CHAPTER 5 OPEN CHANNELS

This chapter focuses on the conveyance of stormwater in open channels. It is divided into natural stream systems and engineered channels. With primarily earthen bank and bed materials, these systems are particularly sensitive to the sheer stresses created by frequent flow conditions. Each section focuses on energy management in addition to traditional capacity and overflow requirements.

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 to the maximum extent practicable.

5.1.2 Stream Preservation and Buffers Zones:

Stream buffers shall be per Article #, Section # of the City of Mexico Stormwater Regulations.

5.1.3 In Stream Construction - General Requirements:

All applicable permits shall be obtained from the USCOE and MoDNR (404/401 permits) prior to initiation of construction in streams or the streamside buffer zone. Each project shall conform to the general requirements of this subsection and to the appropriate specific requirements of the subsections following:

A. Transitions

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

B. Repair of Disturbed Banks

The side slopes of banks where construction occurs shall be restored with vegetation as quickly as possible. Native species are preferred due to their tolerance of local conditions and their deep root systems.

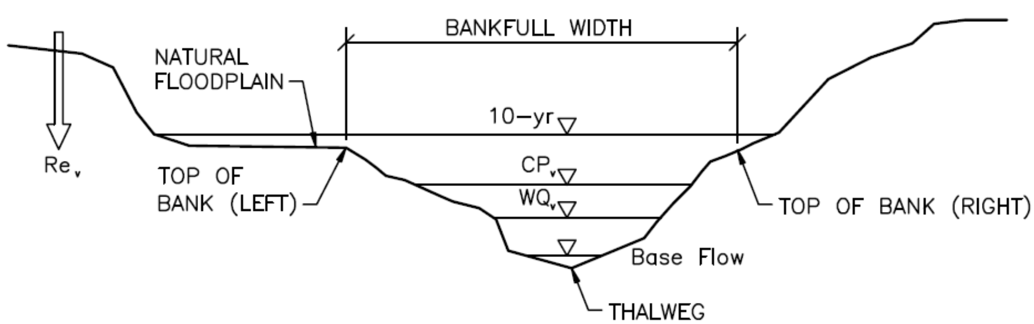
5.1.4 Limited Stream Assessment

A limited stream assessment is required when any construction will enter the stream or streamside buffer zone. It shall include the components listed below, except as modified by the Director to better fit project needs. This should, at a minimum, include the area on the property where encroachments are to be made on the stream or buffer zone plus one wave form upstream and down or 300' upstream and down, whichever is less.

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. For smaller sites, the site topographic survey may be used. The following items shall be shown:

1. Top of bank.
2. Ground contours (if available).
3. Floodplain for the 1% storm.
4. Approximate thalweg and approximate locations of riffles, runs and pools.
5. Active scour and depositional areas, point bars, and islands.
6. Photographs of main channel, streamside vegetation, and each riffle, appropriately referenced to plan-view location.



STREAM SECTION

B. 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 shall be plotted at correct elevation along the profile.

Frequency of field information shall be sufficient to indicate the general condition of the channel and its overall stream structure. This information is more critical when disturbing the stream or discharging a concentrated flow in the stream-side zone.

C. Bed and Bank Materials

The Engineer shall provide a narrative discussing the types of materials found in the bed and bank as they relate to the stream's propensity to change.

Rip-rap used for energy dissipation at outfall

5.1.5 Discharge Outfalls

Energy dissipation shall be provided to reduce 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

