CHAPTER 7
STORM WATER DESIGN

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7.01 General

(A) Intent

The Storm Water Design Standards are intended to provide for a comprehensive and integrated storm water utility system to convey and manage storm waters in order to mitigate safety hazards and minimize property losses and disruption due to heavy storm runoff and flooding, maintain travel on public streets during storm events, enhance water quality of storm runoff by mitigating erosion, sediment and pollutant transport, control and manage increased runoff due to local development, establish effective long-term management of natural drainageways, and provide for ongoing and emergency maintenance of public storm water systems.

(B) Storm Water and Greenways Master Plans

All improvements proposed to the City's storm water system shall conform with the goals, policies, and standards outlined in adopted Storm Water Collection, Major Drainageway, and Greenways Program Master Plans.

(C) Reference Standards

Where not specified in these Standards or the B.R.C. 1981, to protect the public health, safety, and welfare, the Director of Public Works will specify the standards to be applied to the design and construction of storm water improvements and may refer to one or more of the references listed in the References Section of these Standards.

(D) Floodplains

Where improvements are proposed within a designated 100-year floodplain, as defined on the current FEMA Flood Insurance Rate Map (FIRM) or floodplain mapping adopted by the City, an applicant for construction approval shall satisfy and comply with all applicable regulations and requirements as set forth in Chapter 9-9, "Floodplain Regulation," B.R.C. 1981.

(E) Storm Water Quality and Erosion Control

The UDFCD's Urban Storm Drainage Criteria Manual, Volume 3, "Best Management Practices," "Colorado Department of Transportation M-Standards, and/or City of Boulder, "Wetlands Protection Program Best Management Practices" manual shall be applied to address storm water quality management and erosion control for all proposed projects and developments. All storm water reports and plans shall include necessary analyses, mitigation measures, and improvements needed to meet these storm water quality and erosion control standards.

(F) Wetlands Protection

Where improvements are proposed within a delineated wetland or wetland buffer area, as defined under the City's wetland protection ordinance, an applicant for construction approval shall satisfy and comply with all applicable regulations and requirements as set forth in Chapter 9-12, "Wetlands Protection," B.R.C. 1981, including any necessary identification, analyses, avoidance and mitigation measures, and improvements needed to address wetlands protection requirements.

(G) Streets

Streets are an integral part of the local storm water drainage system and may transport local storm runoff as specified in these Standards. However, the primary purpose of streets is for transportation, and storm water conveyance shall not be the major function of a street.

(H) Irrigation Ditches and Laterals

Where a project or development is proposed adjacent to or impacts an existing irrigation ditch, an applicant for construction approval shall meet the following standards:

(1) No storm runoff shall be conveyed into an irrigation ditch or lateral without written approval and permission from the affected irrigation ditch company or lateral owner.

(2) An adequate right-of-way or drainage easement for maintaining the affected irrigation ditch shall be dedicated to the City.

(3) The irrigation ditch or lateral shall not be relocated, modified, or altered without written approval and permission from the affected irrigation ditch company or lateral owner.

(4) The irrigation ditch or lateral shall not be used for the following purposes:

(a) Basin boundaries to eliminate the contribution of the upper basin area in the evaluation of runoff conditions. Irrigation ditches shall not be assumed to intercept storm water runoff.

(b) Outfall points for new development where runoff into irrigation ditches and laterals has increased in flow rate or volume, or where historic runoff conditions have been changed, without written approval and permission from the affected irrigation ditch company or lateral owner.

(I) Multiple Functions of Major Drainageways

Boulder Creek's numerous tributaries are part of a comprehensive natural open drainageway system. These drainageways provide open corridors and serve multiple functions, including without limitation, storm water drainage and flood conveyance, wetlands and water quality enhancement, environmental protection and preservation, open space and wildlife areas, and recreational activities and trail corridors. Storm water improvements impacting these drainageways shall be designed and constructed to respect, restore and enhance these functions in order to maintain the creek corridor ecology, environment and aesthetic value of such drainageways.

7.02 Conceptual Storm Water Report and Plan

(A) Required

The Director of Public Works may require the preparation of a Conceptual Storm Water Report and Plan in order to assess the feasibility of any project or development. The purpose of the report shall be to demonstrate that required drainage facilities and/or easements can be accommodated on the project site, to identify any probable impacts to neighboring properties or drainage facilities, and to provide recommendations for mitigation of these impacts. A Conceptual Storm Water Report and Plan shall be used only for projects or developments where proposed improvements and mitigation measures are contained within the limits of the project site. The Conceptual Storm Water Report shall include a technical report as outlined in the following sections. Approval of a Conceptual Storm Water Report and Plan shall not be construed as approval of specific design details.

