR GRASS-LINED CHANNELS**

| Design Item | Major Drainage Section (UDFCD Manual) | Grass: Erosive Soils | Grass: Erosion Resistant Soils |
|---|---|---|---|
| Maximum 100 year velocity | 3.2.1 | 5.0 ft/sec | 7.0 ft/sec |
| Minimum Mannings "n" For capacity check | Table MD-3 | 0.035 | 0.035 |
| Maximum Mannings "n" For velocity check | Table MD-3 | 0.03 | 0.03 |
| Maximum Froude number | 3.2.1 | 0.5 | 0.8 |
| Maximum Depth – outside Low flow zone | 3.2.2 | 5.0 ft | 5.0 ft. |
| Maximum channel longitudinal slope | 3.2.3.1 | 0.6% | 0.6% |
| Maximum side slope | 3.2.3.2 | 4H:1V | 4H:1V |
| Maximum centerline radius for a bend[1] | 3.2.4 | 2 x top width | 2 x top width |
| Minimum freeboard [3] | 3.2.5 | 2.0 ft[2] | 2.0 ft[2] |

[1] Use 100 ft. if top width is less than 100 ft.
[2] Freeboard criteria have been modified from Table MD-2 and apply to the lowest adjacent habitable structure's lowest floor.
[3] Add superelevation to the normal water surface to set freeboard at bends.

**12.3.3 Composite Channels (Wetlands Bottom Channels).** As described in Section 4.2 of the Major Drainage chapter of Volume 1 of the UDFCD Manual, there are circumstances where the use of a composite channel may be required or preferred. Composite channels shall be designed with reference to Section 4.2 of the Major Drainage Chapter and Section 10.0 of the Structural BMP Chapter of the UDFCD Manual. However, riprap bank protection will generally not be required in wetland bottom channels.

**12.3.4 Bioengineered Channels.** Elements of bioengineered channels as described in Section 4.5 of the Major Drainage chapter of the UDFCD Manual may be used in the design or stabilization of natural channels.

**12.3.5 Riprap-Lined and Concrete-Lined Channels.** The use of riprap-lined or concrete-lined channels is generally not allowed in by SEMSWA.

## 12.4 Grade Control Structures

Grade control structures, such as check structures or drop structures, provide for energy dissipation and are used to establish flatter equilibrium slopes and moderate flow velocities in the upstream channel reach, as discussed in Sections 12.1.2 and 12.2.3. Table 12-1 provides information on maximum drop height for grade control structures. Two general approaches shall be considered when implementing grade control structures, as discussed below.

**12.4.1 100-year Drop Structures**. Drop structures or grade control structures that extend across the entire waterway and convey the major or 100-year flood.  Drop structures shall be limited in height to 5 feet to avoid excessive kinetic energy and to avoid the appearance of a massive structure, keeping in mind that the velocity of the falling water increases geometrically with the vertical fall distance.  Heights in excess of 5 feet may be considered on a case-by-case basis for conditions which warrant a larger drop, however, they must be approved by SEMSWA as a variance, upon review of a detailed analysis that justifies the requirements of a larger drop structure.  Drop structures in excess of 10 feet will be approved only in extreme circumstances and will need to be analyzed for potential jurisdictional dam issues when used downstream of stormwater facilities which impound water.

Drop structure design considerations, design procedures, design details, discussion regarding various types of structures, and construction concerns are provided in Section 2.0 of the Hydraulic Structures chapter of Volume 2 of the UDFCD Manual.

**12.4.2 Low-Flow Drop Structures**. Low-flow drop structures and check structures are grade control structures that extend across the low-flow channel to provide control points to limit degradation at specific locations and to establish flatter thalweg slopes as discussed in Section 12.2.3.  During a major flood, portions of the flow will circumvent the check. Typically, 2-year flows are contained within the protected zone, so that scour around the check structure is controlled. Low-flow drop structures are not appropriate within completely incised floodplains or very steep channels where the velocities shown in Table 12-2 can’t be achieved.

The primary design flow for the check will be the discharge that completely fills the check structure at its crest (usually the 2-year event).  The secondary design flow is the flow that causes the worst condition for lateral overflow around the abutments of the check and back into the low flow channel below (i.e., a 5-year, 10-year, or 100-year event).  The goal is to have the check structure survive such an event with minimal or reasonable damage to the floodplain below. The minimum crest depth for low flow drops structures is 1.5-feet.