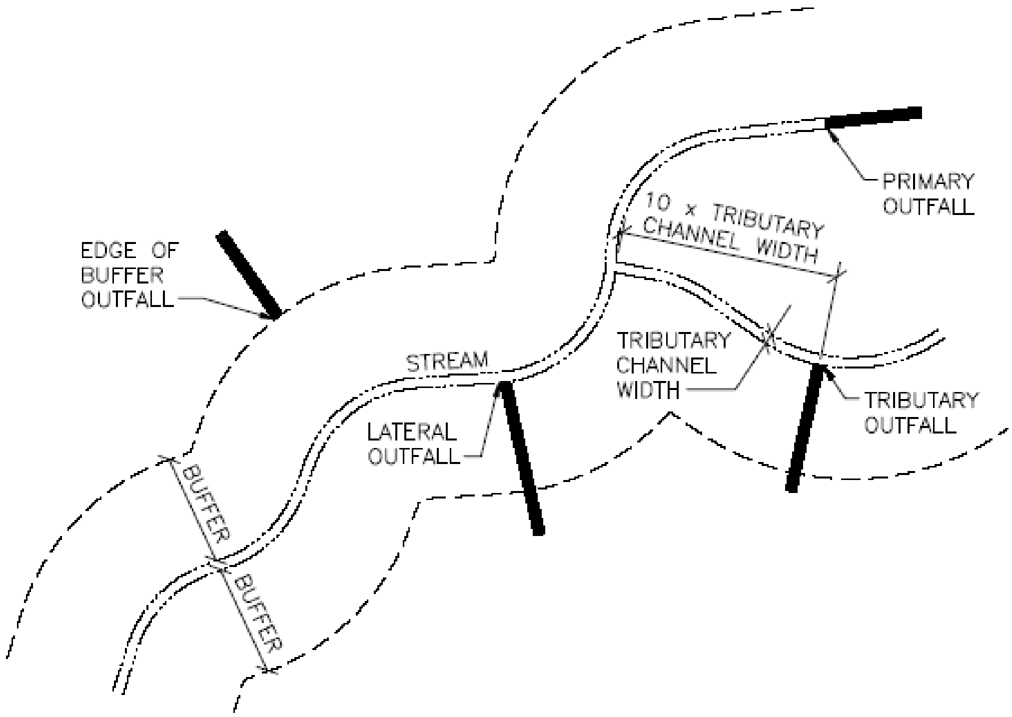
Tributary outfalls are primary outfalls located on a tributary to a larger downstream segment. Energy dissipation and transition to the natural stream flow should take place at least ten tributary channel widths upstream of the confluence. Grade control in the tributary upstream of the confluence shall 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 appropriately reinforced. 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 into a sheet flow condition 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 shall only be used if each individual outfall can be designed to operate without scour or the formation of gullies.



OUTFALL TYPES

5.1.6 Culverts, Bridges, and Above Grade Crossings

A. Crossings should generally be located on a riffle or run. If the width of the roadway, pathway or above grade crossing is large relative to the length of the riffle, then grade control structures may be needed 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.

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 excess design flow shall be above the elevation of the bank-full discharge.

D. For multi-cell 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.

E. Culverts shall be designed so that there is no backwater effect at all flows up to the 2 year (50% annual chance) storm discharge.

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 needed, 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 (at the end of this chapter) 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 control structures may be waived by the Director if it is determined through review of the stream assessment that existing riffles are adequate to prevent or retard advancing headcuts. The City may alternatively choose to accept the risk of future headcut instead of disturbing a stable 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 required by the Director.

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. Fluvial failure may require analysis by an expert in bank stability.

Increased urban stream flows have undercut the stream bank, causing willows to fall into the stream in the picture above.

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

E. Stabilization should begin and end at stable locations along the bank. Bank stabilization should be limited to areas of potential erosion and is 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 trees or forbes for transplantation, 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 Audrain County is adapted to local climatic conditions and is preferred over more remote sources. 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 for bank stabilization projects. A variety of plant species should 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), Chapter 8 and Appendix A.

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 Design Storm

Engineered channels shall be designed to completely contain the design storm for the site and shall provide for the overflow of the 100 year (1% annual chance) storm.

5.2.3 Velocity

Flow velocity in open channels (with the exception of roadway gutters) shall be controlled to prevent erosion in the channel and at the outlet during the design storm. A minimum flushing velocity must also be maintained.

5.2.4 Freeboard

Freeboard shall not be required above the design headwater pool elevation at the culvert entrance. However, the low exterior sill or low opening of adjacent structures shall be at or above the 1% return frequency storm water surface elevation. One foot of freeboard is recommended.

5.2.5 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.).

5.2.6 Lining Material

The types of lining material listed in Table 5.1 at the end of this chapter 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 5.1 at the end of this chapter may be used when approved by the Director.

The use of concrete lined open channels requires pre-approval from the Director of Public works. The Director would consider use of concrete-lined channels in certain redevelopment projects where site conditions did not allow for adjustments to grade or channel location and where structures may be threatened by potential erosion.