(B) Technical Report

The technical report shall provide a description of the proposed project or development, historic and developed runoff conditions, approximate storm water runoff flow rates and volumes, water quality and erosion control measures, storm water attenuation or detention ponding measures, proposed storm water utility improvements, basic design requirements, and a reference of study data sources, methods and findings, and include the following information:

(1) **Background:** Provide a written statement describing the proposed project or development that includes the following information:

(a) Site location, including legal description and a discussion of the area characteristics, identifying land development patterns and features, transportation networks and storm water systems (creeks, channels, irrigation ditches, and storm sewers) in the surrounding area.

(b) Site description, including the total land area, general topography, and existing ground cover, wetlands, groundwater conditions, and storm water and irrigation ditch systems.

(2) **Development Proposal:** Provide a general description of the proposed project or development, including land use, density, site development plans and coverage, and storm water planning concepts.

(3) **Existing Storm Water Basins and Drainage Patterns:** Include a description and of the storm water basins and drainage patterns that are impacted by site development, including:

(a) Offsite drainage patterns and their effect on site development,

(b) Onsite drainage patterns, existing runoff systems, and infall and outfall points,

(c) Previous drainage studies for the site, drainage basin, or local area that may influence drainage design, and

(d) Existing drainage problems, floodplain impacts, and ground water conditions contributing to site runoff.

(5) **Storm Water Quality and Erosion Control Measures:** Describe mitigation measures and improvements that will be utilized to address Subsection 7.13 of these standards and how and where these improvements will be accommodated within the site development plan.

(6) **Wetlands Impacts:** Identify any delineated wetland or wetland buffer areas as set forth in Chapter 9-12, "Wetlands Protection," B.R.C. 1981, and include a discussion of any necessary analyses, avoidance and mitigation measures, and improvements needed to address wetlands permitting requirements.

(7) **Hydrology:** Provide sufficient hydrological analysis to determine the approximate size and location of storm water conveyance and detention facilities on the site. Calculations should be consistent with the methodologies identified in Section 7.05, "Hydrology," of these Standards.

(8) **Storm Water Detention:** Identify the approximate size and location of any detention facilities required by Section 7.12, "Storm Water Detention," of these Standards.

(9) **Developed Storm Water Conditions:** Describe and define proposed storm runoff conditions following development, estimated by using the proposed land use and development patterns for the subject site based on the initial and major storm events, including a discussion of the following:

(a) Acceptance and conveyance of offsite runoff through the proposed site development,

(b) Proposed flow patterns, approximate onsite drainage rates, drainage facilities, detention ponds, water quality measures, and outfall points,

(c) Proposed on-site storm water systems and facilities, including a discussion of general concepts and alternatives for site drainage improvements, such as the provision, layout, alignment and size of storm sewers, open swales and channels, drainageways, inlets, detention ponds and outlets.

(10) **Conclusions and Recommendations:** Include conclusions and recommendations for proposed drainage facilities to be provided in conjunction with site development, and conformance with the B.R.C. and these Standards. The Conclusions and Recommendations section of the report must include a statement addressing the feasibility of designing and constructing required stormwater improvements without substantial modification of the proposed site development plan.

(11) **Drawings and Figures:** Include a Conceptual Storm Water Plan, as outlined in Section 7.02(C), "Conceptual Storm Water Plan," of these Standards.

(C) Conceptual Storm Water Plan

A storm water plan shall be included in the storm water report to provide a reference for the proposed improvements and identify systems and issues addressed in the report unless all required information can be clearly identified on the site development plan. The storm water plan shall be prepared on a 24 by 36 inch drawing using an engineering scale ranging from 1 inch equals 20 feet to 1 inch equals 100 feet, including the following:

(1) **Property Boundaries:** Reflect legal boundaries for the proposed project or development site, including existing and proposed property and lot lines, existing and proposed rights-of-way and easements (with reception numbers and purposes noted), and boundaries of abutting properties.

(2) **Topography:** Illustrate existing topography at minimum 2-foot interval contours, and elevation and location of City-recognized benchmarks with reference to local, USGS, and NGVD-29 data (monument information may be obtained from the City's Land Information Services). Illustrate proposed topography using 2-foot interval contours or flow arrows.

(3) **Storm Water Basins:** Illustrate existing and proposed storm water basins, inflow and outfall points, and upstream and downstream storm water conveyance systems. Mapping shall extend beyond the property boundaries far enough to identify offsite drainage systems that affect the proposed development. Storm water basins may be delineated on a separate sheet.