The best approach to analyze the hydraulics of low flow drops is to estimate unit discharges, velocities, depths, along overflow paths.  The unit discharges can be estimated at the crest or critical section for the given total flow.  Estimating the overflow path around the check is difficult and requires practical judgment.  Slopes can be derived for the anticipated overflow route, and protective measures can be devised such as buried rock.

Seepage control is also important because piping and erosion under and around these structures can be a problem.  It is advisable to provide a cutoff wall that extends laterally at least 5 to 10 feet into undisturbed bank and has a cutoff depth appropriate to the profile dimension of the check structure.

Information and design guidance for low-flow grade-control check structures are provided in Section 2.9 of the Hydraulic Structures Section of Volume 2 of the UDFCD Manual.

**12.4.3 Drop Structure Types.** SEMSWA encourages the use of drop structure types and configurations that are functional, natural looking, and blend-in with the drainageway and surrounding environment. The most common type of drop structure in the Denver metro area is the Grouted Sloping Boulder drop structure. Grouted boulders can be used to develop more unique, natural looking configurations such as a horseshoe-arch shape or stepped configurations. Other drop types that have been used in the Denver Metro area include: sheet pile drops, sculpted concrete drops, and soil cement drops. The sculpted concrete drops have become more popular for aesthetic reasons, particularly in upland prairie settings. The concrete is shaped, sculpted, and colored with earth tones to emulate natural rock outcroppings. Use of the following drop structure types is preferred:

- Grouted Sloping Boulder
- Grouted Boulder in natural configurations
- Sculpted Concrete

Design guidance, detailed design criteria, and construction details have not been developed by the UDFCD for sculpted concrete drop structures. It is the responsibility of the design engineer to develop and provide the detailed construction drawings, based on previous experience in the design of sculpted concrete drop structures or research and review of past designs that have been constructed in the Denver Metro area.

The use of soil cement and roller compacted concrete drop structures may be allowed, but only on a case-by case basis as approved by SEMSWA and UDFCD. Specifications and construction quality control needed for soil cement and roller compacted concrete are extensive and generally must be in accordance with standard specifications developed by organizations such as the Portland Cement Association.

SEMSWA shall have final approval on the type of drop structure that is allowed.

## 12.5 Easements, Maintenance, and Ownership

**12.5.1 Drainage Easement.** Drainage easements are required in order to allow for proper maintenance and operation of open channels. Drainage easements, shall be granted to SEMSWA for inspection and maintenance purposes, and shall be shown on the Drainage Plan, Final Plat and Final Development Plan. Drainage easements shall be kept clear of impediments to the flow. Easements must also be provided to allow access to channels for maintenance.

**12.5.2 Drainageway Ownership - Residential.** To ensure that drainageways and the associated conveyances are adequately preserved and properly maintained, all major drainageways and minor drainageways within residential areas that convey flows from other properties should be placed on tracts of land owned by a common entity (i.e., Park or Metro district, Homeowner's Association, County, City, SEMSWA, other regional agencies, etc.). Easements are allowed for drainage swales between individual lots, provided they accept a limited amount of drainage, from no more than two adjacent lots.

