SECTION 5 – OPEN CHANNELS
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SECTION 5.0 OPEN CHANNELS

5.1 INTRODUCTION AND DEFINITIONS

This section addresses the technical criteria for the hydraulic evaluation and hydraulic design of open channels in the City. This information shall be considered a minimum standard. Except as modified herein, all open channel criteria shall be in accordance with the most current edition and/or revisions of the Urban Storm Drainage Criteria Manual (USDCM).

Channels in the City are defined as natural or artificial, and either major drainage ways or small drainage ways. Natural channels include all watercourses that have occurred naturally, such as the Cache la Poudre River and Sheep Draw. Artificial channels are those constructed or developed by human effort: large designated floodways, irrigation canals and flumes, roadside ditches, and grassed or lined channels.

Major drainage ways, as defined by these criteria, are identified and classified in conjunction with the City of Greeley, Public Works Department. All remaining drainage ways shall be classified as small drainage ways. Channels conveying 20 cfs or greater flow shall be considered a major drainageway channel.

5.1.1 DEFINITIONS

cfs - cubic feet per second

fps - feet per second

Thalweg - a line drawn to join the lowest points along the entire length of a channel or streambed.

5.2 CHANNEL TYPES, MAJOR AND SMALL DRAINAGEWAYS

These standards cover the design of major and small drainage ways. The design standards for open channels cannot be presented in a step-by-step fashion because of the wide range of design options available to the Design Engineer. Certain planning and conceptual design criteria are particularly useful in the preliminary design of a channel. These criteria, which have the greatest effect on the performance and cost of the channel, are discussed below.

For these criteria Major drainage ways are defined as channels with flow rates of more than 20 cfs whereas small drainage ways are channels with flow rates less than 20 cfs and that are not classified as a major drainage way. Additional flexibility and less stringent standards are allowed for small drainage ways.

5.2.1 NATURAL CHANNELS

The hydraulic properties of natural channels vary along the channel reach and can be either controlled to the extent desired or altered to meet given requirements. The initial decision made regarding natural channels is whether or not the channel is protected from erosion due to high velocity flows, or protected from excessive silt deposition due to low velocity flows.

Many natural channels in urbanized and developing areas have mild slopes, are reasonably stable, and are not in a state of serious degradation or aggradation. However, if a natural channel is used for carrying storm runoff from an urbanized area, the altered nature of the runoff peaks and volumes from urban development will cause erosion. Detailed hydraulic and channel stability analyses are required for natural channels in order to identify the erosion tendencies and the affect of the storm runoff on channel stability. Some on-site modifications of the natural channel may be required to assure a stabilized condition.

The investigations necessary to assure that the natural channels will be adequate are different for every waterway. The Design Engineer shall prepare cross sections of the channel, define the water surface profiles for the initial and major design storm events, investigate the bed and bank material to determine erosion tendencies, and study the stability of the channel bed and bank under future conditions of flow. Super critical flow does not normally occur in natural channels, but calculations shall be made to assure that the results do not reflect super critical flow. If super critical flow is present, drop structures or other appropriate energy dissipater structures shall be provided.

5.2.1.A NATURAL CHANNELS – MAJOR DRAINAGE WAYS

The design criteria and evaluation techniques for natural channels are:

1. The channel and over bank areas shall have adequate capacity for the 100-year storm runoff.
2. Natural channel segments which have a calculated Froude Number greater than 0.8 for the 100-year flood peak shall be protected from erosion.
3. The water surface profile shall be defined so that the floodplain can be zoned and protected.
4. Roughness factors (Manning's n), which are representative of un-maintained channel conditions, shall be used for the analysis of water surface profiles.
5. Roughness factors (Manning's n), which are representative of maintained channel conditions, shall be used to determine velocity limitations.
6. Erosion control structures, such as drop structures or check dams, may be required to control flow velocities, including the initial storm runoff.
7. If a natural channel is utilized as a major drainage way for a developed area, then the applicant shall meet with the City to discuss the concept and to obtain the requirements for planning and design documentation, including the completion of a detailed channel stability analysis.
8. Plan and profile drawings of the floodplain shall be prepared. Appropriate allowances for known future bridges or culverts, which can raise the water surface profile and cause the floodplain to be extended, shall be included in the analysis. The applicant shall contact the City for information on future bridges, culverts or other planned improvements.

Many specifications governing artificial channels do not apply to natural ones. Extensive modifications should not be undertaken unless they are necessary to avoid excessive erosion with subsequent deposition downstream. However, with most natural waterways, erosion control structures should be constructed at regular intervals to decrease the thalweg (flow line) slope and to control erosion. All structures constructed along the natural channel shall be elevated a minimum of two feet above the 100-year water surface level. Also, some advantages may become evident during peak runoff events, if overtopping and localized flooding areas are laid out during design.

5.2.1.B NATURAL CHANNELS – SMALL DRAINAGE WAYS

The design criteria and evaluation techniques for natural channels are:

1. The channel and over bank areas shall have adequate capacity for the 100-year storm runoff.

2. Natural channel segments, which have a calculated Froude Number greater than 0.8 for the 100-year flood peak shall be protected from erosion.
3. Roughness factors (Manning's n), which are representative of un-maintained channel conditions, shall be used for the analysis of water surface profiles.
4. Roughness factors (Manning's n), which are representative of maintained channel conditions, shall be used to determine velocity limitations.
5. Erosion control structures, such as check drops or check dams, may be required to control flow velocities, including the initial storm runoff.
6. A channel stability analysis will be completed to determine the impact of urbanization on the stability of the channel bed and banks.
7. Plan and profile drawings shall be prepared showing the 100-year water surface profile, floodplain, and details of erosion protection, if required.

5.2.2 GRASS LINED CHANNELS

Grass lined channels are the most desirable of the artificial channels. The grass will stabilize the body of the channel, consolidate the soil mass of the bed, check the erosion on the channel surface, and control the movement of soil particles along the channel bottom. Channel storage, lower velocities, and greenbelt multiple-use benefits create significant advantages over other artificial channels.

The presence of grass in channels creates turbulence, which results in loss of energy and increased flow retardance. Therefore, the designer must give full consideration to sediment deposition and to scour, as well as hydraulics. Unless existing development within the City restricts the availability of right-of-way, only channels lined with grass will be considered acceptable for major drainage ways. Grass lined channels may require an acceptable trickle channel, as defined below.

5.2.2.A GRASS LINED CHANNELS – MAJOR DRAINAGE WAYS

Key parameters in grass lined channel design include velocity, slope, roughness coefficients, depth, freeboard, curvature, cross-section shape, and lining materials. Other factors such as water surface profile computation, erosion control, drop structures, and transitions also play an important role. A discussion of these parameters is presented below.

1. Flow Velocity (Major Drainage Way)
   The maximum normal depth velocity for the 100-year flood peak shall not exceed 5.0 fps. The Froude Number shall be less than 0.8 for grass-lined channels. The minimum velocity, wherever possible, shall be greater than 2.0 fps for the initial storm runoff.
2. Longitudinal Channel Slope (Major Drainage Way)
   Grass-lined channel slopes are dictated by velocity and Froude Number requirements. Where the natural topography is steeper than desirable, drop structures shall be utilized to maintain design velocities and Froude Numbers.
3. Freeboard (Major Drainage Way)
   Except where localized overflow in certain areas is desirable for additional ponding benefits or other reasons, the freeboard for the 100-year flow shall be as follows. The minimum freeboard shall be 1.0 foot.

$$H_{FB} = 2.0 + 0.025V(yo)^{1/3} + \Delta y \qquad \textbf{Equation 5.2.2.A}$$

Where: H_{FB} = freeboard height (feet)
V = average channel velocity (fps)
yo = depth of flow (feet)
Δy = increase in water surface elevation due to super elevation at bends (see USDCM, equation MD-9) (no bends allowed in supercritical channels)

4. Horizontal Curvature (Major Drainage Way)
   The centerline curvature shall have a radius twice the top width of the design flow but not less than 100 feet.