(4) **Storm Water Drainage Facilities:** Reflect existing and proposed storm water drainage facilities and systems, including storm sewers, inlets, manholes, culverts, swales, detention ponds, water quality systems, roadside swales, crosspans, and drainageways.

(5) **Streets:** Reflect existing and proposed streets, indicating curb type and approximate slopes.

(6) **Irrigation Ditches:** Reflect existing irrigation ditches and laterals, including ownership information.

(8) **Floodplains:** Delineate any 100-year floodplain, conveyance, and high-hazard zones

limits.

(9) **Building Floor Elevations:** Identify minimum finished floor elevations for existing and proposed structures.

7.03 Preliminary Storm Water Report and Plan

(A) Required

The Director of Public Works may require the preparation of a Preliminary Storm Water Report in order to assess the impacts and public improvements needs of any project or development prior to preparation of a Final Storm Water Report and Plan. The Preliminary Storm Water Report shall be prepared by the Engineer and include a technical report and storm water plan as outlined in the following sections. Approval of a Preliminary Storm Water Report and Plan shall not be construed as approval of specific design details.

(B) Technical Report

The technical report shall provide an overview and impacts analysis of the proposed project or development, historic and developed runoff conditions, storm water runoff flow rates and volumes, water quality and erosion control measures, storm water attenuation or detention ponding measures, proposed storm water utility improvements, basic design requirements, and a reference of study data sources, methods and findings, and include the following information:

(1) **Background:** Provide a discussion of the proposed project or development including the following information:

(a) Site location, including legal description (county, city, township, range, and section) and a discussion of the area characteristics, identifying land development patterns and features, transportation networks and storm water systems (creeks, channels, irrigation ditches, and storm sewers) in the surrounding area.

(b) Site description, including the total land area, general topography, and existing ground cover, wetlands, groundwater conditions, and storm water and irrigation ditch systems.

(2) **Development Proposal:** Provide a general description of the proposed project or development, including land use, density, site development plans and coverage, and storm water planning concepts.

(3) **Storm Water Basins and Drainage Patterns:** Include a description of the storm water basins and drainage patterns that are impacted by site development, including:

(a) The major storm water basin containing the project site and the tributary major drainageway,

(b) The minor and major storm water basins that are onsite, upstream, and downstream of the site,

(c) Offsite drainage patterns and their effect on site development,

(d) Onsite drainage patterns, existing runoff systems, and infall and outfall points,

(e) Previous drainage studies for the site, drainage basin, or local area that may influence drainage design, and

(f) Existing drainage problems, floodplain impacts, and ground water conditions contributing to site runoff.

(4) **Conformance with Storm Water Master Plans:** Describe how the proposed storm water system improvements conform with adopted Storm Water Collection, Major Drainageway, and Greenways Program Master Plans.

(5) **Storm Water Quality:** In compliance with Subsection 7.13, of these Standards, include a storm water quality analysis, and describe necessary mitigation measures and improvements that will be incorporated into the Storm Water Quality and Erosion Control Plan as part of the project or development construction plans.

(6) **Wetlands Impacts:** Identify any delineated wetland or wetland buffer areas as set forth in Chapter 9-12, "Wetlands Protection," B.R.C. 1981, and include a discussion of any necessary analyses, avoidance and mitigation measures, and improvements needed to address wetlands permitting requirements.

(7) **Hydrology:** Provide sufficient hydrological analysis to determine the approximate size and location of storm water conveyance and detention facilities. Calculations shall be consistent with the methodologies identified in Section 7.05, "Hydrology," of these Standards.

(8) **Storm Water Detention:** Include a technical analysis of storm water detention proposed for the development in conformance with Section 7.12, "Storm Water Detention," of these Standards.

(9) **Developed Storm Water Conditions:** Describe and define proposed storm runoff conditions following development, estimated by using the proposed land use and development patterns for the subject site based on the initial and major storm events, including a discussion of the following:

(a) Acceptance and conveyance of offsite runoff through the proposed site development,

(b) Proposed onsite drainage rates, flow patterns, drainage facilities, detention ponds, water quality measures, and outfall points,

(c) Downstream properties and systems, such as streets, utilities, existing structures, and developments, impacted by the proposed development from the site to the receiving major drainageway, and

(d) Proposed storm water systems and facilities design, including a discussion of the following:

(i) General concepts and alternatives for site drainage improvements, such as the provision, layout, alignment and size of storm sewers, open swales and channels, inlets, detention ponds and outlets.

