

SECTION 7
OPEN CHANNELS

**CITY OF FORT LUPTON
STORM DRAINAGE DESIGN AND TECHNICAL CRITERIA**

SECTION 7 OPEN CHANNELS

7.1 INTRODUCTION

This section addresses the technical criteria for the hydraulic evaluation and design of open channels in the CITY. The information presented herein is considered to be a minimum standard. It is still the responsibility of the design engineer to exercise sound engineering judgement in the design of the facilities (see CODE Section 11-6-5(B)). Except as modified herein, all open channel criteria shall be in accordance with the MANUAL.

For the purposes of these CRITERIA, sandy soils are defined as non-cohesive sands classified as SW, SP, or SM in accordance with the Unified Soil Classification System.

7.2 CHANNEL TYPES

The channels in the CITY are defined as natural or artificial. Natural channels include all water courses that have occurred naturally by the erosion process such as Walnut Creek and Big Dry Creek. Artificial channels are those constructed or developed by human effort such as large designated floodways, irrigation canals, roadside ditches, concrete-lined channels, rock-lined channels, and grass-lined channels.

7.2.1 Natural Channels

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

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

The hydraulic analysis necessary to assure the adequacy of natural channels vary for every waterway.

At a minimum, the design engineer must prepare cross-sections of the channel, define the water surface profile for the minor and major design storm, determine the major and minor storm velocities, determine the Froude number, investigate the bed and bank material to determine erosion tendencies, and study the bank slope stability of the channel under future flow conditions. Since supercritical flow does not normally occur in natural channels, the results of the hydraulic analysis should not reflect supercritical flow.

7.2.2 Grass-Lined Channels

Grass-lined channels are the most desirable of the artificial channels. Unless existing development within the CITY restricts the availability of right-of-way (ROW) or easement, **only** grass-lined channels are acceptable for drainageways. The grass stabilizes the body of the channel, consolidates the soil mass of the bed, checks the erosion on the channel surface, and controls the movement of soil particles along the channel bottom. The presence of grass in channels creates a turbulence which results in loss of energy and increased flow retardance. The channel storage, the lower velocities, and the potential greenbelt multiple-use benefits obtained from grass-lined channels create significant advantages over other artificial channels.

7.2.3 Concrete-Lined Channels

Concrete-lined channels for drainageways will be permitted only where ROW or easement restrictions within existing development prohibit the use of grass-lined channels. If the project constraints suggest the use of a concrete-lined channel, the applicant shall present the justification to the Public Works Director/City Engineer for consideration and approval.

A design report is required for the approval of a concrete-lined channel. The contents of such a report shall be determined by the Public Works Director/City Engineer. 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 the supercritical flow conditions.

7.2.4 Rock-Lined Channels

Rock-lined channels are generally discouraged and shall be permitted only in areas where ROW or easement restrictions within existing development prohibit the use of grass-lined channels. If the project constraints suggest the use of a rock-lined channel, the design engineer must present the concept and justification to the Public Works Director/City Engineer for consideration and approval.

A design report is required for the approval of a rock-lined channel. The contents of such a report shall be determined by the Public Works Director/City Engineer. The design of rock-lined channels shall be in accordance with the MANUAL.

The advantages of a rock-lined channel are that a steeper longitudinal channel grade can be used due to the higher friction of the rock and that steeper side slopes are permitted. Rock-linings (i.e., revetments) are also permitted as a means of controlling erosion for natural channels. The disadvantages are the large initial cost of construction and high maintenance costs due to vandalism.

7.2.5 Other Lining Types

The use of synthetic fabrics for the lining of channels is discouraged and shall only be permitted in areas where ROW or easement restrictions within existing development prohibit the use of a grass-lined channel. The linings shall be restricted to channels with a Froude number of 0.8 or less. If the project constraints suggest the use of such a channel type, the design engineer must present the concept and justification to the City Engineer for consideration and approval. The use of synthetic fabrics shall be allowed only upon the written approval from the Public Works Director/City Engineer.

The use of synthetic fabrics in construction and geotechnical engineering has increased tremendously in the last decade or more. The use of fabrics for drainage construction (i.e., erosion control liners) has actually taken place over the past several years. The placement of a slope revetment mat is a method of erosion control. The products which consist of discrete blocks on a continuous fabric backing are included in this category of channel lining.

The mattresses generally consist of double layers of woven fabric forms placed on the slope to be protected. The fabric forms are filled with concrete or grout. This type of forming system is a simple, fast, and economical technique for the placement of concrete for slope protection both above and below the water without the need for dewatering. The systems make use of the pressure injection of fluid fine-aggregate concrete into flexible fabric forms. Controlled bleeding of mixing water through the porous fabric produces all the desirable features of low water/cement ratio mortar -- rapid stiffening, high strength, and exceptional durability. The performance characteristics and cost advantages make the process adaptable for stabilizing and protecting shorelines, levees, dikes, canals, and similar erosion control projects.

For normal installations, the fabric forms which are prefabricated to job specifications and dimensions are simply spread over the terrain which has received minimal grading. The fabric form is then pumped full of mortar. This same concept can be used where slide problems are caused by the erosion of the toe of the slopes and where access is difficult for the placement of rip-rap.

7.3 FLOW COMPUTATION

All channels shall convey the 100-year peak flow within the main channel and overbank area assuming a fully developed basin. Uniform flow and critical flow computations shall be in accordance with the MANUAL.

7.4 DESIGN STANDARDS FOR MAJOR DRAINAGEWAYS

These standards cover the design of major drainageways as defined in Section 3.2.5. The design standards for channels cannot be presented in a step-by-step fashion due to the wide range of design options available to the design engineer. The criteria, which have the greatest effect on the performance and cost of the channel, are discussed below.

