7.0 Open Channels

7.1 Introduction

Open drainage channels are the most common components of drainage systems. The well-established hydraulic design principles of channeled flow must be integrated into the recreation, aesthetic, water quality, and aquatic habitat preservation goals of the City of Greenwood Village (Village).

The City Manager or designee shall review and approve the drainage analysis and design of all proposed development projects that will potentially impact the Major Drainageways and other natural channels within the Village limits. The City Manager or designee shall review and approve any proposed channel modifications, including but not restricted to, erosion and grade control structures, realignment, outfalls, and crossings.

7.2 Channel Types

Open channels are defined in terms of origin as artificially constructed or naturally occurring. Artificial channels are generally prismatic with a constant cross sectional geometry along the length of the reach. Natural channels generally do not exhibit these characteristics. Traditional artificial channels include all designed and constructed watercourses such as the Highline Canal, irrigation canals and flumes, roadside ditches, and vegetated channels. Natural channels are formed by concentration of sheetflow into erosion-incised channels and include within the Village limits, named channels such as Big Dry Creek, Little Dry Creek, Greenwood Gulch, Prentice Gulch, Goldsmith Gulch, and Cottonwood Creek.

7.2.1 Natural Channels

Natural channels are formed by erosion and exist in a state of equilibrium regulated by the dynamic interaction between soil and water. A proposed development can change flow rates for both base and flood flow conditions. This can cause significant changes in the sediment erosion and deposition patterns of the channel, significantly changing its appearance and capacity. These changes can have significant adverse effect on property, aquatic habitat, and wetlands.

The most common and the most difficult design issue that arises when incorporating natural channels into a proposed drainage system is destabilization of the sediment-water equilibrium by development induced changes in velocity. Urbanization can potentially degrade the channel bed by increasing both the peak discharge and runoff volume. Conversely, a reduction in peak discharge and runoff volume can decrease the sediment carrying capacity of the channel and increase the potential for deposition. Both alterations may require localized design modification of the channel to ensure a stabilized hydraulic flow condition and to protect wetland areas as well as the water quality and aquatic habitat of receiving streams.

7.2.2 Vegetation-Lined Channels

Vegetation-lined channels provide multiple-use benefits not available from smooth-lined channels. Vegetation stabilizes the channel perimeter, provides in-line storage to attenuate peak discharge rates, reduces erosion potential by stabilizing the soil mass of the bed, and provides a visually pleasing and aesthetically integrated form of drainage conveyance.

The Village strongly encourages use of vegetation-lined channels designed with a meandering alignment to reduce levels of phosphorus contained in runoff from developed watersheds. A meandering alignment increases the contact time between the vegetated perimeter and the pollutant load by reducing the velocity. The channel hydraulic analysis must ensure that design modifications to provide or improve water quality treatment do not adversely impact the sediment transport capacity of the channel.

7.2.3 Smooth-Lined Channels

Concrete and other smooth-lined channels, such as roller-compacted concrete, soil cement, and shotcrete, can adversely impact the integrated hydraulic performance of regional drainage facilities. Smooth-lined conveyance channels concentrate and accelerate flow which alters the temporal characteristics of surface runoff in a regional context and can result in larger downstream peak rates of discharge which may, in turn, adversely impact downstream channels and floodplains.

Within the Village, concrete and other smooth-lined channels will be permitted only where restrictions within the drainage easement within existing development prohibit use of vegetation-lined channels.

7.2.4 Rock-Lined Channels

Rock-lined channels, including ordinary riprap, grouted riprap, and wire enclosed riprap (gabions), are typically designed for higher flow velocities with the same potential adverse impacts on downstream channels and floodplains, as described for smooth-lined channels.

Design criteria for rock-lining are typically derived from field experience or computer modeling because failure modes and preventative design mechanisms are stochastic. Individual rock is designed for collective hydraulic function. Performance of rock as a protective lining against the hydraulic force of flowing water depends on achieving an optimal design balance between the rock gradation and the thickness of the rock layer and the thickness of the granular bedding and the number of increasingly finer granular layers.