(ii) Solutions and alternatives for conveying onsite and contributing offsite runoff, mitigating drainage impacts, enhancing water quality, erosion and sedimentation control, and maintenance.

(10) **Conclusions and Recommendations:** Include conclusions determined by analysis and proposed recommendations for onsite and offsite drainage facilities to be provided in conjunction with site development, and conformance with the B.R.C. and these Standards.

(11) **Technical Appendices:** Provide all technical support materials in an appendix, including without limitation, engineering equations, assumptions, and calculations used in preparing the report, and hydrologic and hydraulic sources, references, and methods. The hydrologic analysis shall include areas, storm frequencies, runoff coefficients, times of

concentration, and all runoff computation. If the CUHP is used, the synthetic unit hydrographs shall also be included.

(12) **Drawings and Figures:** Include the following drawings and figures in the technical report:

(a) General location map, providing a vicinity map identifying the major drainage basin and surrounding development and public infrastructure systems. This map should provide sufficient detail to identify drainage flows entering and leaving the development, and any other development occurring in the vicinity. Typically, this map should be 8 ½ by 11 inches or 11 by 17 inches in size at a scale ranging from 1 inch equals 400 feet to 1 inch equals 2,000 feet.

(b) Storm water plan, as outlined in Section 7.03, "Storm Water Plan," of these Standards.

(c) General concept drawing details for proposed open drainage systems (such as cross-sections for swales and channels), culverts, bridges, detention ponds, outlet structures, and storm water quality and erosion control measures.

(d) Floodplain map, identifying the 100-year floodplain, conveyance, and high hazard zones for sites impacted by adopted floodplains.

(C) Preliminary Storm Water Plan

A storm water plan shall be included in the storm water report to provide a reference for the proposed improvements and identify systems and issues addressed in the report. The storm water plan shall be prepared on a 24 by 36 inch drawing using a scale ranging from 1 inch equals 20 feet to 1 inch equals 100 feet, including the following:

(1) **Property Boundaries:** Reflect legal boundaries for the proposed project or development site, including existing and proposed property and lot lines, existing and proposed rights-of-way and easements (with reception numbers and purposes noted), and boundaries of abutting properties.

(2) **Topography:** Illustrate existing and proposed topography at minimum 2-foot interval contours, and elevation and location of City-recognized benchmarks with reference to local, USGS, and NGVD data (monument information may be obtained from the City Surveyor). The Director may approve the use of flow direction arrows in lieu of proposed contours if no significant changes to site grading are anticipated.

(3) **Storm Water Basins:** Illustrate existing and proposed storm water basins, inflow and outfall points, and upstream and downstream storm water conveyance systems. Mapping shall extend beyond the property boundaries far enough to identify offsite drainage systems that affect the proposed development.

(4) **Storm Water Drainage Facilities:** Reflect existing and proposed storm water drainage facilities and systems, including storm sewers, inlets, manholes, culverts, swales, detention ponds, water quality systems, roadside swales, crosspans, and drainageways.

(5) **Streets:** Reflect existing and proposed streets, indicating curb type and approximate slopes.

(6) **Irrigation Ditches:** Reflect existing irrigation ditches and laterals, including ownership information.

(7) **Site Runoff:** Indicate historic and developed runoff flows and volumes, and release rates for detention ponds.

(8) **Floodplains:** Delineate any 100-year floodplain, conveyance, and high-hazard zones limits and based flood elevations.

(9) **Building Floor Elevations:** Identify minimum finished floor elevations for existing and proposed structures.

(10) **Storm Water Routing:** Identify routing and accumulation of storm water runoff flows at various critical points for the initial and major storm runoff.

7.04 Final Storm Water Report and Plan

(A) Required

The Director of Public Works may require the preparation of a storm water report in order to assess the impacts and public improvements needs of any project or development proposal. The storm water report shall be prepared by the Engineer and include a technical report and storm water plan as outlined in the following sections.

(B) Technical Report

The technical report shall provide an overview and impacts analysis of the proposed project or development, historic and developed runoff conditions, storm water runoff flow rates and volumes, water quality and erosion control measures, storm water attenuation or detention ponding measures, proposed storm water utility improvements, basic design requirements, and a reference of study data sources, methods and findings, and include the following information:

(1) **Background:** Provide a discussion of the proposed project or development including the following information:

(a) Site location, including legal description (county, city, township, range, and section) and a discussion of the area characteristics, identifying land development patterns and features, transportation networks and storm water systems (creeks, channels, irrigation ditches, and storm sewers) in the surrounding area.

