# CHAPTER 5 OPEN CHANNELS

## 5.1 NATURAL STREAMS

### 5.1.1 Scope

This section sets forth requirements for the protection of natural streams as a conveyance for stormwater. Unless otherwise provided for by City, State, or Federal ordinance, regulation, or standards, existing natural streams shall be preserved and protected in accordance with this section. Where natural streams are not preserved, the drainage will be handled through systems designed in accordance with Chapter 4, Enclosed Systems or Section 5.2, Engineered Channels.

### 5.1.2 Stream Preservation and Buffers Zones:

Stream buffers shall be per the City of Columbia Stream Buffer Ordinance in Chapter 12A of the City Code of Ordinances.

### 5.1.3 In Stream Construction - General Requirements:

If construction is proposed within the inner stream buffer as defined in Chapter 12A-233 of the ordinances, a stream assessment is required. The information generated by the stream assessment shall be used in designing the bridges, culverts, utility work, stormwater outfalls (other than edge of buffer outfalls) and any other in-buffer infrastructure. Construction in streams or their buffer zones shall conform to the general requirements of this subsection and to the appropriate specific requirements of the subsections following:

#### A. Stream Assessment

A stream assessment shall be conducted in accordance with Section 5.1.4 for all construction within the inner stream buffer zone except for discharge outfalls. Along streams for which no official buffer exists, (i.e. streams in land which was platted prior to the passage of the stream buffer ordinance) the language of the buffer ordinance (Article X of Chapter 12A) will be applied to determine how close to a stream work can be done without requiring an assessment.

Purpose: A stream assessment provides basic knowledge about the stream: bed and bank material, vegetation, general erosion trends, debris and sediment, bank full depth, etc. These things have a direct effect on potential designs.

As part of the assessment, a rating will be determined; if the stream rates poor the engineer should consult with someone who specializes in stream work; if fair, the engineer should be sure to address those items that rated poorly when designing grade control; if good, the engineer can generally imitate the existing riffle.

### B. Hydraulic and Geomorphic Energy Management

The pre-project and post-project hydraulic and energy grade lines for the 100%, 10%, and 1% storm flows shall be plotted. The region of a stream where in-stream construction causes a change in these grade lines is considered the zone of influence. The engineer shall provide adequate sediment transport and channel protection designs within the zone of influence. The extent of the zone of influence downstream shall be generally limited by energy dissipation and grade control. The upstream limit of the zone may extend a distance beyond the construction as a drawdown or backwater curve. Within the zone of influence, the energy of the flow on the channel will be evaluated for the potential of excessive scour, deposition, initiation of headcuts, or other instability. Use of vegetation to increase bank resistance and minimize increases or abrupt changes in velocities is recommended. Bank or bed stabilization may be required in areas of unavoidable velocity or depth increase.

### C. Sediment Transport Continuity

The minimum post-project applied shear to the bed of the channel in the zone of influence at the 100%, 10%, and 4% ultimate-conditions storm flow shall not be less than 90% of the minimum pre-project applied shear in the zone, so as to maintain the ability of the channel to transport sediment. If such shear stresses cannot be maintained, the engineer will evaluate the potential for future sediment removal or maintenance.

### D. Transitions

In-stream structures shall be designed to gradually blend into the natural channel and provide a smooth transition of both geometry and roughness.

### E. Repair of Disturbed Banks

The side slopes of banks where construction occurs shall be restored with vegetation as quickly as possible.

**F. Professional Judgment**

Natural streams are complex, variable, and strongly governed by local geology and climate. These standards are based on general guidelines of good practice on typical local streams and may not be optimal or sufficient in all cases. Specific requirements may be increased or waived by the Director if conditions warrant and decisions should be guided by prudent engineering and fluvial geomorphic judgment.

### 5.1.4 Stream Assessment

The Steam Assessment provides the framework for engineers to gather stream data needed to develop a general indication of the stream condition and to possibly help guide design. A stream assessment, as required above, will extend a minimum of one wavelength up and downstream of the area to be impacted by construction. (or 10 channel widths in streams with ill-defined meander patterns.) It shall include the components listed below, except as modified by the Director to better fit project needs. An example submittal is shown in Figures 5.1.4.1A and B in Appendix F.