5. Roughness Coefficient (Major Drainage Way)
   The variation of Manning's "n" with the retardance and the product of mean velocity and hydraulic radius, as presented in Figure 5-1, shall be used in the capacity computation.
   Retardance curve C shall be used to determine the channel capacity, since a mature channel (substantial vegetation with minimal maintenance) will have a higher Manning's "n" value. However, a recently constructed channel will have minimal vegetation and the retardance will be less than the mature channel. Therefore, retardance curve D shall be used to determine the limiting velocity in a channel.
   For the purpose of floodplain definition, only the higher Manning's "n" values need to be considered in the hydraulic analysis.

6. Cross-Sections (Major Drainage Way)
   The channel shape may be almost any type suitable to the location and to the environmental conditions. Often the shape can be chosen to suit open space and recreational functions. Representative cross-sections are presented in Figures 5-2, 5-3, and 5-4. The limitations within which the design must fall for the major storm design flow include:

   a. Trickle Channel - The base flow shall be carried in a trickle channel except for sandy soils. The minimum capacity shall be 2.0 percent to 4.0 percent of the 100-year flow but not less than 1 cfs. Trickle channels shall be grass-lined with a perforated under drain for water quality enhancement wherever practical. Where the water quality trickle channel is impractical, construct the channel with concrete or other approved materials to minimize erosion, to facilitate maintenance, and to aesthetically blend with the adjacent vegetation and soils. Recommended trickle channel sections are presented in Figure 5-5. The minimum trickle channel width shall be three feet.
      An alternative configuration for a trickle channel may consist of a subsurface storm drain pipe. If used, this alternative would consist of a minimum 24" diameter pipe, provided with access manholes, and sloped to maintain a minimum pipe flow velocity of 3 feet per second at one-half of full pipe depth.

   b. Main Channel - Representative main channels, and limitations for these channels, are shown in Figures 5-2, 5-3, and 5-4. Figure 5-4 indicates channel configurations for sandy soils.

   c. Bottom Width - The minimum bottom width shall be consistent with the maximum depth and velocity criteria. The minimum width shall be four (4) feet or the trickle channel width, where required.

d. Right-Of-Way Width - The minimum ROW width shall include freeboard and a twelve (12) foot wide maintenance access. In some situations, the City may require a twelve (12) maintenance access on both sides of the channel.

e. Flow Depth - The maximum design depth of flow (outside the trickle channel area and main channel area) for the 100-year flood shall be limited to five (5) feet in grass-lined channels.

f. Maintenance/Access Road - Continuous maintenance access shall be provided for all major drainage ways at a minimum width of twelve (12) feet. The City may require six (6) inches of Class 2 road base or a concrete slab.

g. Side Slopes - Side slopes shall be 4H (horizontal) to 1V (vertical) or flatter.

7. Grass lining (Major Drainage Way)
   The grass lining for channels shall be in accordance with the USDCM, "Major Drainage", Section 4.1, "Grass-lined Channels,".
8. Erosion Control (Major Drainage Way)
   The requirements for erosion control for grass-lined channels shall be as defined in the USDCM, "Major Drainage", Section 4.1, "Grass-lined Channels." The design of riprap and erosion control devices shall be in accordance with Sections 10.1 and 10.2 of these Criteria.
9. Water Surface Profiles (Major Drainage Way)
   Computation of the water surface profile shall be presented for all open channels utilizing standard backwater methods, taking into consideration losses due to changes in velocity or channel cross section, drops, waterway openings, or obstructions. The energy gradient shall be included in the Final Drainage Report.

5.2.2.B GRASS LINED CHANNELS – SMALL DRAINAGE WAYS

Key parameters in grass lined channel design include velocity, slope, roughness coefficients, depth, freeboard, curvature, cross section shape, and lining materials. Other factors such as water surface profile computation, erosion control, drop structures, and transitions also play an important role. A discussion of these parameters is presented below.

1. Flow Velocity (Small Drainage Way)
   The maximum normal depth velocity for the 100-year flood peak shall not exceed 5.0 fps. The Froude Number shall be less than 0.8 for grass-lined channels. The minimum velocity, wherever possible, shall be greater than 2.0 fps for the initial storm runoff.

2. Longitudinal Channel Slope (Small Drainage Way)
   Grass-lined channel slopes are dictated by velocity and Froude Number requirements. Where the natural topography is steeper than desirable, drop structures shall be utilized to maintain design velocities and Froude Numbers.

3. Freeboard (Small Drainage Way)
   A minimum freeboard of 1 foot shall be included in the design of the 100-year flow. For swales (i.e. small drainage ways with a 100-year flow less than 20 cfs), the minimum freeboard requirement is 6 inches.

4. Horizontal Curvature (Small Drainage Way)
   The minimum radius for channels with a 100-year runoff of 20 cfs or less shall be 25 feet.

5. Roughness Coefficient (Small Drainage Way)
   The variation of Manning's "n" with the retardance and the product of mean velocity

and hydraulic radius, as presented in Figure 5-1, shall be used in the computation of capacity and velocity.

6. Cross-Sections (Small Drainage Way)
   The channel shape may be almost any type suitable to the location and to the environmental conditions. Often the shape can be chosen to suit open space and recreational functions. Representative cross sections are presented in Figures 5-2, 5-3, and 5-4. The limitations on the cross-sections are as follows:

   a. Trickle Channel - The base flow (except for swales) shall be carried in a trickle channel. The minimum capacity shall be 1.0 percent to 3.0 percent of the 100-year flow. Trickle channels shall be constructed of concrete or other approved materials to minimize erosion, to facilitate maintenance, and to aesthetically blend with the adjacent vegetation and soils. For sandy soils, a main channel is required in accordance with Figure 5-4. Trickle channel requirements will be evaluated for each case. Trickle channels help preserve swales crossing residential property.

   b. Right-Of-Way, Easement, or Outlot Width - The minimum width shall include freeboard and a 12-foot wide maintenance access road.

   c. Flow Depth - The maximum design depth of flow outside the trickle channel area and main channel area for the 100-year flood shall be limited to 5.0 feet in grass-lined channels.

   d. Side Slopes - Side slopes shall be 4H (horizontal) to 1V (vertical) or flatter.

7. Grass Lining (Small Drainage Way)
   The grass lining for channels shall be in accordance with the USDCM, Volume 1, Chapter, "Major Drainage", Section 4.1, “Grass lined Channels."

8. Erosion Control (Small Drainage Way)
   The requirements for erosion control for grass-lined channels shall be as defined in the USDCM, Volume 1, Chapter, "Major Drainage", Section 4.1, “Grass lined Channels." The design of riprap and erosion control devices shall be in accordance with Section 10.1 and 10.2 of these Criteria.

9. Hydraulic Information (Small Drainage Way)
   Calculations of the capacity, velocity, and Froude Numbers shall be submitted with the Final Drainage Report.

5.2.3 CONCRETE LINED CHANNELS

Concrete lined channels for major drainage ways will be permitted only where right-of-way restrictions within existing development prohibit grass lined channels. The lining must be designed to withstand the various forces and actions, which tend to overtop the bank, deteriorate the lining, erode the soil beneath the lining, and erode unlined areas, especially for super critical flow conditions.

If the project constraints suggest the use of a concrete channel for a major drainage way, the City shall allow such use only upon approval. The applicant shall present the justification and design to the City for consideration of a variance from these Criteria.
A Design Report is required for approval of a concrete lined channel. The City shall determine the contents of such report.

5.2.3.A CONCRETE LINED CHANNELS – MAJOR DRAINAGE WAYS

1. Hydraulics (Major Drainage Way)

$$H_{FB} = 2.0 + 0.025\ V\ (d)^{1/3}$$ **Equation 5.2.3.A**

Where: H_{FB} = freeboard height (feet)
V = velocity (fps)
d = depth of flow (feet)

a. Freeboard - Adequate channel freeboard above the designed water surface shall be provided and shall not be less than determined by the following:
Freeboard shall be in addition to super-elevation, standing waves, and/or other water surface disturbances. These special situations shall be addressed in the Final Drainage Report.
Concrete side slopes shall be extended to include the freeboard height.

b. Super-elevation - Super-elevation of the water surface shall be determined at all horizontal curves, and design of the channel section adjusted accordingly.

c. Velocities - Flow velocities shall be such that critical or super critical flow conditions are not created. In no case shall the velocity exceed 18 fps.

d. Critical or super critical flow conditions are not allowed. Drop structures or other appropriate energy dissipation facilities may be required to maintain a sub critical flow regime.