(b) Site description, including the total land area, general topography, and existing ground cover, wetlands, groundwater conditions, and storm water and irrigation ditch systems.

(2) **Development Proposal:** Provide a general description of the proposed project or development, including land use, density, site development plans and coverage, and storm water planning concepts.

(3) **Storm Water Basins and Drainage Patterns:** Include a description and discussion of the storm water basins and drainage patterns that are impacted by site development, including:

(a) The major storm water basin containing the project site and the tributary major drainageway,

(b) The minor and major storm water basins that are onsite, upstream, and downstream of the site,

(c) Offsite drainage patterns and their effect on site development,

(d) Onsite drainage patterns, existing runoff systems, and infall and outfall points,

(e) Previous drainage studies for the site, drainage basin, or local area that may influence drainage design, and

(f) Existing drainage problems, floodplain impacts, and ground water conditions contributing to site runoff.

(4) **Conformance with Storm Water Master Plans:** Describe how the proposed storm water system improvements conform with adopted Storm Water Collection, Major Drainageway, and Greenways Program Master Plans.

(5) **Storm Water Quality and Erosion Control Measures:** In compliance with Subsection 7.13, of these Standards, include a storm water quality and erosion control analysis, and describe necessary mitigation measures and improvements that will be incorporated into the Storm Water Quality and Erosion Control Plan as part of the project or development construction plans. Provide a discussion of how proposed erosion and sedimentation control measures will ensure that downstream properties and drainageways will not be adversely impacted by site development and construction activities.

(6) **Wetlands Impacts:** Identify any delineated wetland or wetland buffer areas as set forth in Chapter 9-12, "Wetlands Protection," B.R.C. 1981, and include a discussion of any necessary analyses, avoidance and mitigation measures, and improvements needed to address wetlands permitting requirements.

(7) **Hydrology:** Include a technical analysis of the historical and developed runoff conditions for the proposed development in conformance with Section 7.05, "Hydrology," of these Standards.

(8) **Storm Water Detention:** Include a technical analysis of storm water detention proposed for the development in conformance with Section 7.12, "Storm Water Detention," of these Standards.

(9) **Developed Storm Water Conditions:** Describe and define proposed storm runoff conditions following development, estimated by using the proposed land use and development patterns for the subject site based on the initial and major storm events, including a discussion of the following:

(a) Acceptance and conveyance of offsite runoff through the proposed site development,

(b) Proposed onsite drainage rates, flow patterns, drainage facilities, detention ponds, water quality measures, and outfall points,

(c) Downstream properties and systems, such as streets, utilities, existing structures, and developments, impacted by the proposed development from the site to the receiving major drainageway, and

(d) Proposed storm water systems and facilities design, including a discussion of the following:

(i) General concepts and alternatives for site drainage improvements, such as the provision, layout, alignment and size of storm sewers, open swales and channels, inlets, detention ponds and outlets.

(ii) Solutions and alternatives for conveying onsite and contributing offsite runoff, mitigating drainage impacts, enhancing water quality, erosion and sedimentation control, and maintenance.

(10) **Conclusions and Recommendations:** Include conclusions determined by analysis and proposed recommendations for onsite and offsite drainage facilities to be provided in conjunction with site development, and conformance with the B.R.C. and these Standards.

(11) **Final Storm Water Design Features:** Construction plans for any project or development

proposal, shall include final storm water design features in the storm water report and storm water plan. The final design information in the report shall provide the technical basis and support for the proposed construction design and all detailed engineering calculations for storm water systems, including without limitation:

(a) Inlet sizing and design,

(b) Storm sewer sizing, design and type,

(c) Open channel (swale and drainageway) design and sizing,

(d) Storm water routing for storm water conveyance (storm sewers and swales) and detention ponding facilities,

(e) Curb and gutter conveyance capacities,

(f) Detention pond outfall structures (orifices, inlets, and weirs),

(g) Water quality measures, and

(h) Any unique storm water improvements design details.

(12) **Technical Appendices:** Provide all technical support materials in an appendix, including without limitation, engineering equations, assumptions, and calculations used in preparing the report, and hydrologic and hydraulic sources, references, and methods. The hydrologic analysis shall include areas, storm frequencies, runoff coefficients, times of concentration, and all runoff computation. If the CUHP is used, the synthetic unit hydrographs shall also be included.

(13) **Drawings and Figures:** Include a Storm water plan, as outlined in Section 7.04 (C), “Storm Water Plan,” of these Standards.