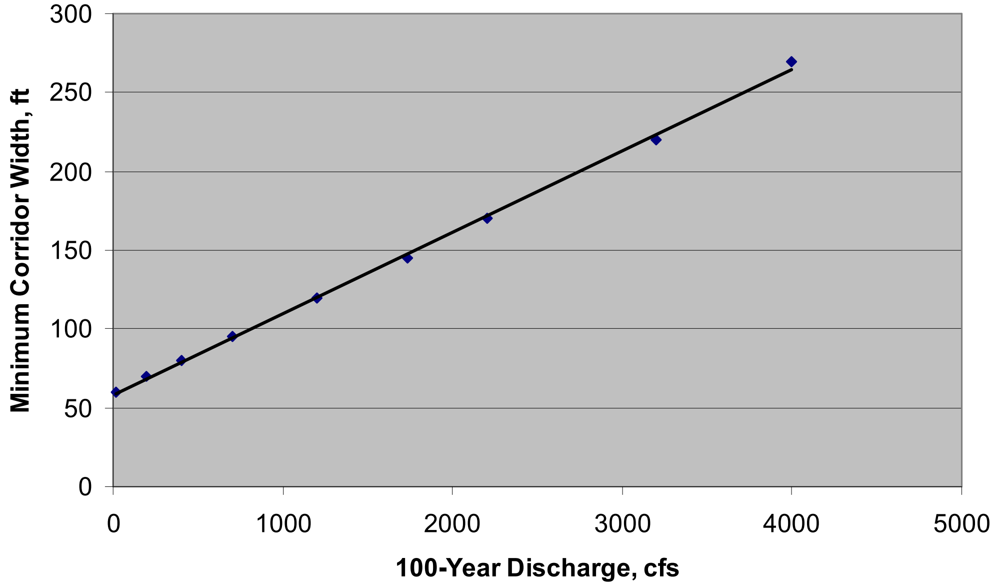
**12.5.3 Drainageway Ownership – Business/Commercial.** Within business and commercial land uses, all major drainageways and those minor drainageways which convey flows from other properties, must be placed within drainage easements or within separate tracts with a drainage easement.

**12.5.4 Easements for Natural Drainageways.** Required easement widths for natural drainageways need to provide for conveyance of design flow rates, the required freeboard, and access for maintenance. Any banks allowed to remain in place at a slope steeper than 4 to 1 shall have the easement line set back from the top of bank to allow for some lateral movement or future grading improvements to the bank. The easement line shall be no closer than the intersection of a 4 to 1 line extending from the toe of the slope to the proposed grade at the top of the bank, plus an additional width of 15-feet for an access bench, if access is not feasible within the floodplain.

The easement widths discussed above are minimum requirements. Narrow existing channels and high flow velocities merit consideration of easements that may be wider than the existing floodplain limits. As a guideline, Figure 12-3 shows a generalized relationship of recommended easement width based on 100-year discharge. The formula for width is listed below and was developed to provide an adequate width if the channel was to be completely reconstructed according to design criteria for natural and grass channels. Proposed easement widths less than indicated in Figure 12-3 will be subject to the approval of SEMSWA.

$$\text{Minimum easement width (ft)} = 0.06*Q_{100}+60,$$
$$\text{Where } Q_{100} = \text{100-year discharge in cfs.}$$

FIGURE 12-5
MINIMUM EASEMENT WIDTH FOR NATURAL DRAINAGEWAYS




**12.5.5 Design for Maintenance.** Open channels and swales should be designed to minimize future maintenance needs, to the extent possible, and with adequate maintenance access to assure continuous operational capability of the drainage system. When provisions for maintenance access are being developed, consideration must be given to the potential maintenance activities and the equipment normally used to perform those activities. Designs which rely on the establishment of a vegetative cover, such as bio-engineered or grass-lined, must include a plan for establishment, including temporary or permanent irrigation of the area.

Continuous maintenance access, such as with a trail, shall be provided along the entire length of all major drainageways. The stabilized maintenance trail shall meet all UDFCD requirements, shall have a stabilized surface at least 8-feet wide and a minimum clear width of 12-feet for a centerline radius greater than 80-feet and at least 14-feet for a centerline radius between 50- and 80-feet. The minimum centerline radius shall be 50-feet. The maximum longitudinal slope shall be 10 percent. The stabilized surface does not need to be paved with concrete or asphalt, but shall be of all-weather construction and capable of carrying loads imposed by maintenance equipment. Under certain circumstances, adjacent local streets or parking lots may be acceptable in lieu of a trail.

Minor drainageways shall have continuous maintenance access along the entire length of the drainageway. The minimum clear width reserved for maintenance access along the channel shall be 12-feet for a centerline radius greater than 80-feet and at least 14-feet for a centerline radius between 50- and 80-feet. The minimum centerline radius shall be 50-feet. Depending on the channel size, tributary area, expected maintenance activities, and the proximity of local streets and parking areas, a continuous stabilized trail may or may not be required along minor drainageways.