7.4.1 Natural Channels

The design criteria and evaluation techniques for natural channels are:

1. The channel and overbank areas shall have adequate capacity for the 100-year storm runoff assuming a fully developed basin.
2. Natural channel segments, which have a calculated Froude number greater than 0.95 for the 100-year flow peak, shall be protected from erosion.
3. The 100-year floodplain and floodway shall be defined so that the floodplain can be zoned and protected in accordance with the CITY's floodplain regulations. The first-floor elevation for all structures constructed along the channel shall be a minimum of 1-foot above the 100-year water surface elevation and be outside the 100-year floodplain.
4. Roughness factors (n), which are representative of unmaintained channel conditions, shall be used in the determination of the water surface profiles and floodplain delineation.
5. Roughness factors (n), which are representative of maintained channel conditions, shall be used to determine the channel velocity in both the major and minor storm events.
6. Erosion control structures such as check dams may be required to control flow velocities in both the major and minor storm events.
7. Plan and profile drawings shall be prepared showing the 100-year water surface profile, floodplain, floodway, and the details of erosion protection, if required. Appropriate allowances for known future bridges or culverts, which would affect the floodplain delineation, shall be included in the analysis. The applicant shall contact the CITY's Engineering Division for information on future bridges and culverts.
8. A maintenance access road at least 12-feet wide shall be constructed where feasible. The access road shall be constructed of concrete and meet the specifications for construction of a sidewalk.

9. At a minimum, a drainage and maintenance access easement that encompasses the 100-year floodplain and maintenance access road shall be dedicated to the CITY. However, the maintenance of the channel, overbank areas, and hydraulic structures shall be the responsibility of the developer or his assigns unless modified by an agreement with the CITY.
10. The natural channel shall be adequately controlled in order to meet the eligibility requirements for the UDFCD maintenance program. The UDFCD shall also inspect the construction as part of their requirements. The developer is responsible for obtaining UDFCD design approval and coordinating the necessary inspections. City Staff will initially refer the construction drawings and the applicable reports to the UDFCD for review.

With most natural waterways, erosion control structures may be needed at regular intervals to decrease the channel slope and to control erosion. However, natural channels should also be left in as near a natural condition as possible. For that reason, extensive modifications to the channel should not be undertaken unless it is necessary in order to avoid excessive erosion with subsequent deposition downstream.

The criteria for freeboard, depth, and curvature as well as the other criteria, which are applicable to artificial channels, do not apply to natural channels.

If a natural channel is to be maintained and utilized for a development, the applicant shall meet with City staff to discuss the concept and to obtain the requirements for planning and design documentation.

7.4.2 Grass-Lined Channels

Key parameters in grass-lined channel design include velocity, slope, roughness coefficients, depth, freeboard, curvature, and cross-section shape. Other factors such as erosion control structures, drop structures, and transitions also play an important role. The channel design will also depend on whether the channel is to be constructed in sandy or non-sandy soil. A discussion of these parameters is presented below.

1. Flow Velocity and Froude Number

The maximum normal depth velocity for the 100-year peak flow shall not exceed 7.0 feet per second for grass-lined channels in erosion resistant soils and 5.0 feet per second in easily eroded soil. The minimum velocity, wherever possible, shall be greater than 2.0 feet per second for the minor storm runoff.

The Froude number (turbulence factor) shall be less than 0.8.

2. Longitudinal Channel Slopes

The channel slope is dependent on the 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

The channel freeboard for the 100-year flow peak shall be as determined using Equation 7-1 but not less than 1 foot.

$$H_{fb} = 0.5 + \frac{V^2}{2g} \quad (7-1)$$

Where: H_{fb} = freeboard height (feet)
 V = average channel velocity (ft/sec)
 g = acceleration of gravity (32.2 ft/sec²)

4. Horizontal Curvature

The centerline curvature shall have a radius twice the channel top width at the design flow but not less than 100 feet.

5. Roughness Coefficient

The variation of Manning's "n" with the retardance and the product of the mean velocity and the hydraulic radius, as presented in Figure 701, shall be used in design computations.

Retardance curve "C" shall be used to determine the channel capacity since a mature channel will have a higher Manning's "n" value. However, retardance curve "D" shall be used to determine the channel velocity since a recently constructed channel will have minimal vegetation and the retardance will be less than that of a mature channel.

6. Cross-Sections

The channel cross-section may be any type suitable to the location and environmental conditions. Often the channel cross-section is chosen to suit greenbelt and recreational needs. Figures 702 and 703 present two typical channel cross-sections for use with non-sandy soils. Figure 704 is the **required** channel cross-section for construction in sandy soils.

a. Trickle Channel - Non-sandy Soils

A trickle channel shall be required. The capacity shall be 1.0 percent to 3.0 percent of the 100-year design flow but not less than 1 cfs. Trickle channels shall be constructed of concrete or other approved materials in order to minimize erosion, to facilitate maintenance, and to aesthetically blend with the

adjacent vegetation. Recommended trickle channel sections are presented in Figure 705. The trickle channel shall be four feet wide and 6-inches deep at a minimum.

b. Main Channel

1. Sandy Soils

A main channel is required with a flow capacity between the 2-year and 5-year design flow. The channel side-slopes range from 2:1 to 2.5:1 with required rip-rap lining. The main channel depth is not included in the maximum 100-year flow depth.

2. Non-sandy Soils

The capacity of the main channel shall be greater than 20% of the 100-year design flow. The side-slopes are to be 4:1 or flatter. The main channel depth is included in the maximum 100-year flow depth.

c. Bottom Width

The channel bottom width shall be determined by the depth and velocity criteria. The minimum bottom width shall be the trickle channel width.

d. Flow Depth

The maximum design flow depth (outside the trickle channel area) for the 100-year design flow shall be limited to 5.0 feet in grass-lined channels for non-sandy soils and 5 feet plus the main channel flow depth for sandy soils.

e. Side Slopes

Channel side-slopes shall be 4 to 1 or flatter.

7. Maintenance Access Road

A continuous maintenance access road shall be provided along the entire channel length with a minimum passage width of 12 feet. The access road shall be concrete paved and meet the specifications for sidewalk construction. The edge of the access road shall be at least 10-feet from any property line.

8. Easement Width

At a minimum, a drainage and maintenance access easement for the channel shall be dedicated to the CITY. The minimum easement width shall include the channel, freeboard, and the maintenance access road. The maintenance of the channel,

overbank areas, and hydraulic structures shall be the responsibility of the developer or his assigns unless modified by an agreement with the CITY.