(C) Storm Water Plan

A storm water plan shall be included in the storm water report to provide a reference for the proposed improvements and identify systems and issues addressed in the report. The storm water plan shall be prepared on a 24 by 36 inch drawing using a scale ranging from 1 inch equals 20 feet to 1 inch equals 100 feet, including the following:

(1) **Property Boundaries:** Reflect legal boundaries for the proposed project or development site, including existing and proposed property and lot lines, existing and proposed rights-of-way and easements (with reception numbers and purposes noted), and boundaries of abutting properties.

(2) **Topography:** Illustrate existing and proposed topography at minimum 2-foot interval contours, and elevation and location of City-recognized benchmarks with reference to local, USGS, and NGVD data (monument information may be obtained from the City Surveyor).

(3) **Storm Water Basins:** Illustrate existing and proposed storm water basins, inflow and outfall points, and upstream and downstream storm water conveyance systems. Mapping shall extend beyond the property boundaries far enough to identify offsite drainage systems that affect the proposed development.

(4) **Storm Water Drainage Facilities:** Reflect existing and proposed storm water drainage facilities and systems, including storm sewers, inlets, manholes, culverts, swales, detention ponds, water quality systems, roadside swales, crosspans, and drainageways.

(5) **Streets:** Reflect existing and proposed streets, indicating curb type and approximate slopes.

(6) **Irrigation Ditches:** Reflect existing irrigation ditches and laterals, including ownership information.

(7) **Site Runoff:** Indicate historic and developed runoff flows and volumes, and release rates for detention ponds.

(8) **Floodplains:** Delineate any 100-year floodplain, conveyance, and high-hazard zones limits and based flood elevations.

(9) **Building Floor Elevations:** Identify finished floor elevations for existing and proposed structures.

(10) **Storm Water Routing:** Identify routing and accumulation of storm water runoff flows at various critical points for the initial and major storm runoff.

(11) **Final Storm Water Design Features:** Prior to preparation of construction plans for any project or development proposal, the Engineer shall include final storm water design features in the storm water report and storm water plan. The final design information in the plan shall illustrate details for the proposed construction design, including without limitation:

(a) Inlet sizing and design,

(b) Storm sewer sizing, design and type,

(c) Open channel (swale and drainageway) design and sizing,

(d) Storm water routing for storm water conveyance (storm sewers and swales) and detention ponding facilities,

(e) Curb and gutter conveyance capacities,

(f) Detention pond outfall structures (orifices, inlets, and weirs),

(g) Water quality measures, and

(h) Any unique storm water improvements design details.

7.05 Hydrology

(A) General

The methodologies and design standards for determining rainfall and runoff conditions for any development project are based on the standards prescribed in the Urban Drainage and Flood Control District (UDFCD), Urban Storm Drainage Criteria Manual, with local revisions as prescribed in these Standards.

(B) Storm Frequency

Table 7-1, “Design Storm Frequencies,” indicates initial and major design storm frequencies to be used in the storm water design or any project or development:

Table 7-1: Design Storm Frequencies

Land Use	Initial Storm	Major Storm
Single Family Residential	2 Year	100 Year
All Other Uses	5 Year	100 Year
Detention Ponding Design	10 Year	100 Year

(C) Rainfall

The rainfall intensities to be used in computing runoff were based on the UDFCD on-going hydrology research program and shall be obtained from Figure 7-1, "Rainfall Intensity-Duration-Frequency Curve for the City of Boulder," of these Standards.

D) Runoff

(1) **CUHP Method:** For basins larger than 160 acres, the Colorado Urban Hydrograph Procedure (CUHP) method shall be applied in conformance with the UDFCD Drainage Criteria Manual using local rainfall conditions.

(2) **Rational Method:** For all basins smaller than 160 acres, the Rational Method shall be used to calculate runoff for both the initial and major storms. A detailed description and in-depth discussion of the rational method and its components are presented in the UDFCD Drainage Criteria Manual. The formula for the rational method is as follows:

$$Q = CIA$$

Where: Q = Flow Rate in Cubic Feet Per Second

C = Runoff Coefficient

I = Rainfall Intensity for the Design Storm (inches/hour)

A = Drainage Area (acres)

(3) **Runoff Coefficient:** The runoff coefficient to be used with the Rational Method may be determined based on either zoning/land use classifications or types of surface classifications prescribed in Table 7-2, "Runoff Coefficients for the Rational Method." A composite runoff coefficient may be calculated using land areas impacted by specific classifications.