Use of rock as a construction material requires careful oversight to ensure the rock to be used conforms to gradation design specifications within acceptable tolerance limits.

The long term hydraulic performance of the rock-lining requires intensive maintenance, relative to less structural forms of conveyance such as vegetation-lined channels. Rock-lined channels must be maintained to ensure preservation of the physical integrity of the constructed rock lining that is consistent with design assumptions for gradation and layer thickness.

The specifications for rock-lined channels require careful calibration of the design to the specific hydraulic constraints of the project. This requires consideration of the base flow conditions, minor storm flood events and major storm flood events.

Rock-lined channels will be permitted only where restrictions within the drainage easement within existing development prohibit use of vegetation-lined channels. The Village will consider this option only in very limited circumstances where it has been demonstrated that there are no feasible alternatives. This design will typically be limited to erosion control at channel alignment discontinuities such as outfalls, confluences, sharp bends, and steepened bed slopes.

7.2.5 Revetment Mattresses

Revetment mattresses consist of synthetic flexible fabric that is structurally reinforced by pressure injecting a fine-aggregate concrete mix to form a stable lining for erosion control on embankments. The fabric is prefabricated to project specifications and dimensions and placed over minimally graded terrain before pressure injecting with concrete mix. Controlled bleeding of the mixing water through the porous fabric produces all the desirable features of concrete mix with a low water to cement ratio, including rapid setting, high strength, and exceptional durability.

Cost effectiveness, performance characteristics, and ease of installation make revetment mattresses a viable form of slope stabilization for diverse applications, including shorelines, levees, dikes, canals, holding basins, slopes with limited access for rock placement, and slopes with a permanent pool that cannot be easily dewatered.

Within the Village, revetment mattresses will be permitted only where restrictions within the drainage easement within existing development prohibit vegetation-lined channels.

7.2.6 Composite Channels

The Village encourages open channel design that is in accordance with the policies as presented in Chapter 1.0, responsive to the site-specific constraints of the project and the criteria presented in this Drainage Criteria Manual, environmentally integrated with the ambient urban, rural, and geographical characteristics, and developed for the purpose of balancing multiple use benefits and economic constraints with limited easement availability.

7.3 Design Criteria

The analysis and design of open channels shall be in accordance with the criteria presented in the Major Drainage Chapter, Volume 1 of the UDFCD Drainage Criteria Manual. Detailed design criteria and design procedures specific for the Village are highlighted in the following Sections.

The design policy of the Village is to provide guidelines that are consistent with regional stormwater drainage policy. The guidelines are intended to serve as a minimum standard and not intended to replace site-specific analysis and design requirements of individual projects..

Alternate cross-sections can be proposed that are appropriate to the project constraints and in accordance with this Drainage Criteria Manual. The feasibility of alternate designs shall include an economic analysis performed in accordance with sound and reliable techniques for estimation of project construction and long-term maintenance costs.

Software packages for analysis and design shall be applied in accordance with the criteria presented in Chapter 17.0.

7.3.1 Natural Channels

7.3.1.1 Hydraulic Design Criteria

Frictional Resistance. Channel conveyance shall be computed using a Manning roughness coefficient (n) selected from Table MD-1 from the UDFCD Drainage Criteria Manual. Maximum flow depths shall be determined using a high n-value to represent unmaintained channel conditions. Maximum limiting velocities shall be determined using a low n-value to represent maintained channel conditions.

Grade Control Structures. Grade control structures to reduce erosive velocities shall be landscaped and designed in accordance with criteria presented in Chapter 12.0.

7.3.1.2 Floodplain Criteria

The applicant shall prepare plan and profile drawings of the floodplain showing existing and proposed conditions, including proposed bridge or culvert crossings that may modify the flow conditions. Any such modifications shall be consistent with the criteria in Chapter 4.0.