9. Grass Lining

The grass-lining for channels shall be in accordance with the seed specifications given in the STANDARD.

10. Hydraulic Structures

Hydraulic structures if required shall be in accordance with the CRITERIA and the MANUAL.

The requirements for erosion control for grass-lined channels shall be as defined in the MANUAL and these CRITERIA.

11. Hydraulic Information

Calculations of the capacity, velocity, depth, and Froude numbers shall be included in the Phase III drainage report.

12. Water Surface Profiles

The water surface profiles for the minor and major storm event shall be computed for all open channels. The water surface profiles shall be calculated using standard backwater methods taking into consideration the losses due to changes in velocity, drop structures, waterway openings, or obstructions. The energy grade line and hydraulic grade line shall be shown on the profile drawings and included in the Phase III drainage report.

13. 100-year Floodplain

The 100-year floodplain shall be delineated on a plan view drawing and included in the Phase III drainage report.

14. UDFCD Maintenance Program

The UDFCD shall approve all channel designs to ensure eligibility in the UDFCD maintenance program. The UDFCD shall also inspect the construction as part of their requirements. The developer is responsible for obtaining UDFCD design approval and coordinating the necessary inspections. City Staff will initially refer the construction drawings and the applicable reports to the UDFCD for review.

7.4.3 Concrete-Lined Channels

The criteria for the design and construction of concrete-lined channels is presented below:

1. Hydraulics

a. Freeboard

Channel freeboard shall be determined by the Equation 7-2 with a minimum requirement of 1 foot. Freeboard shall be in addition to superelevation, standing waves, and/or other water surface disturbances.

$$H_{fb} = 2.0 + 0.025V\sqrt[3]{d} \quad (7-2)$$

Where: H_{fb} = freeboard height (feet)
 V = velocity (feet per second)
 d = depth of flow (feet)

The channel side-slopes shall be extended to provide the required freeboard.

b. Water Surface Disturbances

Superelevation of the water surface shall be determined at all horizontal curves. The design of the channel section will be adjusted accordingly. Standing waves shall be determined as well at the location of hydraulic jumps.

These special situations are to be addressed in a Phase III Drainage Report to be submitted with the construction drawings and specifications.

c. Velocities

Flow velocities shall not exceed 18 feet per second for the 100-year design flow.

2. Concrete Materials

The minimum concrete material specifications are as follows:

- a. Cement type: sulphate resistant.
- b. Minimum cement content: 550 lbs/C.Y.
- c. Maximum water-cement ratio: 0.50 (six gallons per sack).
- d. Maximum aggregate size: 1-1/2 inches.
- e. Air entrainment content: 4 to 7 percent.

- f. Slump: 2 to 4 inches.
- g. Minimum compressive strength (f'_c): 3750 psi at 28 days.
- h. Admixtures: All proposed admixtures shall be discussed on the Design Report.

3. Concrete Lining Section

- a. All concrete lining shall have a minimum thickness of 7 inches.
- b. The side-slopes shall be a maximum of 2:1 or a structurally reinforced wall if steeper.

4. Concrete Joints

- a. Channels shall be continuously reinforced without transverse joints. Expansion/contraction joints shall be installed where new concrete-lining is connected to a rigid structure or to existing concrete-lining which is not continuously reinforced. Dowels will also be required.
- b. Longitudinal joints, where required, shall be constructed on the side-slopes at least 1 foot vertically above channel invert.
- c. All joints shall be designed to prevent differential movement and water seepage.
- 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

The surface of the concrete-lining shall be provided with a wood float finish. Excessive working or wetting of the finish shall be avoided.

6. Concrete Curing

All concrete shall be cured by the application of a liquid membrane-forming curing compound (white pigmented) upon completion of the concrete finish.

7. Reinforcement Steel

- a. Steel reinforcement shall be minimum Grade 40 deformed bars. Wire mesh shall not be used.

- b. Ratio of longitudinal steel area to concrete cross-sectional area shall be greater than 0.006.
- c. Ratio of transverse steel area to concrete cross-sectional area shall be greater than 0.0025.
- d. Reinforcing steel shall be placed at the center of the section with a minimum clear cover of 3 inches adjacent to the earth.
- e. Additional steel shall be required if a retaining wall structure is used.

8. Earthwork

The following areas shall be compacted to at least 95 percent of maximum density as determined by ASTM D698 (Standard Proctor):

- a. The 12 inches of subgrade immediately beneath the concrete-lining (both the channel bottom and side-slopes).
- b. The top 12 inches beneath the maintenance access road.
- c. The top 12 inches of earth surface within 10 feet of concrete channel lip.
- d. All fill material.

9. Bedding

Provide 6 inches of granular bedding equivalent in gradation to 3/4" concrete aggregate (Standard Specifications for Road & Bridge Construction, CDOH, current revision, Section 703.02, No. 67) under the channel bottom and side-slopes.

10. Underdrain

Longitudinal underdrains shall be provided on 10-foot centers and shall daylight at the check drops. A check valve or flap gate shall be provided at the outlet to prevent backflow into the drain. Weep holes shall be provided in vertical wall sections of the channel.

11. Safety Requirements

- a. A 6-foot-high vinyl-coated chain link or comparable fence shall be installed to prevent access wherever the 100-year channel flow depths exceed 3 feet. Gates with a top latch shall be placed at 250-foot intervals and staggered where a fence is required on both sides of channel.

- b. Ladder-type steps shall be installed not more than 400 feet apart on alternating sides of the channel. The 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 channel length with a minimum passage of 12 feet. The access road shall be concrete paved and meet the specifications for sidewalk construction.

13. Easement Requirements

At a minimum, a drainage or maintenance access easement shall be dedicated to the CITY. The easement width shall include the channel, freeboard, and the maintenance access road. Maintenance of the channel will be the responsibility of the developer or his assigns unless modified by an agreement with the CITY.