(4) **Time of Concentration (t_c): For** urban areas, the time of concentration consists of an inlet time or overland flow time (t_i) plus the time of travel (t_t) in a storm sewer, paved gutter, roadside drainage ditch, drainage channel, or other drainage facilities. For non-urban areas, the time of concentration consists of an overland flow time (t_i) plus the time of travel in a combined form, such as a swale, channel, or drainageway. The travel time (t_t) portion of the time of concentration (t_c) is estimated from the hydraulic properties of the storm sewer, gutter, swale, ditch, or drainageway.

(a) The time of concentration is calculated as follows:

$$t_c = t_i + t_t \text{ (Minutes)}$$

Where t_c = time of concentration in minutes

t_i = initial, inlet, or overland flow time in minutes

t_t = travel time in ditch, channel, gutter, storm sewer, etc. in minutes

(b) Non-Urbanized Basins

The initial or overland flow time (t_i) is calculated using the following formula or

Figure 7-2, “Overland Time of Flow Curves.” The initial time of concentration for non-urbanized basins is not to be less than 10 minutes.

$$t_c = \frac{1.8(1.1 - C_5)\sqrt{L}}{\sqrt[3]{S}}$$

Where t_i = initial or overland flow time in minutes

C_5 = runoff coefficient for 5-year frequency

L = length of overland flow in feet (500-foot max)

S = average basin slope in percent

For basins longer than 500-feet, runoff shall be considered to be in a combined form and travel time (t_t) shall be calculated using the hydraulic properties of the swale, ditch or channel, or estimated using Figure 7-3, “Time of Travel.” The time of concentration (t_c) is the sum of the initial flow time (t_i) and the travel time (t_t). The minimum (t_c) shall be ten minutes for non-urbanized basins.

(c) Urbanized Basins

The time of concentration (t_c) to the first design point after urbanization shall be the lesser value determined from the two equations below.

$$t_c = \frac{1.8(1.1 - C_5)\sqrt{L}}{\sqrt[3]{S}}$$

Where t_i = initial or overland flow time in minutes

C_5 = runoff coefficient for 5-year frequency

L = length of overland flow in feet (300-foot max)

S = average basin slope in percent

Or

$$t_c = \frac{L}{180} + 10$$

Where t_c = time of concentration in minutes

L = length of flow to first design point from the most remote point in feet

The travel time (t_t) portion of the time of concentration shall be computed using the hydraulic properties of the ditch, channel, curb and gutter, or storm sewer. The minimum time of concentration (t_c) for urbanized conditions shall be five minutes.