**A. Plan Form Analyses and Inventory**

The plan-view of the natural stream using aerial photographs or planning-level aerial survey shall be plotted to an appropriate scale. Full topographic surveys of the entire reach study area is not required. The following items shall be shown:

1. Ordinary high water mark.
2. Top of bank.
3. Ground contours (if available).
4. "Bank-full" and floodplain for the 1% ultimate-conditions storm (see paragraph B).
5. Thalweg, locations of riffles and pools, and spacing between riffles (see paragraph C).
6. Exposed bedrock, areas of differing bed and bank soil or rock materials, and the D50 and shear stress ratio at each riffle (see paragraph D)
7. Active scour and depositional areas, point bars, and islands.

8. Vegetation within the buffer zone, called out as mowed grass, mowed with trees, unmowed grass and plants, wooded, and bare. Trees greater than 6" diameter within 25 feet of the top of bank shall be located individually or by group. The species of dominant trees should be noted.

9. Meander length, wavelength, meander amplitude, bank-full width, and radius of curvature for each bend.

10. Total meander and valley length and sinuosity for the reach.

11. Photographs of main channel, streamside vegetation, and each riffle, appropriately referenced to plan-view location.

**B. Bank-full Width, Depth and Discharge**

The geomorphic "bank-full" width, depth, and discharge shall be estimated using field indicators as detailed in Chapter 7 of USDA (1994). If field indicators are inconclusive, "bank-full" flow shall be estimated as the elevation and spread of the of the 1-year storm flow, based on routing the 1-year storm flow through the existing channel using Mannings equation at a representative cross section. This assumption is intended to provide a rough upper estimate of the bank-full flow.

**C. Longitudinal Profile and Sections**

The elevations of the profile along the thalweg shall be field surveyed to the nearest 0.1 ft. and the following features noted: riffles, pools, exposed bed rock, and advancing headcuts (areas of bed elevation change that appear to be actively migrating upstream). The top of left and right bank and any field indicators of bank-full flow such as limits of woody vegetation or top of point bars shall be plotted at correct elevation along the profile. The bank-full flow and 1% (100-yr) storm flow profiles shall be plotted.

One field cross section shall be surveyed through each pool and riffle, and the depth and width of bank-full flow and floodplain for the 1% storm shall be shown on each section.

Where pools and riffles are not well defined, survey one cross section every 7 channel widths.

**D. Bed and Bank Materials Analyses**

The type of rock exposed in the bed and banks shall be identified. Bank soils shall be reported by Uniform Soil Classification using the visual-manual procedures (ASTM D 2488-00). Estimate the median partical size (D50) for each reach where the bed material visually changes. A shear stress ratio shall be calculated for each riffle based on the applied shear at bank-full flow divided by the critical shear of the D50 particle in the riffle, using methods and tables described below.

**E. Critical Shear Stress Analysis**

The Shear stress ratio shall be determined in accordance with the guidelines below:

1. The average applied shear stress ($\tau_o$ ) may be calculated from the hydraulic data as follows:

   $\tau_o = \gamma$ RS

   where $\gamma$ is the specific weight of water (62.4 pcf), R is the hydraulic radius at bank-full flow, and S is the water surface slope along the main channel bank-full flow, averaged over several bends in the area of the intervention. Effective flow may be calculated using methods described in detail in USACE 2001 or may be assumed to be equivalent to the 100% storm.

2. The critical shear stress, $\tau_c$, is that at which particles in the bed or bank are entrained and scour ensues.

   Critical shear stresses are listed in Table 5.1.4.1 in Appendix F. This table presents critical shear for sediment-laden water and where noted, clear water. The user must exercise judgment as to future conditions. Clear water values may be used below a heavily piped area, concrete channels designed to contain the future flows or immediately below a managed detention pond.

3. The ratio of average boundary stress to critical stress is the shear stress ratio:

   shear stress ratio = $\tau_o / \tau_c$

   If bed and bank materials are distinct, then the shear stress ratio should be calculated for each. If the shear stress ratio of either streambed or bank is greater than one, the channel is prone to near-term adjustment and any interventions should be designed to prevent accelerated erosion. If the bed consists of rock, then the shear stress ratio is not applicable, unless the rock is prone to fracturing, slaking, or break-up, in which case the median size of particle should be used for calculation of the ratio.