14. UDFCD Maintenance Program

The UDFCD shall approve all channel designs to ensure eligibility in the UDFCD maintenance program. The UDFCD shall also inspect the construction as part of their requirements. The developer is responsible for obtaining UDFCD design approval and coordinating the necessary inspections. City Staff will initially refer the construction drawings and the applicable reports to the UDFCD for review.

15. Record Drawings

On the Record Drawings, the design engineer will be required to affirm that the concrete used in the channel lining was tested and meets the required specifications.

7.4.4 Rock-Lined Channels

The criteria for the design and construction of rock-lined channels shall be in accordance with the MANUAL and these CRITERIA. Freeboard and maintenance access road requirements shall be in accordance with the requirements for grass-lined channels defined in Section 7.4.2 of these CRITERIA.

7.4.5 Other Lining Types

The criteria for the design of 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 Engineer to verify assumptions or design criteria. The following minimum criteria will apply.

1. Flow Velocity

The maximum normal depth velocity will be dependent on the construction material utilized; however, the Froude number shall be less than 0.8.

2. Freeboard

As defined by Equation 7-1.

3. Curvature

The centerline curvature shall have a minimum radius twice the channel top width at the design flow but not less than 100 feet.

4. Roughness Coefficient

A Manning's "n" value range shall be established by the manufacturer's data with the high value used to determine depth and capacity and the low value used to determine the Froude number and velocity.

5. Cross-Sections

Same as for grass-lined channels, Section 7.4.2.

7.5 DESIGN STANDARDS FOR NON-MAJOR DRAINAGEWAYS

Non-major drainageways are drainageways with a tributary area of 130 acres or less and a 100-year flow rate greater than 20 cfs. The following standards apply to the design of channels for non-major drainageways.

7.5.1 Natural Channels

The design criteria and evaluation techniques for natural channels are:

1. The channel and overbank areas shall have adequate capacity for the 100-year design flow.
2. Natural channel segments, which have a calculated Froude number greater than 0.95 for the 100-year flow peak, shall be protected from erosion.
3. Roughness factors (n), which are representative of unmaintained channel conditions, shall be used in the capacity and depth analysis.

4. Roughness factors (n), which are representative of maintained channel conditions, shall be used to determine velocity.
5. Erosion control structures such as check drops may be required to control flow velocities in both the major and minor storm events.
6. Plan and profile drawings shall be prepared showing the 100-year water surface profile for the major and minor storm, floodplain, and details of erosion protection, if required. Appropriate allowances for known future bridges or culverts, which would affect the floodplain delineation, shall be included in the analysis. The applicant shall contact the CITY's Public Works/Engineering Division for information on future bridges and culverts. The 100-year floodplain shall be defined so that the floodplain can be zoned and protected in accordance with the CITY's floodplain regulations. The first-floor elevation of all structures constructed along the channel shall be at least 1-foot above the 100-year water surface elevation and be outside the 100-year floodplain.
7. At a minimum, a drainage and maintenance access easement that encompasses the 100-year floodplain and maintenance access road shall be dedicated to the CITY. However, the maintenance of the channel, overbank areas, and hydraulic structures shall be the responsibility of the developer or his assigns unless modified by an agreement with the CITY.

7.5.2 Grass-Lined Channels

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

1. Flow Velocity

The maximum normal depth velocity for the 100-year flow peak shall not exceed 7.0 feet per second for erosion resistant soils and 5.0 feet per second for easily eroded soils. The minimum velocity, wherever possible, shall be greater than 2.0 feet per second for the minor storm runoff.

The Froude number (turbulence factor) shall be less than 0.8.

2. Longitudinal Channel Slopes

Channel slopes are determined by the velocity and Froude number requirements. Where the natural topography is steeper than desirable, drop structures shall be utilized to maintain the required design velocities and Froude numbers.

3. Freeboard

The minimum freeboard is 1 foot.

4. Curvature (Horizontal)

The centerline curvature shall have a minimum radius of twice the channel top width at the design flow but not less than 50 feet.

5. Roughness Coefficient

Retardance Curve "C" as presented in Figure 701 shall be used in the computation of capacity and velocity.

6. Cross-Sections

The channel cross-section may be almost any type suitable to the location and environmental conditions. Some suggested cross-sections are shown on Figures 702, 703, and 704. The limitations on the cross-sections are as follows:

a. Trickle Channel

The base flow shall be carried in a trickle channel for non-sandy soils. The capacity shall be from 1.0 percent to 3.0 percent of the 100-year design flow but not less than 1 cfs. The trickle channel can be constructed of concrete, rock, cobbles, or other suitable materials in order to minimize erosion, to facilitate maintenance, and to aesthetically blend with the adjacent vegetation. The minimum trickle channel width shall be four feet with a minimum depth of 6 inches. Recommended trickle channel sections are provided in Figure 705.

b. Main Channel

1. Sandy Soils

A main channel is required with a flow capacity between the 2-year and 5-year design flow. The channel side-slopes range from 2:1 to 2.5:1 with required rip-rap lining. The main channel depth is not included in the maximum 100-year flow depth.

2. Non-sandy Soils

The capacity of the main channel shall be greater than 20% of the 100-year design flow. The side-slopes are to be 4:1 or flatter. The main channel depth is included in the maximum 100-year flow depth.

c. Bottom Width

The channel bottom width shall be determined by the depth and velocity criteria. The minimum bottom width shall be the trickle channel width.

d. Flow Depth

The maximum design depth of flow (outside the trickle channel area) for the 100-year flow peak shall be 5.0 feet in non-sandy soils and 5.0 feet plus the main channel depth for sandy soils.

e. Side-Slopes

Channel side-slopes shall be 4 (horizontal) to 1 (vertical) or flatter.

7. Grass Lining

The grass-lining shall be in accordance with the seed specifications given in the STANDARDS.

8. Erosion Control

The requirements for erosion control for grass-lined channels shall be as defined in the MANUAL and these CRITERIA.

9. Hydraulic Information

Calculations of the capacity, velocity, depth, and Froude numbers shall be included in the Phase III drainage report. A plan and profile drawing showing the limits of the major storm event shall also be included.