2. Concrete Materials (Major Drainage Way)
All concrete materials shall meet or exceed Metropolitan Government Engineer's Council (MGPEC) specifications Item 11, Portland Cement Concrete Pavement; Section 11.2, Materials.

3. Concrete Lining Section (Major Drainage Way)

a. All concrete lining shall have a minimum thickness of seven (7) inches.

b. The side slopes shall be a maximum of 2V (vertical) to 1H (horizontal), or shall be designed as a structurally reinforced retaining wall, if steeper.

4. Concrete Joints (Major Drainage Way)

a. Concrete channels shall be continuously reinforced and contain transverse joints. Expansion joints shall be installed where new concrete lining is connected to a rigid structure or to an existing concrete lining which is not continuously reinforced.

b. Longitudinal joints, where required, shall be constructed on the sidewalls at least one foot vertically above the channel invert.

c. All joints shall be designed to prevent differential movement.

d. Construction joints are required for all cold joints and where the lining thickness changes. Reinforcement shall be continuous through the joint.

5. Concrete Finish (Major Drainage Way)
The concrete lining shall be finished per the most current City of Greeley Design Criteria and Construction Specifications (DCCS), Volume I, Streets, Section 03310, paragraph 3.8.

6. Concrete Curing (Major Drainage Way)
Concrete shall be cured per the most current DCCS, Volume 1, Streets, Section 03310, paragraph 3.10.

7. Reinforcement Steel (Major Drainage Way)

a. Steel reinforcement shall be minimum grade 60 deformed bars. Fabric mesh may also be approved. Wire mesh shall not be used.

b. Reinforcing steel shall be placed at the center of the section with a minimum clear cover of three inches adjacent to the earth.

c. All other reinforcement steel requirements shall follow the latest revision of American Concrete Institute ACI 318-89, (latest edition).

8. Earthwork (Major Drainage Way)
   All earthwork shall be performed per the most current DCCS, Volume I, Streets, Sections 02220 – Excavation, Removals, and Embankment; 02223 – Structural Backfill; 02225 – Grading, Compaction Subgrade, and Unimproved area Preparation; and 02227 – Sub-base. Maintenance Roads and any area within 10 feet of the channel lip shall be considered "improved areas".

9. Bedding (Major Drainage Way)
   Provide six inches of granular bedding equivalent in gradation to ¾" concrete aggregate, No. 67 (Standard Specifications for Road & Bridge Construction, CDOT, latest revision) under channel bottom and side slopes.

10. Under Drain (Major Drainage Way)
    Longitudinal under drains shall be provided on 10-foot centers and shall daylight at the check drops. Weep holes shall be provided in vertical wall sections of the channel.

11. Safety Requirements (Major Drainage Way)

    a. A six-foot high vinyl coated chain link or comparable fence shall be installed to prevent access wherever the 100-year channel flow depths exceed three (3) feet. Gates, with top latch, shall be placed at 250-foot intervals and staggered where fence is required on both sides of the channel.

    b. Ladder-type steps shall be installed not more than 400 feet apart on alternating sides of the channel. Bottom rung shall be placed approximately 12 inches vertically above the channel invert.

12. Maintenance Access Road
    A maintenance access road shall be provided along the entire length of all major drainage ways with a minimum passage width of 12 feet. In some situations the City may require maintenance access on both sides of the channel. The City shall require the road to be surfaced with six inches of Class 2 road base or concrete slab.

5.2.3.B CONCRETE LINED CHANNELS – SMALL DRAINAGE WAYS

1. Hydraulics (Small Drainage Way)

   a. Freeboard - Adequate channel freeboard above the designed water surface shall be provided and shall not be less than determined by Equation 5.2.2.A. Freeboard shall be in addition to super elevation, standing waves, and/or other water surface disturbances. These special situations shall be addressed in the Final Drainage Report. Concrete side slopes shall be extended to include the freeboard height.

   b. Super-elevation - Super-elevation of the water surface shall be determined at all horizontal curves, and design of the channel section adjusted accordingly.

   c. Velocities - Flow velocities shall be such that critical or super critical flow conditions are not created. In no case shall the velocity exceed 18 fps.

2. Concrete Materials (Small Drainage Way)
   All concrete materials shall meet or exceed Metropolitan Government Engineer's Council (MGPEC) specifications Item 11, Portland Cement Concrete Pavement; Section 11.2, Materials.

3. Concrete Lining Section (Small Drainage Way)

   a. All concrete lining shall have a sufficient thickness to withstand the structural and hydraulic loads. In all cases concrete lining shall be a minimum of 5" thick.

   b. The side slopes shall be a maximum of 2V (vertical) to 1H (horizontal), or be designed as a structurally reinforced retaining wall, if steeper.

4. Concrete Joints (Small Drainage Way)

   a. Expansion joints shall be installed where new concrete lining is connected to a rigid structure or to existing concrete lining which is not continuously reinforced.

   b. Longitudinal joints, where required, shall be constructed on the sidewalls at least one foot vertically above the channel invert.

   c. All joints shall be designed to prevent differential movement.

   d. Construction joints are required for all cold joints and where the lining thickness changes.

5. Concrete Finish (Small Drainage Way)
   The concrete lining shall be finished per the most current City of Greeley Design Criteria and Construction Specifications (DCCS), Volume I, Streets, Section 03310, paragraph 3.8.

6. Concrete Curing (Small Drainage Way)
   Concrete shall be cured per the most current DCCS, Volume 1, Streets, Section 03310, paragraph 3.10.

7. Reinforcement Steel (Small Drainage Way, where appropriate)

   a. Steel reinforcement shall be minimum grade 60 deformed bars. Fabric mesh may also be approved. Wire mesh shall not be used.

   b. Reinforcing steel shall be placed at the center of the section with a minimum clear cover of three inches adjacent to the earth.

   c. All other reinforcement steel requirements shall follow the latest revision of American Concrete Institute ACI 318-89.

8. Earthwork (Small Drainage Way)
   All earthwork shall be performed per the most current DCCS, Volume I, Streets, Sections 02220 – Excavation, Removals, and Embankment; 02223 – Structural Backfill; 02225 – Grading, Compaction Subgrade, and Unimproved area Preparation; and 02227 – Sub-base. Maintenance Roads and any area within 10 feet of the channel lip shall be considered "improved areas".

9. Bedding (Small Drainage Way)
   Provide six inches of granular bedding equivalent in gradation to ¾-inch concrete aggregate (Standard Specifications for Road & Bridge Construction, CDOT, latest revision) under channel bottom and side slopes.

10. Under Drain (Small Drainage Way)
    Longitudinal under drains shall be provided and shall daylight at the check drops. Weep holes shall be provided in vertical wall sections of the channel.

11. Safety Requirements (Small Drainage Way)

    a. A six-foot high vinyl coated chain link or comparable fence shall be installed to prevent access wherever the 100-year channel flow depths exceed three (3) feet. Gates, with top latch, shall be placed at 250-foot intervals and staggered where fence is required on both sides of the channel.

    b. Ladder-type steps shall be installed not more than 400 feet apart on alternating sides of the channel. Bottom rung shall be placed approximately 12 inches vertically above the channel invert.

5.2.4 ROCK LINED CHANNELS

Riprap lined channels are generally discouraged and shall be permitted only in areas of existing development where right-of-way for major drainage ways is limited and such limitation prohibits the use of grass lined channels. The advantage of rock lining a channel is that a steeper channel grade can be used due to the higher 'n' factor associated with the rock and a higher allowable shear stress. 4H:1V is the steepest side slope permitted. Rock linings, or revetments, are permitted as a means of controlling erosion for natural channels.

If the project constraints dictate the use of riprap lining for a major drainage way, then the Design Engineer shall present the concept, with justification, to the City for consideration of a variance from these Criteria. The design of rock-lined channels shall be in accordance with the most current revision of the USDCM, Volume 1, Chapter, "Major Drainage", Section 4.4, "Riprap – Lined Channels."