5.2.7 Side Slopes

Side slopes shall not be steeper than:

- 3 horizontal to 1 vertical for turf lining.
- 2 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.

5.2.8 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

5.2.9 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 maintenance and pedestrian entry/exit from the channel.

5.3 Easements

Per the Stormwater Management Ordinance, permanent easements shall be dedicated to the City for all open channels.

5.3.1 Engineered/Natural Channels

Easements shall be 16 feet wide or wide enough to contain the water surface from the 100 year (1% annual chance) 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.

5.3.2 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.

Table 5.1

Permissible Shear Stresses for Lining Material

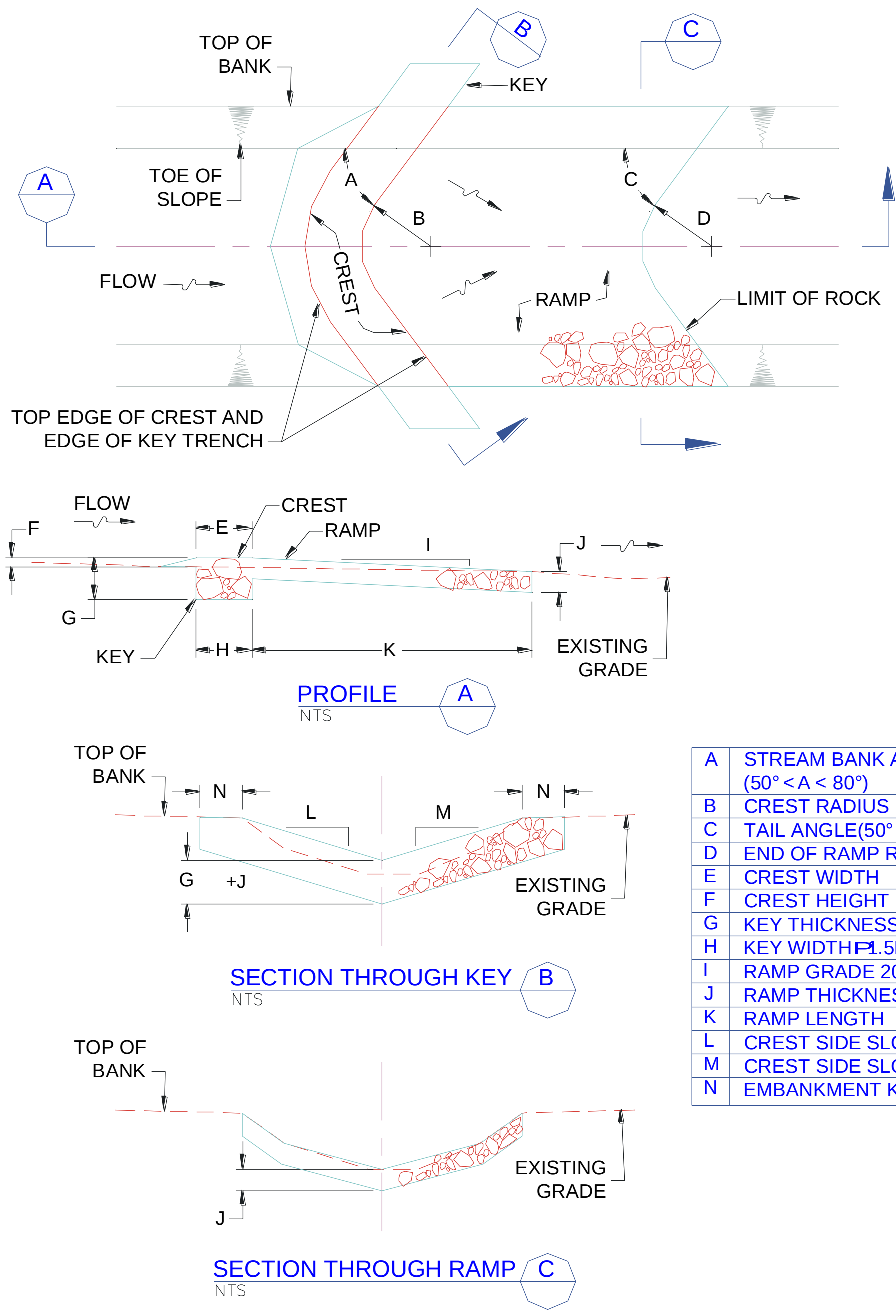
Lining Category	Lining Type	lb/ft^2
General	Erosion Control Blankets	1.55-2.35
	Turf-Reinforced Matrix (TRMs):	-------------------------
	Unvegetated:	3.0
	Vegetated:	8.0
	Geosynthetic Materials	3.01
	Cellular Containment	8.1
	Woven Paper Net	0.15
	Jut Net	0.45
	Fiberglass Roving:	-------------------------
	Single	0.60
	Double	0.85
	Straw With Net	1.45
	Curled Wood Mat	1.55
	Synthetic Mat	2.00
Vegetative	Class A (see Table 5606-2*)	3.70
	Class B (see Table 5606-2*)	2.10
	Class C (see Table 5606-2*)	1.00
	Class D (see Table 5606-2*)	0.60
	Class E (see Table 5606-2*)	0.35
Gravel Riprap	1 inch	0.33
	2 inch	0.67
Rock Riprap	D_{50} = 6 inch	2.00
	D_{50} = 12 inch	4.00
	D_{50} = 15 inch	5.00
	D_{50} = 18 inch	6.00
	D_{50} = 21 inch	7.80
	D_{50} = 24 inch	8.00