**F. Plan-Form Ratios**

The following ratios shall be calculated, and those that lie outside the typical range shall be noted. Streams are highly variable and ratios outsides these ranges do not necessarily indicate problems:

| Ratio | Typical Range |
|---|---|
| Thalweg length / Valley length (sinuosity) | 1.1 to 1.5 |
| Meander length / Bank-full width | 10 to 14 |
| Radius of curvature / Bank-full width | 2 to 5 |
| Riffle Spacing / Bank-full width | 5 to 7 |

**G. Channel Condition Scoring Matrix**

Using information summarized above, the channel condition scoring matrix given in Table 5.1.4.2 in Appendix F shall be completed. A rating of 12 indicates a stream of moderate stability that will likely require only standard levels of protection during construction. A rating between 12 and 18 indicates that special measures may be necessary to address those issues rated as poor in the assessment. Streams with a rating greater than 18 may exhibit significant system-wide instability and should be studied in more detail by experts in river engineering and fluvial geomorphology. (This scoring system is newly developed and its results shall be considered provisional.)

**H. Using the Stream Assement Data and the Channel Condition Scoring Matrix**

For channels with a score of 9.8 to 12, use the data gathered in the Stream Assesment (stream shape, bed and bank material, allowable shear, bank full depth and width, etc.) to guide channel intervention designs. For scores of 12 to 18, use the data not only to guide the design, but to make accommodations for those parameters that were rated fair and poor in the design. For scores of 18 or greater, additional analysis is necessary to identify dominant process driving instability.

### 5.1.5 Discharge Outfalls

Energy management and sediment continuity checks are not required; however, energy dissipation shall be provided to reduce post-development shear stress to pre-development shear stress at the outfall. Discharge points for outflows from enclosed systems or constructed channels shall be designed as one of the following:

**A. Primary Outfall**

Primary outfalls are those where the entire upstream channel is replaced by an enclosed system or constructed channel which discharges flow in line with the direction of the downstream segment. Energy dissipation shall be provided at the outlet to reduce velocities per Section 4.6.4. Grade control downstream of the outlet and energy dissipater shall be provided to prevent undermining of the outfall by future headcuts per Section 5.1.8. The alignment and location of the outfall and associated energy dissipater and grade control should make a smooth transition into the downstream channel. Primary outfalls shall be used whenever the contributing drainage area of the outfalls is greater than 80% of the downstream channel.

**B. Tributary Outfall**

Tributary outfalls are primary outfalls located on a tributary to a larger downstream segment. Energy dissipation and transition to natural stream flow should take place in the tributary at least ten channel widths upstream of the confluence. Grade control in the tributary upstream of the confluence shall be provided. Tributary outfalls may be used in all situations of tributary flow.

**C. Lateral Outfall**

Lateral outfalls are small outfalls that discharge from the banks of a natural stream. Outfalls shall be located to enter on a riffle or from the outside of a bend, but should generally not enter from the inside of a bend. Outfall pipes shall be oriented perpendicular to the flow of the stream with the invert at or slightly below top of the next downstream riffle. Outfalls shall be flush with or setback from the bank. The bank shall be shaped to provide a smooth transition and protected with reinforced vegetation (preferred) or rip-rap. If the outfall is in a bend, it shall be set back from the existing bank a sufficient distance to account for future meander migration, and the transition shall be graded and reinforced with vegetation. Rip-rap or hard armor protection should not be used in a bend. Perpendicular outfalls may only be used when the contributing drainage area of the outfall is less than 40% of that in the downstream channel.

**D. Edge of buffer Outfall**

Edge-of-buffer outfalls are discharge points in the outer half of the riparian buffer that return the discharge to diffused overland flow. Outfalls shall be designed to spread flow and allow overland flow and infiltration to occur. Overland flow shall be directed to run in the outer portion of the buffer parallel to the channel direction to increase length of flow and prevent short-circuiting directly into the stream. Low weirs and berms may be graded to direct flow and encourage short-term ponding. The buffer zone utilized for infiltration shall be maintained in dense, erosion-resistant vegetation designed to withstand the shear stresses of a 10% storm. Edge-of-buffer outfalls that are part of a system of upland drainage using multiple small, distributed overland swales and ditches instead of pipes may provide significant infiltration and water quality treatment. Edge-of-buffer outfalls shall only be used if each individual outfall can be designed to operate without scour or the formation of gullies.

At no time shall Edge of buffer outfalls discharge into a buffer area with an average slope greater than 2% from receiving stream flowline elevation to the edge of buffer outfall flowline elevation.

### 5.1.6 Culverts, Bridges, and Above Grade Crossings

**A.** Crossings should generally be located on a riffle. If the width of the roadway, pathway or above grade crossing is large relative to the length of the riffle, then grade control structures shall be provided at the riffles upstream and downstream to isolate the impact of the crossings. If a crossing cannot be made at a riffle, avoid armoring a pool and place at-grade grade control structures at the riffle immediately upstream and downstream of the crossing. Maintain sediment transport continuity and avoid altering the channel cross-section.