10. Maintenance Access Road

A continuous maintenance access road shall be provided along the entire channel length with a minimum passage width of 12 feet. The access road shall be concrete paved and meet the specifications for sidewalk construction. The edge of the access road shall be at least 10-feet from any property line.

11. Easement Width

At a minimum, a drainage and maintenance access easement shall be dedicated to the CITY. The minimum easement width shall include the freeboard and a 12-foot wide maintenance access road. Maintenance of the channel will be the developer's responsibility or his assigns unless modified by an agreement with the CITY.

12. Water Surface Profiles

The water surface profiles for the minor and major storm event shall be computed for all open channels. The water surface profiles shall be calculated using standard backwater methods taking into consideration the losses due to changes in velocity, drop structures, waterway openings, or obstructions. The energy grade line and hydraulic grade line shall be shown on the profile drawings and included in the Phase III drainage report.

7.5.3 Concrete-Lined Channels

The criteria for the design and construction of concrete-lined channels is presented below:

1. Hydraulics

a. Freeboard

Channel freeboard shall be determined by the Equation 7-3 with a minimum requirement of 1 foot. Freeboard shall be in addition to superelevation, standing waves, and/or other water surface disturbances. These special situations are to be addressed in the Phase III Drainage Report to be submitted with the construction drawings and specifications. The channel side slopes shall be extended to provide the required freeboard.

$$H_{fb} = 1.0 + 0.025V\sqrt[3]{d} \quad (7-3)$$

Where: H_{fb} = freeboard height (feet)
 V = velocity (ft/sec)
 d = depth of flow (feet)

b. Superelevation

Superelevation of the water surface shall be determined at all horizontal curves. The design of the channel section will be adjusted accordingly.

c. Velocities

Flow velocities shall not exceed 18 fps during the 100-year design flow.

2. Concrete Material

The minimum concrete material specifications are as follows:

- a. Cement type: sulphate resistant.
- b. Minimum cement content: 550 lbs/C.Y.

- c. Maximum water-cement ratio: 0.50 (6 gallons per sack).
- d. Maximum aggregate size: 1-1/2 inches.
- e. Air entrainment content: 4 to 7 percent.
- f. Slump: 2 to 4 inches.
- g. Minimum compressive strength (f'c): 3750 psi at 28 days.
- h. Admixtures: All proposed admixtures shall be discussed in the Design Report.

3. Concrete Lining Section

- a. All concrete lining shall be of sufficient thickness to withstand the structural and hydraulic loads.
- b. The channel side slopes shall be a maximum of 2 (vertical) to 1 (horizontal). If the side slopes are steeper, a structurally reinforced wall is required.

4. Concrete Joints

- a. Expansion/contraction joints shall be installed where new concrete-lining is connected to a rigid structure or to existing concrete-lining which is not continuously reinforced. Dowels will also be required.
- b. Longitudinal joints, where required, shall be constructed on the side-slopes at least 1 foot vertically above channel invert.
- c. All joints shall be designed to prevent differential movement and water seepage.
- d. Construction joints are required for all cold joints and where the lining thickness changes.

5. Concrete Finish

The surface of the concrete lining shall be provided with a wood float finish. Excessive working or wetting of the finish shall be avoided.

6. Concrete Curing

All concrete shall be cured by the application of a liquid membrane-forming curing compound (white pigmented) upon completion of the concrete finish.

7. Reinforcement Steel (where used)

- a. Steel reinforcement shall be minimum Grade 40 deformed bars. Wire mesh shall not be used.
- b. Ratio of longitudinal steel area to concrete cross-sectional area shall be greater than 0.006.
- c. Ratio of transverse steel area to concrete cross-sectional area shall be greater than 0.0025.
- d. Additional steel as needed if a retaining wall structure is used.

8. Earthwork

The following areas shall be compacted to at least 95 percent of maximum density as determined by ASTM D-698 (Standard Proctor):

- a. The 12 inches of subgrade immediately beneath the concrete-lining for both the channel bottom and side slopes.
- b. The top 12 inches beneath the maintenance access road.
- c. The top 12 inches of earth surface within 10 feet of concrete channel lip.
- d. All fill material.

9. Bedding

Provide 6 inches of granular bedding equivalent in gradation to 3/4" concrete aggregate (Standard Specifications for Road & Bridge Construction, CDOH, current printing, Section 703.02, No. 67) under the channel bottom and side-slopes.

10. Underdrains

Longitudinal underdrains 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

- a. A 6-foot-high vinyl-coated chain link or comparable fence shall be installed to prevent access wherever the 100-year channel flow depths exceed 3 feet. Gates with a top latch shall be placed at 250-foot intervals and staggered where the 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. The bottom rung shall be placed approximately 12 inches vertically above channel invert.

12. Maintenance Access Road

A maintenance access road shall be provided along the entire channel length with a minimum passage of 12 feet. The access road shall be concrete paved and meet the specifications for sidewalk construction.

13. Easement Requirements

At a minimum, a drainage and maintenance access easement shall be dedicated to the CITY. The minimum easement width shall include the channel, freeboard, and a 12-foot maintenance access. The maintenance responsibility shall be the developers or his assigns unless modified by an agreement with the CITY.

14. Record Drawings

On the Record Drawings, the design engineer will be required to affirm that the concrete used in the channel lining was tested and meets the required specifications.

7.5.4 Rock-Lined Channels

The criteria for the design and construction of rock-lined channels shall be in accordance with the MANUAL and these CRITERIA.

Rock-lined channels shall have a Froude number (turbulence factor) of less than 0.8 for the 100-year design flow. Freeboard requirements shall be in accordance with the standards for grass-lined channels defined in Section 7.5.2 of these CRITERIA.

7.5.5 Other Lining Types

The criteria for the design of 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 Engineer to verify assumptions or design criteria. The following minimum criteria will apply.

1. Flow Velocity

The maximum normal depth velocity will be dependent on the construction material utilized; however, the Froude number shall be less than 0.8.

2. Freeboard

The minimum freeboard is 1 foot.