7.3.2 Vegetation-Lined Channels

7.3.2.1 Hydraulic Design Criteria

Frictional Resistance. Channel conveyance shall be computed using a Manning roughness coefficient (n) selected from Figure 7-1. Maximum flow depths shall be determined using an n-value from Retardance Curve C which represents unmaintained channel conditions. Maximum

limiting velocities shall be determined using an n-value from Retardance Curve D which represents maintained channel conditions.

Flow Velocity. Where vegetation-lined channels are used to control phosphorus loading or where wetlands are located within the proposed alignment, the maximum normal depth velocity for the water quality design storm discharge shall meet the criteria in Chapter 16.0.

Grade Control Structures. Grade control structures to reduce erosive velocities shall be landscaped and designed in accordance with criteria presented in this Chapter 12.0.

7.3.2.2 Cross-Section

The channel cross section shall be designed to provide the required hydraulic conveyance within easements in a manner that maximizes the aesthetic integration with the ambient environment.

Low Flow Channel. The Village strongly encourages use of vegetation-lined low flow channels to minimize degradation of the aquatic habitat and to maximize water quality treatment benefits. Smooth-lined low flow channels are prohibited unless required by existing site development and unless approved by the City Manager or designee. The minimum low flow design capacity shall be 3% of the 100-year peak flow, but not less than 1.0 cfs.

Bottom Width. The minimum bottom width shall be 4 feet where low flow channels are provided. Where low flow channels are not provided, the minimum bottom width shall be consistent with sound hydraulic design and maintenance requirements.

Side Slopes. Side slopes shall be 4 (horizontal) to 1 (vertical) or flatter. Designs with channel side slopes steeper than 4:1 are prohibited unless approved by the City Manager or designee.

Freeboard. Freeboard shall be required for all channels where localized overflow is not permitted for ponding benefits or other reasons. The minimum freeboard height shall be 1.0 foot. Freeboard height shall be provided in accordance with Equation 7-1.

$$H_{FB} = 0.5 + \frac{V^2}{2g} \qquad (7\text{-}1)$$

where H_{FB} = freeboard height (feet)
V = average channel velocity (fps)
g = acceleration of gravity = 32.2 ft/sec^2

Easement Width. The minimum easement width shall include the top width at the freeboard elevation and the width of the maintenance access.

7.3.2.3 Maintenance Requirements

Vegetation-lined channels shall be designed to minimize long-term maintenance requirements by including design features that minimize deterioration by velocity-induced scour.

7.3.3 Concrete-Lined Channels

Concrete-lined channels shall be designed in accordance with the criteria presented in the UDFCD Drainage Criteria Manual. Channels constructed of other smooth linings, such as roller-compacted concrete, soil cement, and shotcrete, shall be designed in accordance with applicable manufacturer's criteria and shall require approval by the City Manager or designee.

7.3.3.1 Hydraulic Design Criteria

Frictional Resistance. Channel conveyance shall be computed using a Manning roughness coefficient (n) selected from Table MD-1 from UDFCD Drainage Criteria Manual. Maximum flow depths shall be determined using a high n-value to represent unmaintained channel conditions. Maximum limiting velocities shall be determined using a low n-value to represent maintained channel conditions.

7.3.3.2 Structural Design Criteria

1) All concrete lining for drainage channels shall be designed to withstand the hydrostatic and hydrodynamic forces of the design discharge. The minimum thickness shall be no less than 7 inches.
2) All concrete-lined side slopes shall be 2:1 or flatter. Use of steeper slopes shall require structurally reinforced retaining wall design.

7.3.3.3 Bedding Compaction

Compaction. Minimum compaction requirements shall be 90% of maximum density, in accordance with ASTM D-1557, Modified Proctor, and shall pertain to all fill material, all bedding material, the top 12 inches of the maintenance access road, and the top 12 inches of finish grade within 10 feet of the edge of the channel.