**B.** Realignment of channels to accommodate crossings and their approach should be avoided and minimized as much as possible. Any areas relocated shall have the banks stabilized in accordance with Section 5.1.9 and shall be included in the reach isolated by upstream and downstream grade control.

**C.** For bridges the multi-stage channel shape should be maintained and additional area to convey the design flow shall be above the elevation of the bank-full discharge.

**D.** For multi-cell pipe and culvert crossings that have a cumulative width larger than the bank-full width, those cells wider than the bank-full width shall have a flowline located at the lowest estimated bank-full depth, or a weir wall or other structure upstream of the culvert opening shall be installed with a height to prevent access to the cell during flows less than bank-full flow. The weir wall shall be designed so that the hydraulic efficiency at the 1% ultimate conditions storm is not reduced. Without these features, the culvert will have a tendency to build up deposits and lose capacity or require frequent maintenance, particularly when crossings are located in sharp bends or streams with high sediment loads.

**E.** Culverts shall be designed so that there is no backwater effect at all flows up to the 50% storm discharge. Energy management and sediment transport continuity shall be checked.

### 5.1.7 Below Grade Stream Crossings

**A.** Below grade stream crossings primarily include utility pipelines. Crossings should generally be at riffles and grade control structures constructed at the riffle, in addition to or constructed integrally with any encasement of the line the utility may require.

**B.** If riffle crossing is not feasible, the crossing should be in a pool that is protected by a downstream grade control structure. The top of crossing elevation should be at least two feet below the top of grade control. Crossings under pools should not be armored directly, but are protected by downstream grade control.

**C.** Below grade crossings shall be perpendicular to the stream whenever possible. If a perpendicular crossing is not feasible, the grade control protecting the crossing shall be perpendicular.

**D.** Constriction or alteration of the pre-existing channel shape shall be avoided. If alteration occurs, sediment transport continuity and energy management shall be verified. Stream banks shall be repaired using vegetative methods whenever possible and the hydraulic roughness of the repaired stream bank should match that of the undisturbed stream banks.

### 5.1.8 Grade Control

**A.** Where grade control structures are required, they shall be placed in locations where the stream bed profile will support the creation or continuance of a riffle. The flowline of the grade control shall match the existing riffle.

**B.** Where stream slope is less than 2%, the Newberry-style grade control structure detailed in Figure 5.1.8.1 is recommended. Structures shall be constructed from durable stone sized using USACE methodology for steep channels (USACE EM 1110-2-1601, page 3-8, Equation 3-5). Rock shall generally comply with USACE gradations as given in (USACE EM 1110-2-1601, Hydraulic Design of Flood Control Channels, Chapter 3). Shotrock with sufficient fines to fill voids may be used. The use of filter fabric and uniform gradations of stone are discouraged in stream beds.

**C.** Where grades are in excess of 2%, low-drop step structures should be used.

**D.** Alternate styles of grade control may be approved by the Director. Guidance for grade control design is given in Thomas et.al.

**E.** Construction of new grade controls structures may be waived by the Director if it is determined that existing riffles are adequate to prevent or retard advancing headcuts, or if it is preferable to The City to accept the risk of future headcut than to further disturb the channel.

### 5.1.9 Bank Stabilization Projects

**A.** Bank stabilization projects should generally be limited to cases where existing buildings or infrastructure face significant property damage or safety issues. Projects to stabilize banks to facilitate reductions in buffer widths for new construction shall be avoided.

**B.** Prior to stabilization, the causes of the instability should be considered, including the stream's current phase of channel evolution (Interagency, 2001, Chapter 7) and direction of meander migration. Stabilization may be unnecessary if a channel has ceased incision and widening and is in the process of deposition and restoration. If stability issues appear widespread or complex, a systematic evaluation of the stream system by professionals with expertise in river engineering and fluvial geomorphology may be justified.

**C.** Instability caused by geotechnical failure (slumping of banks due to weak soils in the adjacent slopes) shall be distinguished from fluvial failure (erosion of banks caused by stream flows). For geotechnical issues, a geotechnical engineer shall evaluate the slope stability. Geotechnical designs shall provide for a 1.5 factor of safety (ratio of theoretical resisting forces to driving forces) against slope failure where it would endanger buildings, roadways, or other infrastructure, unless a lower factor of safety is approved by the Director.