3. Curvature

The centerline curvature shall have a minimum radius of twice the channel top width at the design flow but not less than 50 feet.

4. Roughness Coefficient

A Manning's "n" value range shall be established by the manufacturer's data, with the high value used to determine depth and capacity and the low value used to determine Froude number and velocity.

5. Cross-Sections

Same as for grass-lined channels, Section 7.5.2.6.

7.6 SWALES

Swales are channels with a 100-year flow rate of less than 20 cfs. The cross-section should be a simple V-section. The minimum freeboard requirement is 6 inches. Trickle channel requirements will be evaluated on a case-by-case basis since trickle channels help preserve swales through residential property. The minimum centerline curvature radius shall be 25 feet.

7.7 RUNDOWN CHANNELS

A rundown channel is used to convey surface runoff from gutters or paved areas at the top of a channel bank to the invert of an open channel. The purpose of the rundown channel is to minimize channel bank erosion caused by concentrated overland flow. The design criteria for channel rundowns are as follows:

7.7.1 Cross-Sections

The channel rundowns details are presented in Figure 706. The rundown channel shall be a minimum of 4 feet wide and 6 inches deep.

7.7.2 Design Flow

The design flow is the flow amount to be conveyed by the rundown channel during the major storm event. If the minor storm runoff is conveyed by inlets and pipes to the main channel invert, the design flow is the difference between the major and minor storm runoff.

7.7.3 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. In addition, each entrance condition must be analyzed to assure the rundown channel will intercept the flow.

7.7.4 Freeboard

Minimum freeboard is 4 inches.

7.7.5 Outfall Configuration

The channel rundown shall enter the main channel at the trickle channel flowline. Erosion protection consisting of a 24-inch layer of grouted Type L rip-rap shall be provided on the opposite channel bank as well as adjacent to the rundown channel. The width of the erosion protection on the opposite channel bank shall be at least three times the rundown channel width and extend up the bank to the minor storm flow depth in the main channel or 2 feet, whichever is greater. Erosion protection shall also be provided adjacent to the rundown channel. The erosion protection shall be at least the width of the rundown channel on either side of the rundown channel and extend up the bank to the minor storm flow depth in the main channel or 2 feet, whichever is greater.

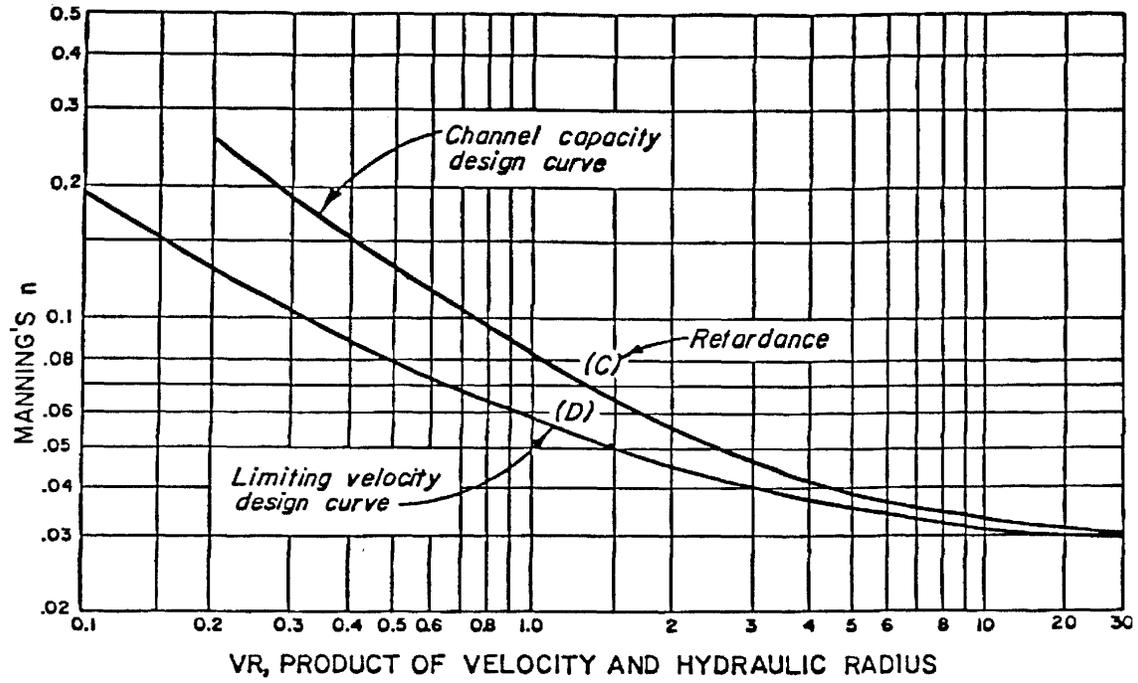
7.8 CHECKLIST

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

1. All calculations must include the results for the major and minor storm events.
2. Check the 100-year design flow and the soil conditions to determine the classification of the channel.
3. Check the flow velocity with the low retardance factor and the channel capacity with the high retardance factor.
4. Check the Froude number at all critical flow conditions.
5. Grass-lined channel side-slopes must be 4:1 or flatter.
6. Show the energy grade line and the hydraulic grade line on the design drawings. Show the 100-year floodplain delineation on the plan drawings.

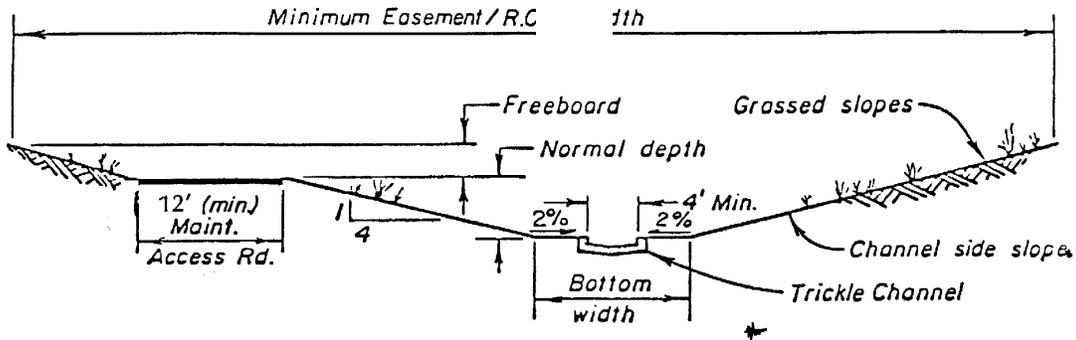
7. Consider all culverts and bridges when determining channel capacity and floodplain delineation.
8. Check the channel velocity at critical locations and without the backwater effects.
9. Provide adequate freeboard.
10. Provide adequate drainage and maintenance access easements for the channel and maintenance access road.