Geotextiles. The use of geotextile fabrics shall require approval by the City Manager or designee.

7.3.3.4 Maintenance

Maintenance and public access shall be as required by the City Manager or designee. Ladder-type steps shall be installed at maximum intervals of 400 feet and staggered on both sides of the channel. The bottom rung shall be no more than one-foot vertical above the channel invert.

7.3.4 Rock-Lined Channels

Rock-lining is typically most cost effective when applied as a localized form of erosion control for short channel reaches, less than 0.25 mile, where site constraints dictate a change in flow velocity, alignment, or cross section. Rock-lining may also be used for low flow channels.

The ease of placement, construction, and installation of various types of rock linings must be balanced with increased long-term maintenance required for sustaining hydraulic conveyance and visual esthetics. Channels lined with gabions or light riprap are susceptible to degradation by erosion and destruction by vandalism.

Rock lining is classified for design purposes as ordinary riprap, grouted riprap, or wire-enclosed rock, also known as gabions.

7.3.4.1 Hydraulic Design Criteria

Frictional Resistance. Channel conveyance shall be computed using a Manning roughness coefficient (n) selected from Table MD-1 from UDFCD Drainage Criteria Manual. Maximum flow depths shall be determined using a high n-value to represent unmaintained channel conditions. Maximum limiting velocities shall be determined using a low n-value to represent maintained channel conditions.

7.3.4.2 Maintenance Requirements

Maintenance and public access shall be as required by the City Manager or designee.

7.3.4.3 Ordinary Riprap

Ordinary or loose riprap consists of a layer of large rock that meets specified material properties and placed by machine to achieve the design specifications. Material design properties of riprap include the size, weight, and shape of the individual rocks, the composite gradation, thickness, and slope of the rock layer, and the type of bedding. Hydraulic design properties include velocity, direction of flow, and localized turbulence due to eddies and vortices.

Riprap smaller than 18 inches must be mixed with soil, covered with topsoil, and revegetated in order reduce vandalism and improve the aesthetics of the installation. The Village strongly encourages similar treatment of installations with larger riprap.

Riprap failures typically result from undersized or rounded rock or rock with an improperly specified gradation, all of which can reduce the protection provided by interlocking of the individual rock pieces and improperly designed bedding which permits leaching of channel particles through the riprap layer.

7.3.4.4 Grouted Riprap

Grouted riprap provides a relatively impervious channel lining that is subject to less vandalism and is typically less maintenance intensive than loose riprap when properly designed and constructed. Structural failure and aesthetic deterioration result from improper design, construction, and/or maintenance. The Village discourages use of grouted rock as a construction material for channel linings or grade control structures unless required by existing site constraints. All grouted riprap designs shall require approval by the City Manager or designee.

All grouted riprap designs shall minimize to the maximum extent practical, including the selection of larger riprap and the volume and thickness of the grout in the design.

7.3.4.5 Wire-Enclosed Rock

Wire enclosed rock refers to a protective layer formed by enclosing rock in a wire basket, or gabion, which functions as a single structural unit. Wire enclosed rock provides a structurally stronger alternative for designs requiring individual rock larger than commercially available and having greater geometric versatility.

Wire-enclosed riprap shall be used as a construction material for channel linings, erosion protection, and grade control structures only as a last resort and shall require approval by the City Manager or designee. Wire enclosed riprap shall not be used in areas exposed to annual flooding.

7.3.5 Composite Channels

Composite channels shall be designed in accordance with the UDFCD Drainage Criteria Manual and the manufacturer’s criteria applicable to the selected channel lining materials. The applicant shall include any applicable manufacturer’s data and design specifications in the drainage studies.

Insert Figure 7-1.