**D.** Bank stability projects shall have a design life greater than the useful life of the facility being protected, or a life cycle cost analyses shall be performed that considers replacement and repair over the entire protection period. Responsible parties for future maintenance shall be identified.

**E.** Stabilization should begin and end at stable locations along the bank. Bank stabilization should be limited to areas of potential erosion and are rarely required on the inside of bends. For long projects, stabilization may alternate from side to side and is rarely necessary across an entire cross section. The existing cross section should be mimicked to the extent practical and need not be planar or uniform over the entire length. Grade control shall be provided at the riffle both upstream and downstream of the stabilization to isolate it from the surrounding stream and protect the foundation from undercutting. Control at intermediate points for longer projects may also be required. Energy management and sediment transport continuity shall be checked, and energy dissipation provided if necessary.

**F.** "Hard-Armor" projects are those projects that use rip-rap, placed stone, gabions, retaining walls, or other rigid structures to provide geotechnical and fluvial stability. Such projects shall be designed in accordance with EM 1110-2-1205 (USACE, 1989), EM1110-2-1601 (USACE, 1994), or HEC-11 (FHWA 1989). Materials shall be sized to prevent dislodgement in the 1% storm. Gradation should comply with USACE or FHWA recommendations. Stones should be placed to maintain roughness and variations. All material shall be well placed to ensure interlock and stability. Materials shall be keyed into the bed and banks with adequate allowance for scour along the toe and the structure should have adequate foundation. Vertical walls should be avoided when possible as they tend to concentrate scour at their toe and are typically smoother than the natural channel.

**G.** Soil bioengineering involves the use of living vegetation in combination with soil reinforcing agents such as geogrids to provide bank stabilization by increasing soil shear resistance, dewatering saturated soils, and by reducing local shear stresses through increased hydraulic roughness.

**H.** Bio-engineering projects shall be designed in accordance with the principals of NRCS (1996) and Gray and Sotir (1996). Designs will be tailored to the urban environment by consideration of the requirement for immediate functionality upon construction, the extreme variability and high shear stress of urban flows and the availability of mechanized equipment and skilled operators.

**I.** Selection of plants and specifications for planting methods and soil amendments shall be prepared by a professional competent in the biological and stabilization properties of plants.

**J.** Plants selected shall be appropriate to local conditions and shall be native varieties to the greatest extent practical. Evaluation of local conditions includes assessment of site microclimate, bank slope, soil composition, strength and fertility, type and condition of existing vegetation, proximity to existing infrastructure, soil moisture conditions and likelihood of wildlife predation. Engineering factors influencing plant selection include frequency, height and duration of inundation, near-bank shear stress, size and volume of bed load as well as depth and frequency of scour.

**K.** Plants may be either locally harvested or purchased from commercial nurseries. When harvesting, no more than 10% of a given stand may be removed and no plant on the state rare or endangered species list may be harvested or damaged in harvesting operations. Plant material grown near the metropolitan area is adapted to local climatic conditions and is preferred over more remote sources. Some species such as red maple are particularly sensitive to locale and may only be used if locally available. Seed, plant plugs, rhizomes, whips, live stakes, bare root and container stock may be used. Turf grasses, noxious or invasive species shall not be used. A variety of plant species shall be used to provide greater reliability to a design. For critical functions such as protection from toe scour a minimum of three species should generally be employed.

**L.** Soil bioengineering methods are properly applied in the context of a relatively stable stream system, and relevant general requirements for all stream bank stabilization projects given in this section apply to bio-engineered projects. Soil bioengineering alone is not appropriate when the zone of weakness lies below the root zone of the plantings, or when rapid draw down can occur, such as in a spillway or dam embankment.

**M.** Composite methods are those which employ both hard armor and soil bio-engineering. Typically, armor for toe protection in critical locations is provided, with soil-bioengineering for the remainder. Design principals for both hard armor and soil-bioengineering shall be observed as appropriate.

**N.** In-stream Stability Structures: In-stream structures are used to focus flow, control grade, dissipate energy and selectively lower near-bank stress. Stream barbs, weirs, guide vanes, vegetative sills, longitudinal peak stone, and grade controls are among the more commonly used in-stream structures. When constructed of natural material such as rock, such structures also create aquatic habitat. They may be used alone or in combination with hard armor, bio-engineering or composite methods. In-stream structure design is a river engineering practice and is beyond the scope of this standard. Preliminary guidance and references for the design of some common structures is given in Castro (1999) and Interagency (2001).