*Table 5606-2 from the Kansas City APWA Section 5600 is included for ease of reference on the next page.

Table 5606-2
Classification of Vegetal Covers as to Degree of Retardance

Retardance Class	Cover	Condition
A	Weeping Love Grass	Excellent stand, tall (average 760 mm)
	Yellow Bluestem Ischaemum	Excellent stand, tall (average 910 mm)
B	Bermuda Grass	Good stand, tall (average 300 mm)
	Native Grass Mixture (little bluestem, bluestem, blue gamma, and other long and short midwest grasses)	Good stand (unmowed)
	Weeping lovegrass	Good stand, tall (average 610 mm)
	Lespedeza sericea	Good stand, not woody, tall (average 480 mm)
	Alfalfa	Good stand, uncut (average 280 mm)
	Blue Gamma	Good stand, uncut (average 280 mm)
C	Bermuda grass	Good stand, mowed (average 150 mm)
	Common Lespedeza	Good stand, uncut (average 280 mm)
	Grass-Legume mixture – summer (orchard grass, redtop, Italian, ryegrass, and common lespedeza)	Good stand, uncut (150 to 200 mm)
	Centipedegrass	Very dense cover (average 150 mm)
	Kentucky bluegrass	Good stand, headed (150 to 300 mm)
D	Bermuda grass	Good stand, cut to 60-mm height
	Common Lespedeza	Excellent stand, uncut (average 110 mm)
	Buffalo grass	Good stand, uncut (80 to 150 mm)
	Grass-legume mixture – fall, spring (orchard grass, redtop, Italian, ryegrass, and common lespedeza)	Good stand, uncut (100 to 130 mm)
	Lespedeza sericea	After cutting to 50 mm height. Very good stand before cutting.
E	Bermuda grass	Good stand, cut to height of 40 mm
	Bermuda grass	Burned stubble
Note: Covers classified have been tested in experimental channels. Covers were green and generally uniform		

Figure 5.1: Newberry Style Grade Control Structure



A	STREAM BANK ANGLE (50° < A < 80°)
B	CREST RADIUS
C	TAIL ANGLE(50° < A < 80°)
D	END OF RAMP RADIUS
E	CREST WIDTH
F	CREST HEIGHT
G	KEY THICKNESS ≥ 1.5 D_{90}
H	KEY WIDTH ≥ 1.5 D_{90}
I	RAMP GRADE 20H:1V
J	RAMP THICKNESS ≥ 1.5 D_{100}
K	RAMP LENGTH
L	CREST SIDE SLOPE
M	CREST SIDE SLOPE
N	EMBANKMENT KEY

Notes

1. The depth of key trench shall be a minimum of 1.5 D_{90}. The crest shall slope downward from the stream bank to the center of the structure to focus the flow to the channel center. The tail ramp is generally sloped at 20 horizontal to 1 vertical and dissipates energy gradually over it length. The upstream face is not perpendicular to the flow but has an upstream oriented "V" or arch shape in plan form.