5.2.4.A ROCK LINED CHANNELS – MAJOR DRAINAGE WAYS

The criteria for the design and construction of riprap channel linings shall be in accordance with the USDCM, Volume 1, Chapter, "Major Drainage", Section 4.4, "Riprap – Lined Channels." Riprap lined channels shall be designed for a turbulence factor (Froude Number) less than 0.8 for the 100-year flood peaks.

The riprap shall be designed and constructed in accordance with Section 10.2 of these Criteria. Freeboard and maintenance access road requirements shall be in accordance with the standards for grass-lined channels as defined in Section 5.2.2.A of these Criteria.

5.2.4.B ROCK LINED CHANNELS – SMALL DRAINAGE WAYS

The criteria for the design and construction of riprap channel linings shall be in accordance with the USDCM, Volume 1, Chapter, "Major Drainage", Section 4.4, "Riprap – Lined Channels." Riprap lined channel shall be designed for a turbulence factor (Froude Number) less than 0.8 for the 100-year flood peaks. The riprap shall be designed and constructed in accordance with Section 10.2 of these Criteria. Freeboard requirements shall be in accordance with the standards for grass-lined channels (see Section 5.2.2.B). Riprap channels are not encouraged.

5.2.5 OTHER LINING TYPES

The use of synthetic fabrics and slope revetment mats for major drainage ways in the City is restricted to areas of existing development where the ROW constraints prohibit the use of a grass lined section. A synthetic lining, such as a soil stabilization fabric, in combination with grass lining may be acceptable in some situations. If a soil stabilization fabric also referred to as turf reinforcement mat (TRM) is used in combination with grass, a permanent irrigation system must be included. Grass shall always be planted prior to installing the fabric. Pro-

vide details on construction drawings for proper installation of the fabric, according to manufacturer's recommendations. Such use shall be allowed only upon written approval from the City. The linings shall be restricted to channels with a Froude Number of 0.8 or less.

Note: The use of TRM that uses fish line netting to hold the filler material together has caused birds and reptiles to become trapped resulting in death. This type of TRM shall not be used.

Below are soil stabilization materials that may be used for Froude Numbers greater than 0.8.

Terra Cell, a Geo Cell, is another type of soil stabilization product. It is a cellular confinement mat, manufactured in different depths. These mats are anchored with 'J' hooks and the cells filled with rock or amended soil.

Articulating Block (AB) Mat is an articulating block mat with cable reinforced concrete block mattresses that resist erosive forces.

5.2.5.A OTHER LINING TYPES – MAJOR DRAINAGE WAYS

The criteria for the design of major drainage way channels with linings other than grass, rock, or concrete will be dependent on the manufacturer's recommendations for the specific product. The applicant will be required to submit the technical data in support of the proposed material. Additional information or calculations may be requested by the City to verify assumptions or design criteria. The following minimum criteria will also apply.

1. Flow Velocity (Major Drainage Way)
   The maximum normal depth velocity will be dependent on the construction material used; however, the Froude Number shall be less than 0.8.
2. Freeboard (Major Drainage Way)
   Same as for grass lined channels (see Section 5.2.2.A).
3. Curvature (Major Drainage Way)
   The centerline curvature shall have a minimum radius twice the top width of the design flow but not less than 100 feet.
4. Roughness Coefficient (Major Drainage Way)
   A Manning's "n" value range shall be established by the manufacturer's data, with the high value used to determine depth/capacity requirements and the low value used to determine the Froude Number and velocity restrictions.
5. Cross Sections (Major Drainage Way)
   Same as for grass lined channels (see Section 5.2.2.A).

5.2.5.B OTHER LINING TYPES (SMALL DRAINAGE WAY)

The criteria for the design of small drainage way channels with linings other than grass, rock, or concrete will be dependent on the manufacturer's recommendations for the specific product. The applicant will be required to submit the technical data in support of the proposed material. Additional information or calculations may be requested by the City to verify assumptions or design criteria. The following minimum criteria will also apply.

1. Flow Velocity (Small Drainage Way)
   The maximum normal depth velocity will be dependent on the construction material used; however, the Froude Number shall be less than 0.8.
2. Freeboard (Small Drainage Way)
   Same as for grass lined channels (see Section 5.2.2.B).

3. Curvature (Small Drainage Way)
   The minimum radius of curvature for channels with a 100-year runoff of 20 cfs or less shall be 25 feet.
4. Roughness Coefficient (Small Drainage Way)
   A Manning's "n" value range shall be established by the manufacturer's data, with the high value used to determine depth/capacity requirements and the low value used to determine the Froude Number and velocity restrictions.
5. Cross Sections (Small Drainage Way)
   Same as for grass lined channels (see Section 5.2.2.B).

5.2.6 WETLANDS VEGETATION BOTTOM CHANNELS

The selection of a particular channel can be based on many factors, including hydraulic practice, environmental design, sociological considerations, and basic project requirements. However, prior to choosing the channel type, the need or desire for channelization should be established.

Once a decision is made to channelize, investigations into the status of the present drainage way are necessary to define the constraints on the channel design. For instance, if the channel presently has wetland characteristics, then the Section 404 requirements of the Clean Water Act may require that the design maintain a wetland area. The Design Engineer should contact the Corps of Engineers for additional information.

The process of choosing a channel configuration and the design criteria for a wetlands bottom channel (if this type is selected) shall follow the latest revision of the USDCM. The Design Engineer is referred to these interim criteria (USDCM, Chapter, “Major Drainage”, Sections 2 and 3) for the procedures and criteria for all channel design.

5.3 FLOW COMPUTATION

Uniform flow and critical flow computations shall be in accordance with the USDCM, "Major Drainage", Section 3, and shall use the Manning's equation as follows:

$$Q = \frac{1.49}{n}(AR^{2/3}S^{1/2}) \qquad \textbf{Equation 5.3}$$

Where: Q = flow rate (cfs)
n = Manning's roughness coefficient
A = Area of channel cross-section (ft^2)
R = A/P = hydraulic radius (ft)
P = wetted perimeter (ft)
S = channel bottom slope (ft/ft)

5.4 ROADSIDE DITCHES

1. The criteria for the design of roadside ditches are similar to the criteria for grass-lined channels with modification for the special purpose of initial storm drainage. The criteria is as follows (refer to Figure 5-6):
2. Capacity - Roadside ditches shall have adequate capacity for the initial storm runoff peaks. During the initial storm runoff event, encroachment shall not extend beyond the street right-

of-way. Where the storm runoff exceeds the capacity of the ditch, a storm drain system shall be required.

3. Flow Velocity - The maximum velocity for the initial storm flood peak shall not exceed 5 feet per second.
4. Longitudinal Slope - The slope shall be limited by the average velocity of the initial storm flood peaks. Check drops may be required where street slopes are in excess of 2%. Maximum permissible slope is 5%.
5. Freeboard - Freeboard shall be equal to the velocity head, or a minimum of six inches.
6. Curvature - The minimum radius of curvature shall be 25 feet.
7. Roughness Coefficient - Manning's "n" values presented in Figure 5-1 shall be used in the capacity computation for roadside ditches.
8. Grass Lining - The grass lining shall be in accordance with USDCM, "Major Drainage", Section 3, "Grass Lined Channels -Grass."
9. Driveway Culverts - Driveway culverts shall be sized to pass the initial storm ditch flow capacity without overtopping the driveway. The minimum size culvert shall be a 12-inch diameter pipe (or equivalent) with flared end sections. More than one culvert may be required.
10. Major Drainage Capacity - The capacity of roadside ditches for major drainage flow is restricted by the maximum flow depth allowed at the street crown (see Section 8). However, the flow spread should not inundate the ground line of residential dwellings, or public, commercial, or industrial buildings.