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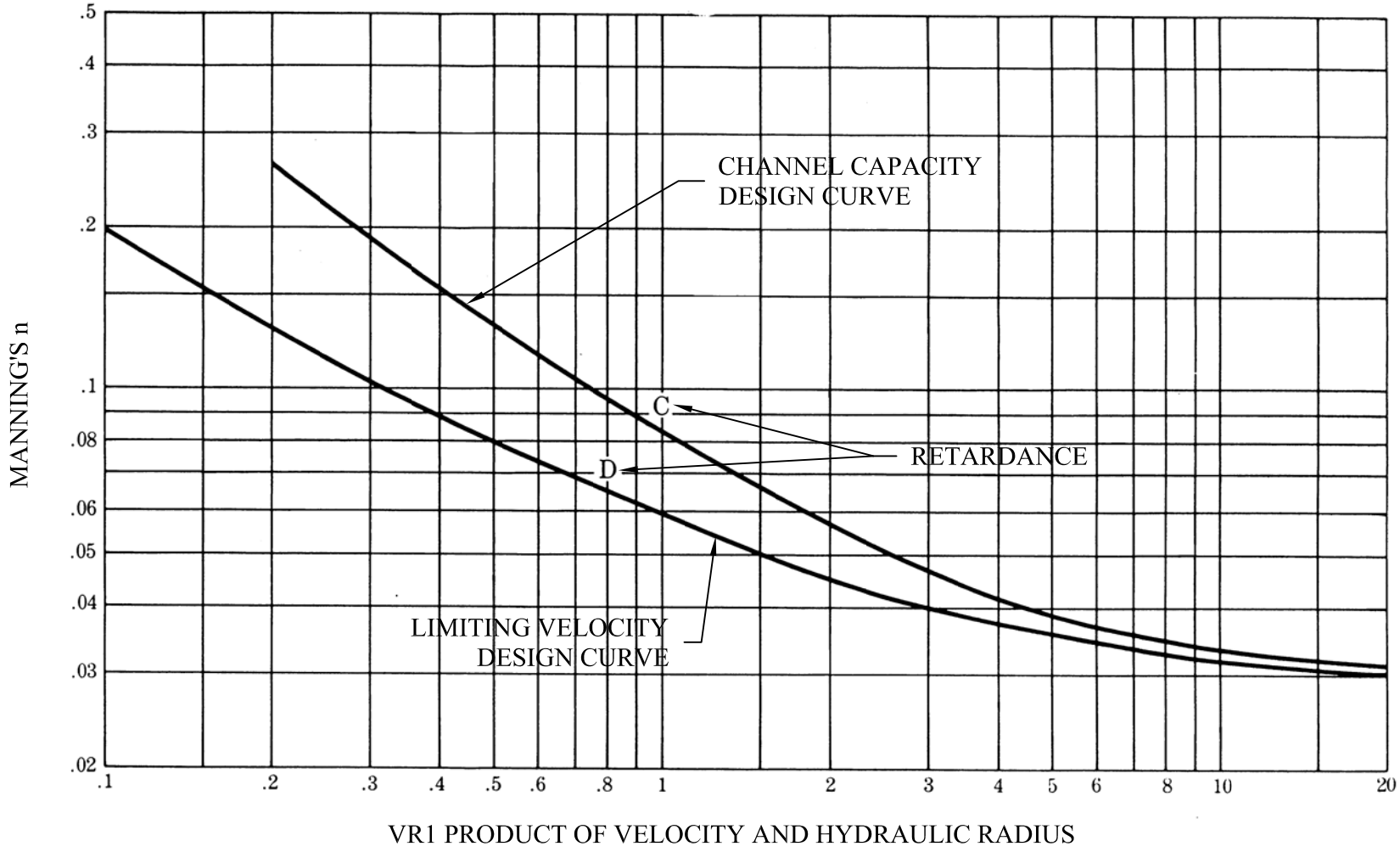

Greenwood Village
Open Channels
October 2003

Figure 7–1
Manning Roughness Coefficient (n)
for Grass Lined Channels

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