Figure 701
Roughness Coefficients for Grassed Channels



Reference: "Handbook of Channel Design For Soil and Water Conservation," U.S. Department of Agriculture, Soil Conservation Service, No. SCS-TP-61 March, 1947, Rev. June, 1954

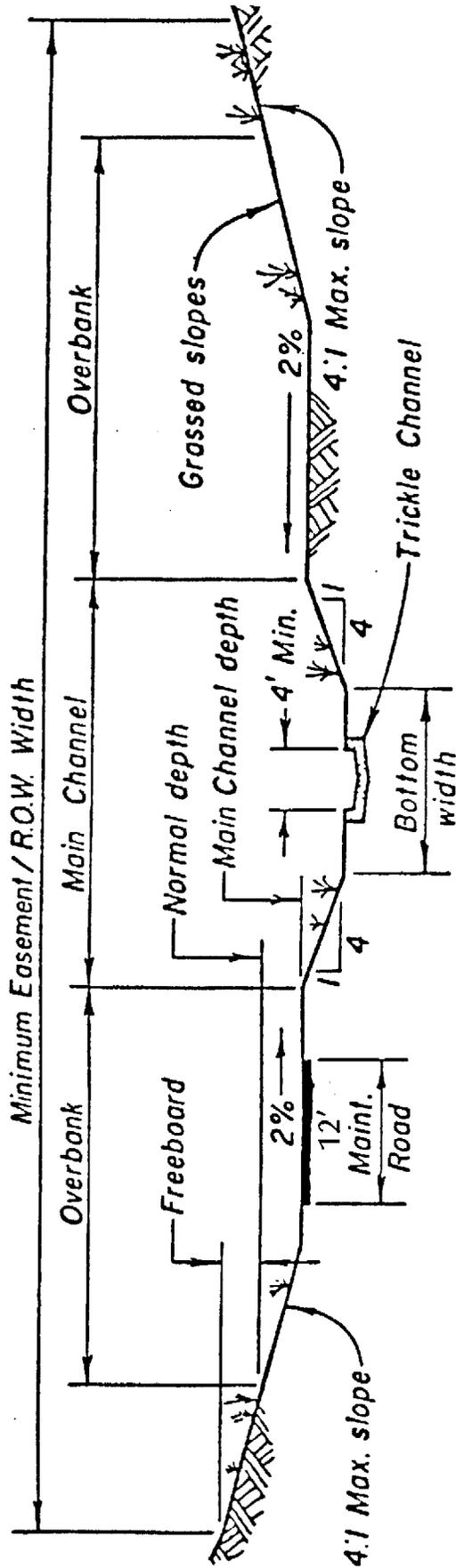
Figure 702
 Typical Grassed-lined Channel Section
 Type A



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 1% to 3% of 100-year flow but not less than 1 cfs. Channel to be constructed of concrete, grouted rip-rap or other approved materials. See Figure 705 for recommended trickle channel sections.
3. Normal Depth: Normal depth at the 100-year design flow shall not exceed 5 feet. Maximum 100-year flow velocity at normal depth shall not exceed 7 fps.
4. Freeboard: Freeboard to be a minimum of 1 foot.
5. Maintenance Access Road: Minimum width to be 12 feet and constructed of concrete.
6. Easement Width: Minimum width to include freeboard and maintenance access road. Maintenance access road to be at least 10-feet from the property line.
7. Channel Side Slope: Maximum side slope for grassed channels is 4:1.
8. Froude Number: Maximum value shall not exceed 0.8 for minor and major floods.

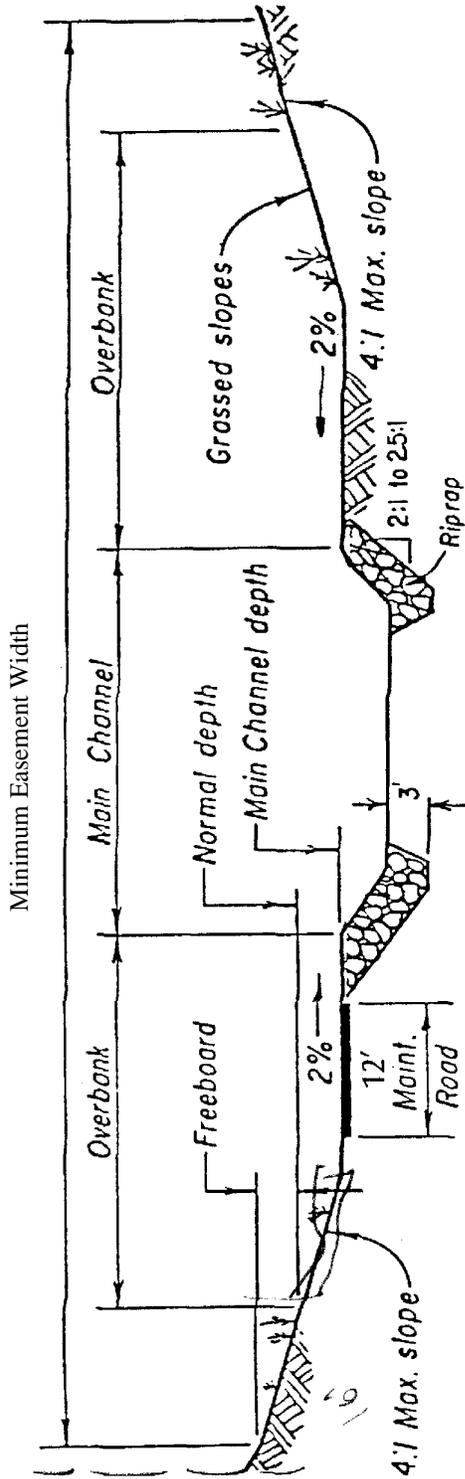
Figure 703
 Typical Grassed-lined Channel Section
 Type B