5.5 CHANNEL RUNDOWNS

A channel rundown is used to convey storm runoff from the bank or side-slope of a channel or detention pond to the channel invert or to the bottom of a detention pond. The purpose of the structure is to minimize channel bank erosion from concentrated overland flow. The design criteria for channel rundowns is as follows:

1. Cross Sections - Typical cross sections for channel rundowns are presented in Figure 5-7.
2. Design Flow - The channel rundown shall be designed to carry a minimum flow of a one hundred year frequency storm.
3. Flow Depth - The maximum depth at the design flow shall be 12 inches. Due to the typical profile of a channel rundown beginning with a flat slope and then dropping steeply into the channel, the design depth of flow shall be the computed critical depth for the design flow.
4. Outlet Configurations Into Channels - The channel rundown outlet shall enter the drainageway at the trickle channel flow line. Erosion protection of the opposite channel bank shall be provided by a 24-inch layer of grouted Type M riprap. The width of this riprap erosion protection shall be at least three times the channel rundown width or pipe diameter. Riprap protection shall extend up the opposite bank to the initial storm flow depth in the drainage way or 2 feet, whichever is greater. Riprap shall only be used with bedding or fabric on slopes less than or equal to 4H (horizontal): 1V (vertical).
5. Outlet Configurations Into Detention Ponds - the channel rundown outlet shall be constructed with a flared end section, a concrete cutoff wall and an adequately reinforced splash pad at the bottom of the rundown.
   Cut off walls shall be concrete, eight inches (8") thick, four-feet (4') deep, and four-feet (4')

wider than the flared end section, two-feet (2') either side. Rebar centered within the cutoff wall shall be #4-12" o.c. each way (horizontal and vertical).
The splash pad may be constructed with eight-inch (8") thick concrete; a twenty-four (24") layer of grouted Type M riprap or may be bluegrass with a Geo fabric designed to withstand the splash pad forces.
All components must be sized for a 100-year frequency storm. Consult the latest edition of the USDCM, Volume 2, for guidance in designing various components of the rundown.

6. Turf Reinforcement Mat (TRM) on soil with native grass is not allowed for channel rundowns. Only a Geo fabric designed to withstand the splash pad forces with irrigated bluegrass is allowed in conjunction with a cut off wall and Geo fabric at the base of the slope, which will allow the flow to dissipate in different directions.
7. If concrete V-pan rundowns sized for 5-year frequency storms are used they must be constructed with an eighteen-inch (18") layer of grouted Type M riprap on both sides to accommodate for a 100-year frequency storm. This type of rundown must have a FES, an adequate concrete cutoff wall at the FES and an adequately reinforced splash pad at the bottom of the rundown.
8. Rundowns may be constructed with a 24-inch layer of Type M riprap, on bedding, on Geo fabric that is completely grouted and sized for a 100-year frequency storm. A concrete cutoff wall must be provided with an adequate splash pad at the bottom.

5.6 MAINTENANCE AND ACCESS EASEMENTS

An important aspect of storm drainage facilities is continued maintenance. Maintenance of storm drainage channels and structures may include periodic removal of sediment and debris; repair of channel erosion; and repair of inlet, outlet, and drop structures. The City requires the following minimum right-of-way or easement widths, which must be shown on the Final Plat or separate document when a plat is not proposed:

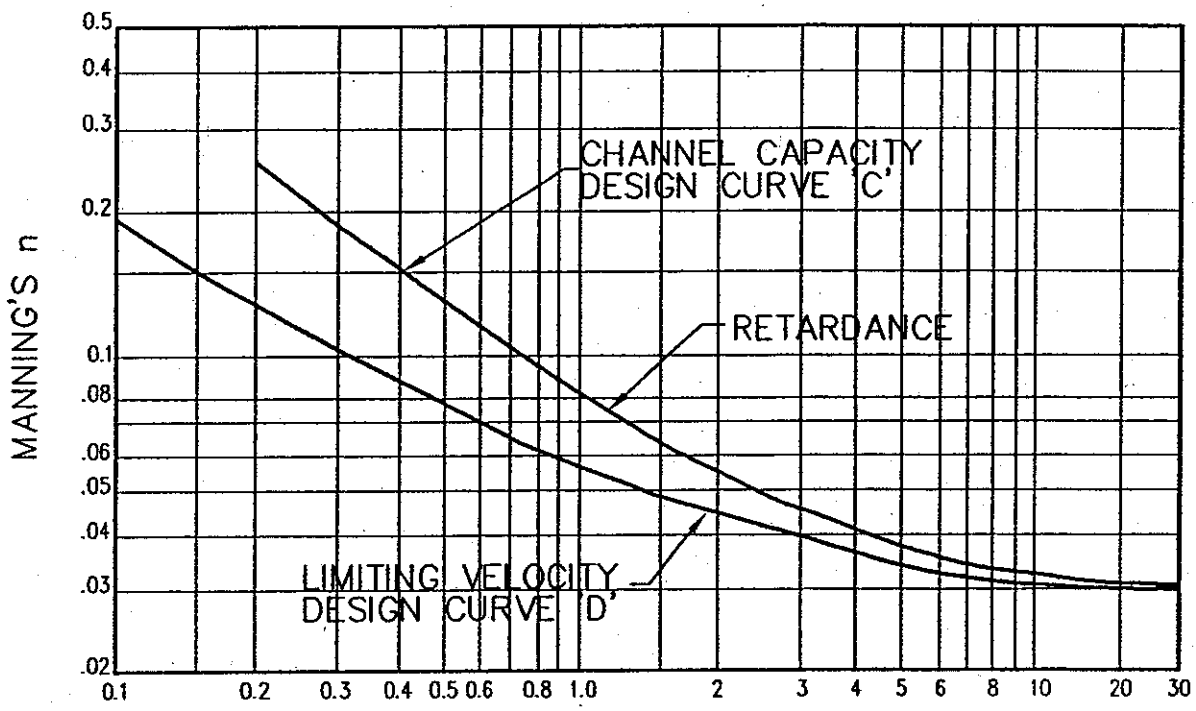
TABLE 5.6 - MINIMUM CHANNEL EASEMENTS WIDTHS

Channel Size	Total R.O.W. or Easement Width
Q_{100} less than 20 cfs	15 feet
Q_{100} less than 100 cfs	25 feet
Q_{100} greater than 100 cfs	Minimum width calculated to include freeboard plus 12-foot wide access road. The City shall determine if access is required on both sides of channel.

5.7 CHECKLIST

To aid the designer and reviewer, the following checklist has been prepared.

1. Check flow velocity with the low retardance factor and capacity with the high retardance factor.
2. Check the Froude Number and critical flow conditions.
3. Grass channel side slopes must be 4H:1V or flatter.
4. Show the energy grade line and the hydraulic grade line in the Drainage Report.
5. Consider all backwater conditions at culverts when determining channel capacity.
6. Check the flow velocity for flood conditions without backwater effects.
7. Provide adequate freeboard.
8. Provide adequate right-of-way for the channel and continuous maintenance access.



V_R, PRODUCT OF VELOCITY AND HYDRAULIC RADIUS

NOTE: FROM "HANDBOOK OF CHANNEL DESIGN FOR SOIL AND WATER CONSERVATION," U.S. DEPARTMENT OF AGRICULTURE. SOILS CONSERVATION SERVICE, NO. SCS–TP–61 MARCH, 1947 REVISED JUNE, 1954

City of Greeley Colorado
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ROUGHNESS COEFFICIENT FOR GRASS CHANNELS

FIGURE 5-1

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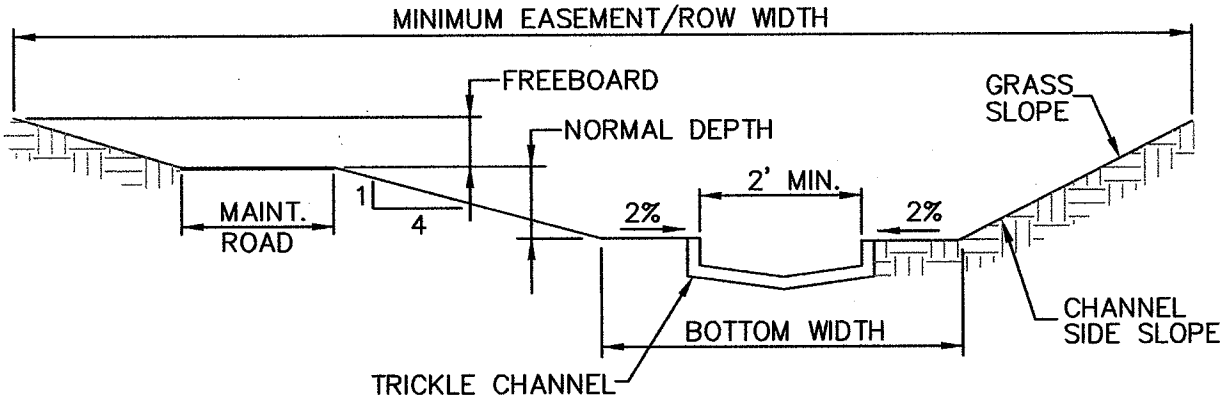
SCALE: NTS
REVISED AUG 1996