12.5.6 **Maintenance Responsibility.** Maintenance responsibility lies with the owner of the land, except as modified by specific agreement. Maintenance responsibility shall be delineated on the Final Plat and Final Development Plan, and described in the drainage report. Maintenance of an open channel includes routine maintenance such as periodic sediment and debris removal. Channel bank erosion, damage to drop structures, low flow channel deterioration, and other channel degradation must be repaired to avoid reduced conveyance capability, unsightliness, water quality issues and ultimate failure. Maintenance operations shall be accordance with the approved Operations and Maintenance Manual (O&M Manual) for the project as described in Section 4.8.

12.5.7 **Major Drainageways and UDFCD Maintenance Assistance.** Major drainageways within the UDFCD boundary shall be designed and constructed in accordance with UDFCD maintenance eligibility requirements. The design and construction shall be reviewed and approved by the UDFCD prior to SEMSWA acceptance. Appropriate drainage easements and access improvements shall be provided to ensure that adequate access is provided to the channel and related structures. When the channel design and construction are accepted by the UDFCD, it will be eligible for maintenance assistance. When channel improvements are eligible for UDFCD maintenance assistance it does not relieve the property owner, or other designee from the responsibility of providing the necessary maintenance. It does, however provide the potential for the responsible entity to receive maintenance assistance from the UDFCD, if requested by SEMSWA. Maintenance assistance requests are accepted by SEMSWA, prioritized, and submitted to the UDFCD. The actual maintenance that can be performed by the UDFCD is limited based on the funding availability.

## TABLE 12.4
## ROUGHNESS COEFFICIENTS

| Channel Type | Roughness Coefficient (n) | | |
|---|---|---|---|
| | Minimum | Typical | Maximum |
| Natural Streams (top width at flood stage <100 feet) | | | |
| 1. Streams on Plain | | | |
| a. Clean, straight, full stage, no rifts or deep | 0.025 | 0.030 | 0.033 |
| pools | 0.030 | 0.035 | 0.040 |
| b. Same as above, but more stones and weeds | 0.033 | 0.040 | 0.045 |
| c. Clean, winding, some pools and shoals | 0.035 | 0.045 | 0.050 |
| d. Same as above, but some weeds and stones | 0.040 | 0.048 | 0.055 |
| e. Same as above, lower stages, more | | | |
| ineffective slopes and sections | 0.045 | 0.050 | 0.060 |
| f. Same as c, but more stones | 0.050 | 0.070 | 0.080 |
| g. Sluggish reaches, weedy, deep pools | 0.075 | 0.100 | 0.150 |
| h. Very weedy reaches, deep pools, or | | | |
| floodways with heavy stand of timber and | | | |
| underbrush | see | | |
| 2. Mountain Streams, no vegetation in channel, banks | Jarrett's | | |
| usually steep, trees and brush along banks | equation* | | |
| submerged at high stages | | | |
| a. Bottom: gravels, cobbles, and few boulders | | | |
| b. Bottom: cobbles with large boulders | | | |
| Major Streams (top width at flood stage > 100 feet) | | | |
| 1. Regular section with no boulders or brush | 0.025 | | 0.060 |
| 2. Irregular and rough section | 0.035 | | 0.100 |
| Grass Areas ** | **Flow | | Flow Depth |
| 1. Bermuda grass, buffalo grass, Kentucky bluegrass | Depth = | | > 3.0 ft |
| a. Mowed to 2 inches | 0.1-1.5 ft | | 0.030 |
| b. Length = 4 to 6 inches | 0.035 | | 0.030 |
| 2. Good Stand, any grass | 0.040 | | |
| a. Length = 12 inches | | | 0.035 |
| b. Length = 24 inches | 0.070 | | 0.035 |
| 3. Fair Stand, any grass | 0.100 | | |
| a. Length = 12 inches | | | 0.035 |
| b. Length = 24 inches | 0.060 | | 0.035 |
| | 0.070 | | |

*Jarrett's equation: $n = 0.39 S_f^{0.38} R^{-0.16}$, where $S_f$ equals friction slope and R equals the hydraulic radius.

** The n values shown for the Grassed Channel at the 0.1-1.5 ft depths represent average values for this depth range. Actual n values vary significantly within this depth range. For more information see the *Handbook of Channel Design for Soil and Water Conservation (SCS, 1954.)*