### 5.1.10 Stream Restoration

Restoration of urban streams is defined as the re-establishment of natural channel geometry, materials and vegetative buffers with the intent of restoring natural geometry and functions to streams that have been disturbed or eliminated. While there are significant potential ecological and quality of life benefits from stream restoration, successful design is data-intensive and requires an interdisciplinary approach. Design of stream restoration projects is beyond the scope of this standard. Interagency (2001) describes the general procedures, benefits, and requirements of stream restoration.

## 5.2 ENGINEERED CHANNELS

### 5.2.1 Scope

The criteria in this section apply to created open channels or modified existing open channels where a stream buffer does not exist.

### 5.2.2 Easements

Permanent easements shall be dedicated to the City for all open channels.

**A. Engineered Channels**

Easements shall be 16 feet wide or wide enough to contain the water surface from the 1% return frequency storm, whichever is greater. Easements shall be continuous between street rights-of-way. When an improved channel begins or ends at a point other than the right-of-way of a dedicated street, a 16-foot or wider easement graded to provide maintenance equipment access shall be dedicated from the end of the channel to a street right-of-way. These are minimum requirements.

Generally, easements shall be required for swales that collect stormwater runoff from more than two properties or as required by the City.

**B. Roadside Channels**

Roadside ditches are engineered channels that are located wholly or partly within the street right-of-way. Roadside ditches in the street right-of-way do not require an easement. Otherwise, roadside ditches shall have a dedicated easement from the street right-of-way extending to five feet outside of the top of the outside bank of the channel.

### 5.2.3 Design Storm

Engineered channels shall be designed to completely contain the 1% return frequency storm and be stable during the 10% return frequency storm.

### 5.2.4 Velocity

Flow velocity in open channels (with the exception of roadway gutters) shall not exceed the following:

Flow depths greater than 6" - 6 feet per second
Flow depths 6" or less - 15 feet per second (or whatever the lining can withstand, whichever is less)

### 5.2.5 Freeboard

Freeboard shall not be required above the design headwater pool elevation at the culvert entrance. However, the low floor of adjacent structures shall be 1’ above the 1% return frequency storm water surface elevation.

### 5.2.6 Channel Linings

**A.** Minimum lining height shall be the selected design storm water profile plus at least a 0.5-foot freeboard.

**B.** All channel linings, except turf, shall contain provision for relieving back pressures and water entrapment at regular intervals and shall be provided with a filter underlayment to prevent soil piping.

**C.** Lining height on the outside bend of curves shall be increased by:

$$y = \frac{D}{4}$$ where:

$y$ = Increased vertical height of lining in feet
$D$ = Depth of design flow in feet

**D.** Increased lining height shall be transitioned from y to zero feet over a minimum of:

$30 \times y$ feet downstream from the point of tangency (P.T.).

$10 \times y$ feet upstream from the point of curvature (P.C.).

### 5.2.7 Lining Material

The types of lining material listed in Table 5.2.7.1 in Appendix F shall be used to control damage and erosion. All riprap and gabion linings shall be designed with a filter fabric. The design of the lining material shall protect the channel for conditions up to the 1% storm. This criterion may be reduced to the 10% storm if the Director approves and if responsibility for repair of channel linings in storms greater than 10% is clearly established.

Other types of lining materials not specifically listed in Table 5.2.7.1 in Appendix F may be used when approved by the Director.

Concrete lined open channel bottoms are discouraged.

### 5.2.8 Side Slopes

Side slopes shall not be steeper than:

- 3 horizontal to 1 vertical for turf lining.
- 2.5 horizontal to 1 vertical for all other lining materials, unless a geotechnical analysis indicates a steeper slope can be used.
- Side slopes may need to be flatter than 3H:1V, if necessary to stabilize slopes.

### 5.2.9 Alignment Changes

Alignment changes shall be achieved by curves having a minimum radius of:

$$R = \frac{V^2 \cdot W}{8D}$$ where:

$R$ = Minimum radius on centerline in feet
$V$ = Design velocity of flow in feet per second
$W$ = Width of channel at water surface in feet
$D$ = Depth of flow in feet

### 5.2.10 Vertical Wall Channels

Vertical walls may be used for structural lining of improved channels when site conditions warrant; subject to the following special requirements:

- Walls shall be designed and constructed to act as retaining walls.
- Adequate provisions shall be made for pedestrian entry/exit from the channel.

### 5.2.11 Energy Management

Use of grade control structures can be used to manage boundary shear.

Energy dissipation structures shall be designed in accordance with Natural Stream Section.