TYPE A



NOTES:

1. BOTTOM WIDTH: CONSISTENT WITH MAXIMUM ALLOWABLE DEPTH AND VELOCITY REQUIREMENTS, SHALL NOT BE LESS THAN TRICKLE CHANNEL WIDTH.
2. TRICKLE CHANNEL: MINIMUM CAPACITY TO BE 2% TO 4% OF 100-YEAR FLOW BUT NOT LESS THAN 1 CFS. CHANNEL TO BE CONSTRUCTED OF CONCRETE, GROUTED RIPRAP, OR OTHER APPROVED MATERIALS.
3. NORMAL DEPTH: NORMAL DEPTH AT 100-YEAR FLOW SHALL NOT EXCEED 5 FEET. MAXIMUM 100-YEAR FLOW VELOCITY AT NORMAL DEPTH SHALL NOT EXCEED 5.0 FPS.
4. FREEBOARD: FREEBOARD TO BE A MINIMUM OF 1 FOOT.
5. MAINTENANCE ACCESS ROAD: MINIMUM WIDTH TO BE 12 FEET. CITY MAY REQUIRE ALL OR PART OF THE ROAD TO BE SURFACED.
6. EASEMENT/ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.
7. CHANNEL SIDE SLOPE: MAXIMUM SIDE SLOPE FOR GRASSED CHANNELS TO BE 4:1.
8. FROUDE NUMBER: MAXIMUM VALUE SHALL NOT EXCEED 0.8 FOR MINOR AND MAJOR STORM EVENTS.
9. LOW FLOW PIPE MAY BE USED IN LIEU OF TRICKLE CHANNEL.

City of Greeley Colorado
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TYPICAL GRASS LINED CHANNEL SECTION

FIGURE 5-2

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SCALE: NTS
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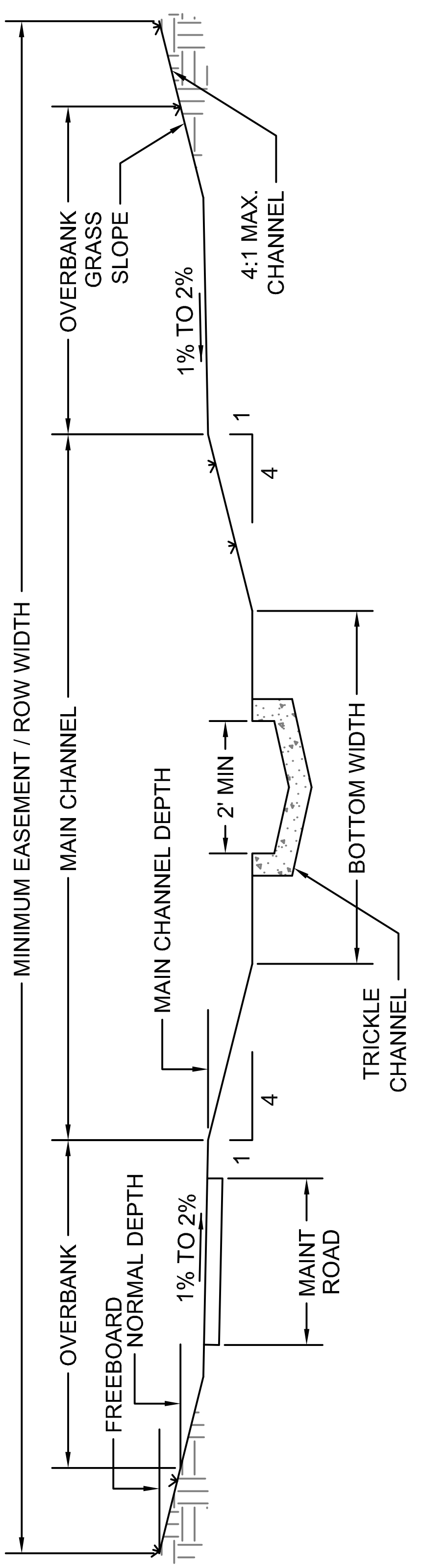

NOTES:

1. MAIN CHANNEL: CAPACITY TO BE NO LESS THAN 20% OF 100-YEAR AT MAIN CHANNEL DEPTH. MAXIMUM 100-YEAR FLOW VELOCITY IS 5.0 FPS.
2. TRICKLE CHANNEL: MINIMUM CAPACITY TO BE 2% TO 4% OF 100-YEAR FLOW BUT NOT LESS THAN 1 CFS. CHANNEL TO BE CONSTRUCTED OF CONCRETE, GROUTED RIPRAP OR OTHER APPROVED MATERIAL. SEE FIGURE 5-4 FOR REQUIREMENTS IN SANDY SOILS.
3. NORMAL DEPTH: SHALL INCLUDE MAIN CHANNEL DEPTH. FLOW DEPTH FOR 100-YEAR SHALL NOT EXCEED 5 FEET.
4. FREEBOARD: FREEBOARD TO BE A MINIMUM OF 1 FOOT.
5. MAINTENANCE ACCESS ROAD: MINIMUM WIDTH TO BE 12 FEET. CITY MAY REQUIRE ALL OR PART OF THE ROAD TO BE SURFACED.
6. EASEMENT / ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.
7. OVERBANK: FLOW IN EXCESS OF MAIN CHANNEL TO BE CARRIED IN THIS AREA. AREA MAY BE USED FOR RECREATION PURPOSES.

TYPICAL GRASS LINED CHANNEL SECTION

FIGURE 5-3

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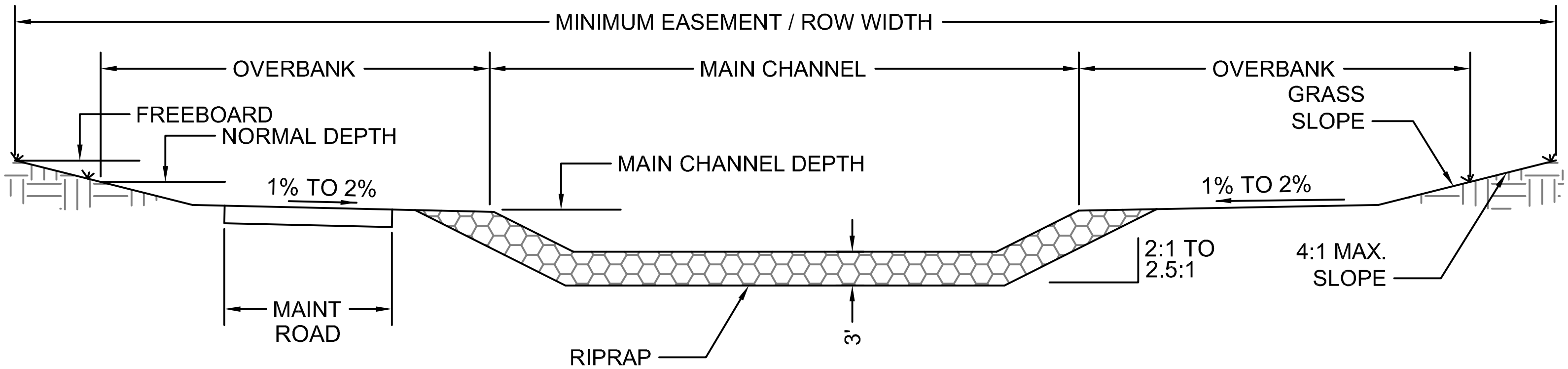
TYPE C



NOTES:

1. THIS SECTION IS REQUIRED FOR CHANNELS IN SANDY SOILS.

2. MAIN CHANNEL: CAPACITY TO BE THE EQUIVALENT OF THE INITIAL STORM RUNOFF. MAXIMUM 100-YEAR FLOW VELOCITY IS 5 FPS. PROTECT SLOPES WITH RIPRAP. USE A MANNINGS N-VALUE OF 0.03 FOR HYDRAULIC CALCULATIONS.