NOTES:

1. Main Channel: Capacity to no less than 20% of 100-year design flow at main channel depth. Maximum 100-year flow velocity is 7 fps.
2. Trickle Channel: Minimum capacity to be 1% to 3% of 100-year design flow but not less than 1 cfs. Channel to be constructed of concrete, grouted rip-rap, or other approved materials. See Figure 705.
3. Normal Depth: Flow depth for 100-year design flow shall not exceed 5 feet from bottom of main channel.
4. Freeboard: Freeboard to be a minimum of 1 foot.
5. Maintenance Access Road: Minimum width to be 12 feet and constructed of concrete.
6. Easement Width: Minimum width to include freeboard and maintenance access road. Maintenance access road to be at least 10-feet from the property line.
7. Overbank: Flow in excess of main channel to be carried in this area. Area may be used for recreation purposes.

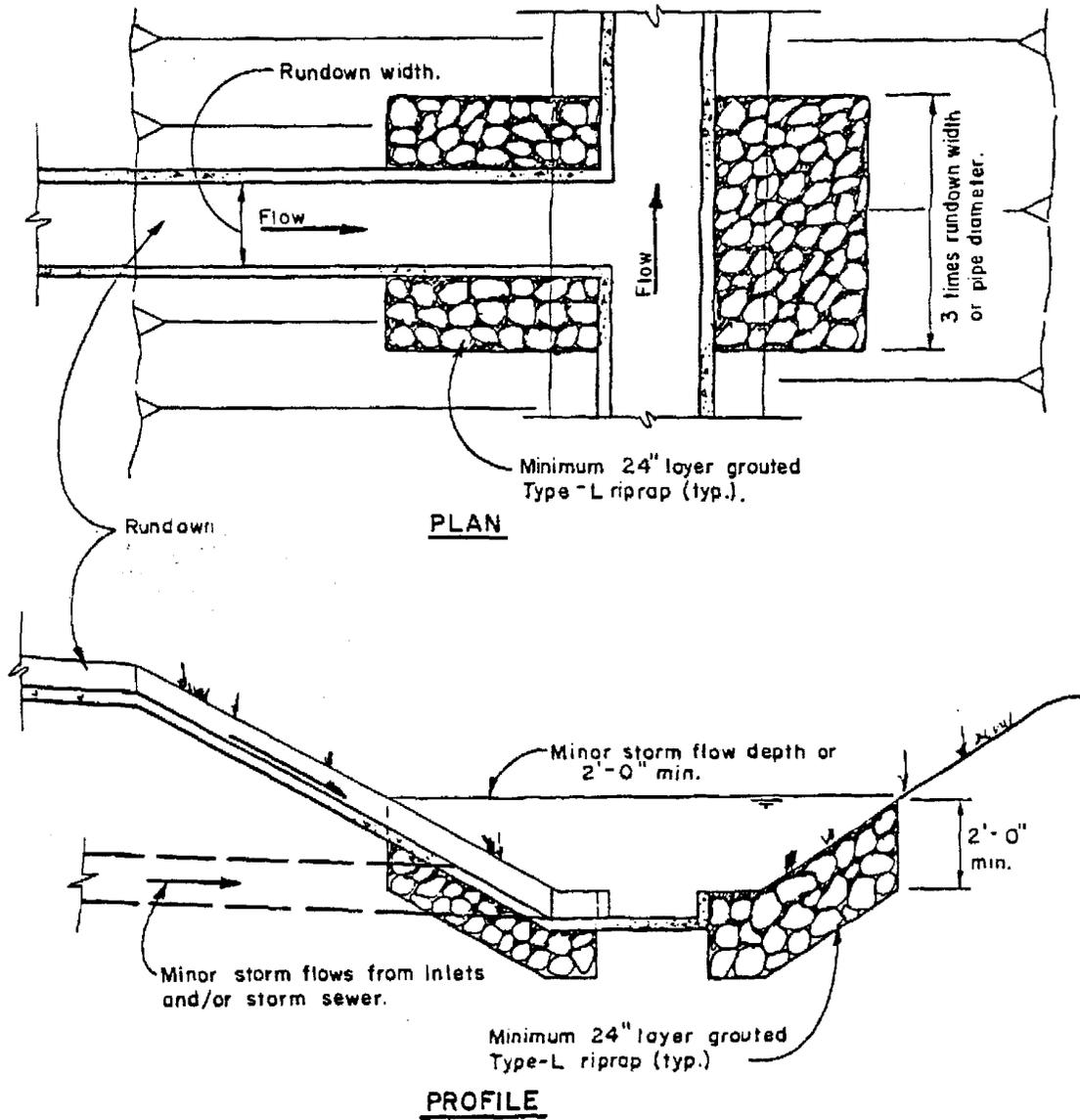
Figure 704
 Typical Grassed-lined Channel Section
 Type C



NOTES:

1. This channel section is required for channels in sandy soils.
2. Main Channel: Capacity to be from the 2-year to the 5-year design flow. Maximum 100-year flow velocity is 5 fps. Protect side slopes with rip-rap. Use a manning's n-value of 0.03 for hydraulic calculations.
3. Normal Depth: Flow depth for 100-year design 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 is 12-feet and constructed of concrete.
6. Easement Width: Minimum width to include freeboard and maintenance access road. Maintenance access road to be at least 10-feet from the property line
7. Overbank: Flow in excess of main channel to be carried in the overbank area. This area may be used for recreation purposes.

Figure 706
Channel Rundown Details



Reference: Urban Storm Drainage Criteria Manual, DRCOG, 1969