3. NORMAL DEPTH: FLOW DEPTH FOR 100-YEAR FLOW SHALL NOT EXCEED 5 FEET, NOT INCLUDING THE MAIN CHANNEL DEPTH.

4. FREEBOARD: FREEBOARD TO BE A MINIMUM OF 1 FOOT.

5. MAINTENANCE ACCESS ROAD: MINIMUM WIDTH TO BE 12 FEET. CITY MAY REQUIRE ALL OR PART OF THE ROAD TO BE SURFACED.

6. EASEMENT / ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.

7. OVERBANK: FLOW IN EXCESS OF MAIN CHANNEL TO BE CARRIED IN THIS AREA. AREA MAY BE USED FOR RECREATION PURPOSES.

TYPICAL GRASS LINED CHANNEL SECTION FOR SANDY SOILS

FIGURE 5-4

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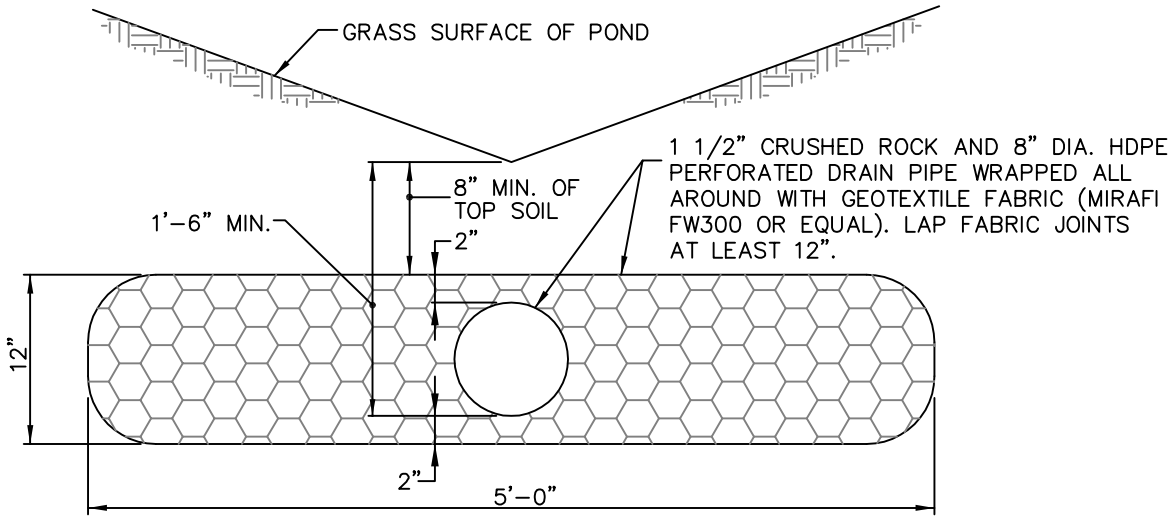
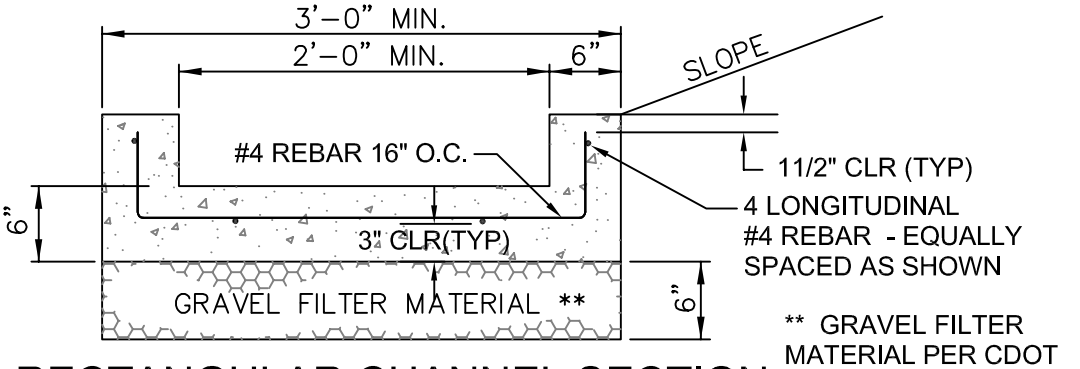
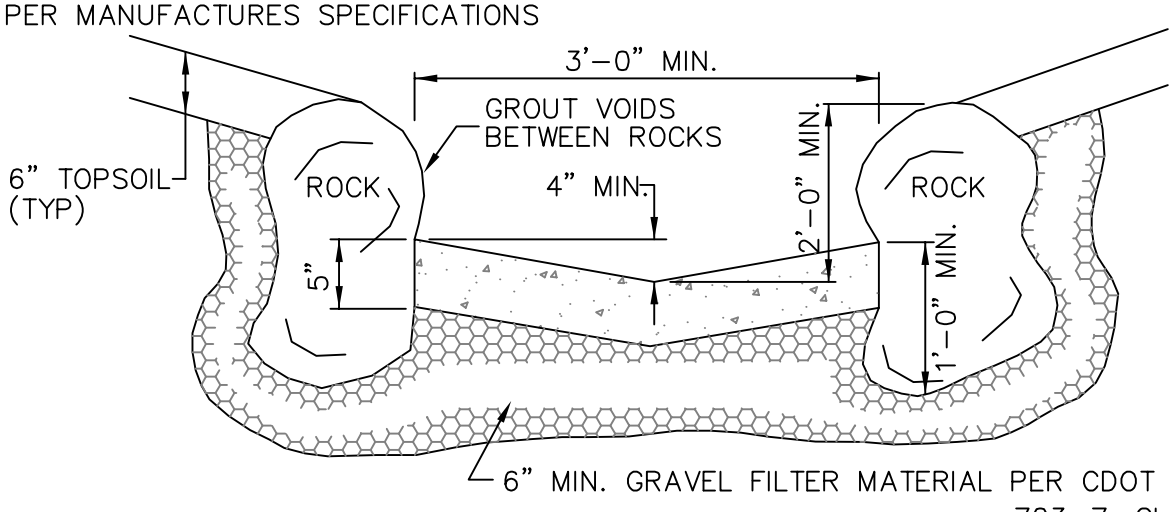


WATER QUALITY CHANNEL SECTION



RECTANGULAR CHANNEL SECTION

NOTES:
CONCRETE TO BE REINFORCED WITH FIBERMESH PER MANUFACTURES SPECIFICATIONS



COMBINATION CHANNEL SECTION

TRICKLE CHANNEL DETAILS

FIGURE 5-5

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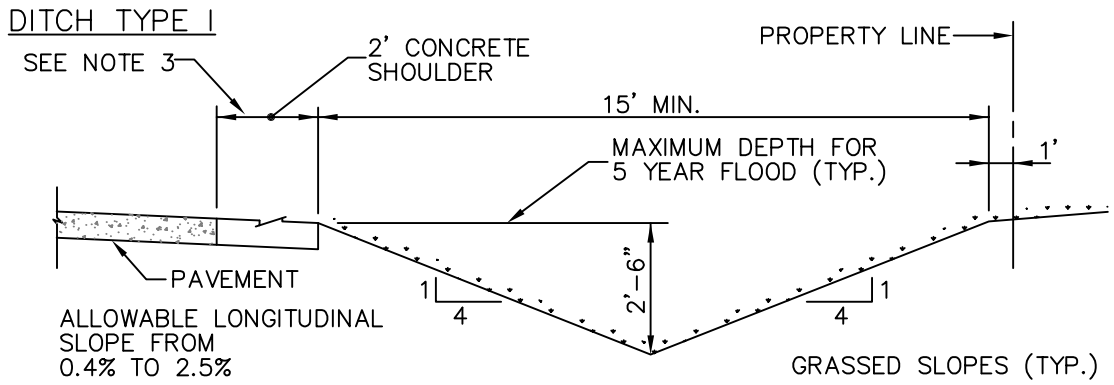

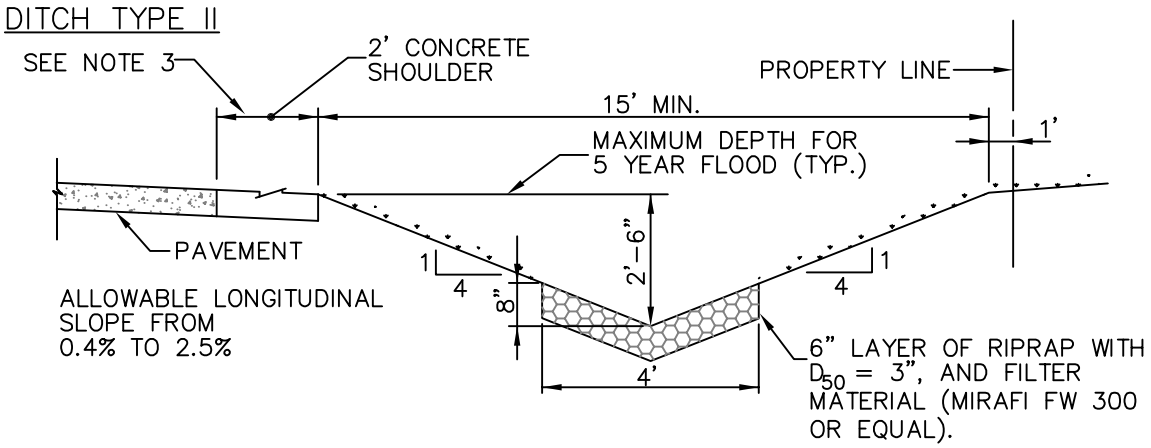

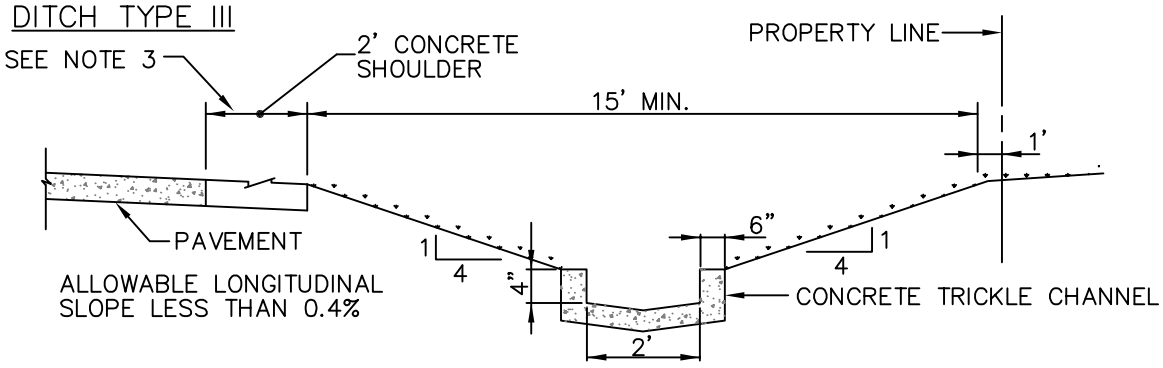

NOTE:

1. FOR STREET SLOPES GREATER THAN MAXIMUM ALLOWABLE, CHECK DROPS (2' MAXIMUM HEIGHT) WILL BE REQUIRED.
2. STREET CROSS SECTION MAY INCLUDE CONCRETE CURB AND GUTTER.
3. PROVIDE 2' WIDE 8" THICK CONCRETE CURB, SEE STREET STANARDS DETAIL NO. S-1.

STORM DRAINAGE CRITERIA
ROADSIDE DITCH SECTIONS

FIGURE 5-6

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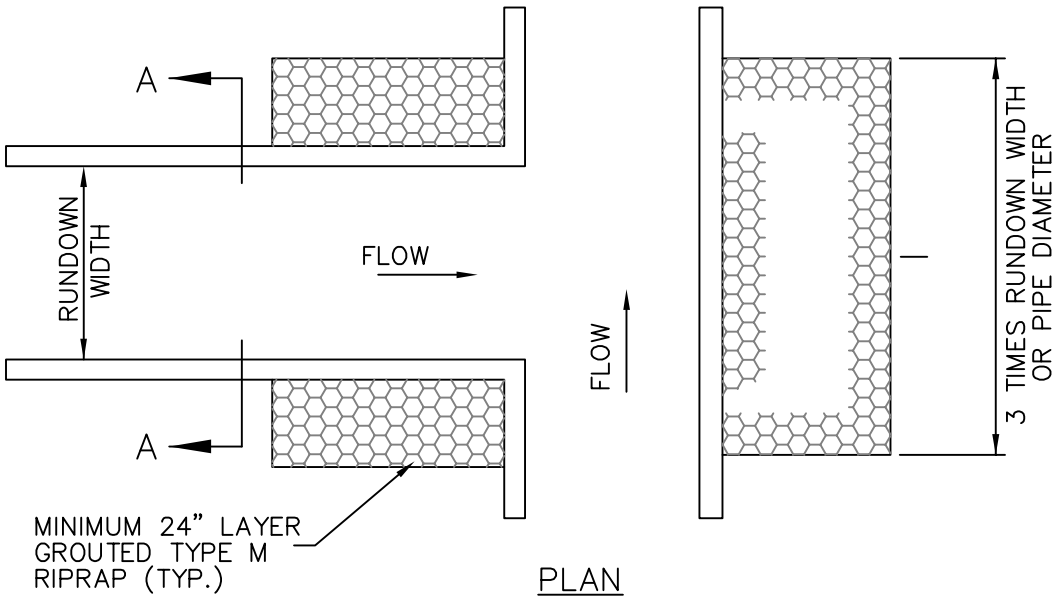
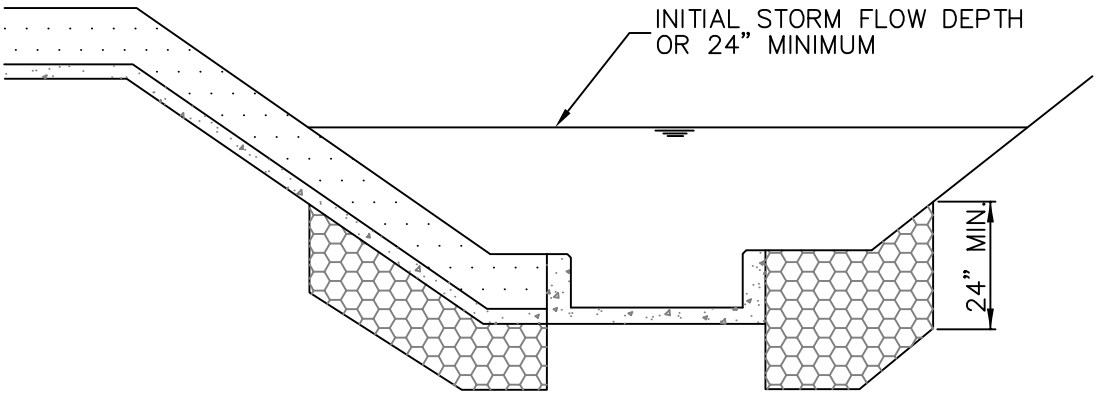
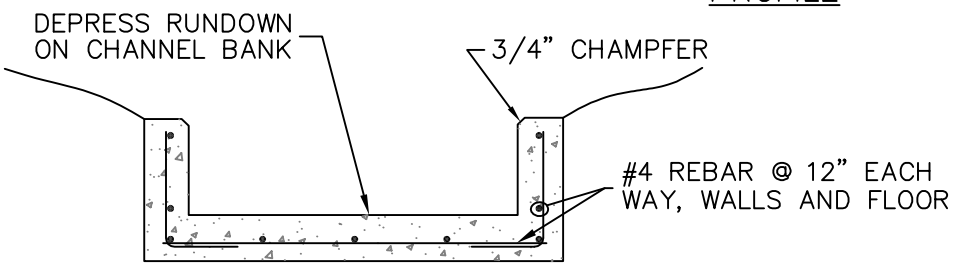


PLAN



PROFILE



SECTION A–A

CHANNEL RUNDOWN

FIGURE 5-7

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