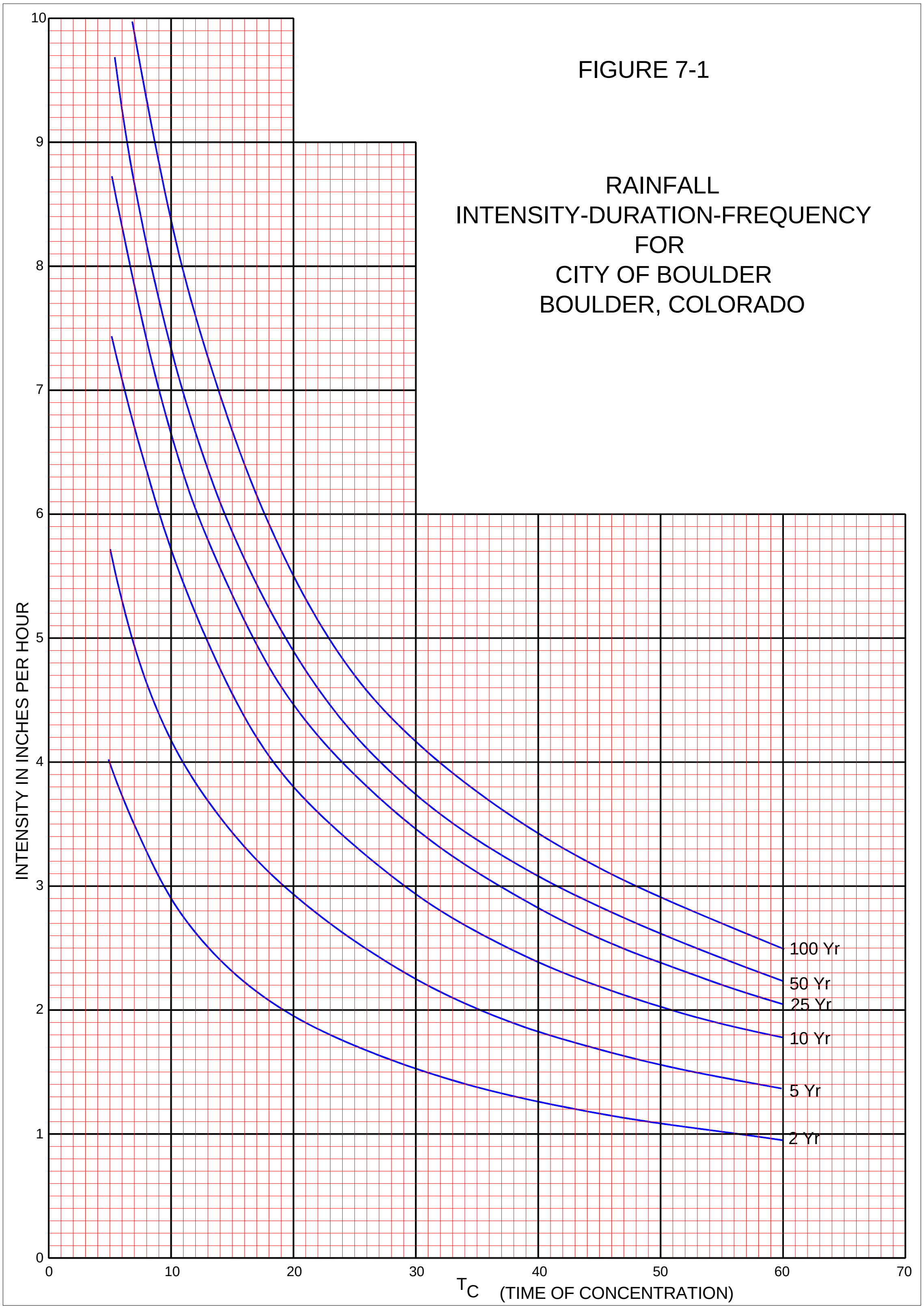


FIGURE 7-1
RAINFALL
INTENSITY-DURATION-FREQUENCY
FOR
CITY OF BOULDER
BOULDER, COLORADO
INTENSITY IN INCHES PER HOUR
TC (TIME OF CONCENTRATION)
100 Yr
50 Yr
25 Yr
10 Yr
5 Yr
2 Yr
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70

Table 7-2: Runoff Coefficients for the Rational Method

LAND USE OR SURFACE CHARACTERISTICS	PERCENT IMPERVIOUS	STORM FREQUENCY			
		2-Yr	5-Yr	10-Yr	100-Yr
Business:					
Commercial Areas	95	0.87	0.88	0.90	0.93
Neighborhood Areas	65	0.60	0.65	0.70	0.80
Residential:					
Single-Family	40	0.40	0.45	0.50	0.70
Multi-Unit (detached)	50	0.50	0.55	0.60	0.75
Multi-Unit (attached)	70	0.65	0.70	0.70	0.80
½ Acre Lot	30	0.30	0.40	0.45	0.65
Apartments	70	0.65	0.70	0.70	0.80
Industrial:					
Light Areas	80	0.75	0.80	0.80	0.85
Heavy Areas	90	0.80	0.80	0.85	0.90
Parks, Cemeteries:	7	0.15	0.25	0.35	0.60
Playgrounds:	13	0.20	0.30	0.40	0.70
Schools:	50	0.50	0.55	0.60	0.75
Railroad Yard Areas:	40	0.40	0.45	0.50	0.70
Undeveloped Areas:					
Historic Flow Analysis	2	0.10	0.20	0.30	0.60
Greenbelts, Agricultural	-	-	-	-	-
Offsite Flow Analysis (when offsite land use is not defined)	45	0.45	0.50	0.55	0.72
Streets:					
Paved	100	0.87	0.88	0.90	0.93
Gravel	7	0.15	0.25	0.35	0.65
Drives and Walks:	96	0.85	.087	0.90	0.92
Roofs:	90	0.80	0.85	0.90	0.90
Lawns:					
Sandy Soil	0	0.00	0.10	0.20	0.50
Clayey Soil	0	0.10	0.20	0.30	0.60

NOTE: These rational formula coefficients do not apply for larger basins where the time-of-concentration exceeds 60 minutes.

(Source: Urban Drainage and Flood Control District)

(5) **Intensity:** The rainfall intensity to be used in the Rational Method is be obtained from Figure 7-1, "Rainfall Intensity-Duration-Frequency Curve for the City of Boulder," for the corresponding design storm frequency.

FIGURE 7-2: OVERLAND TIME OF FLOW CURVES

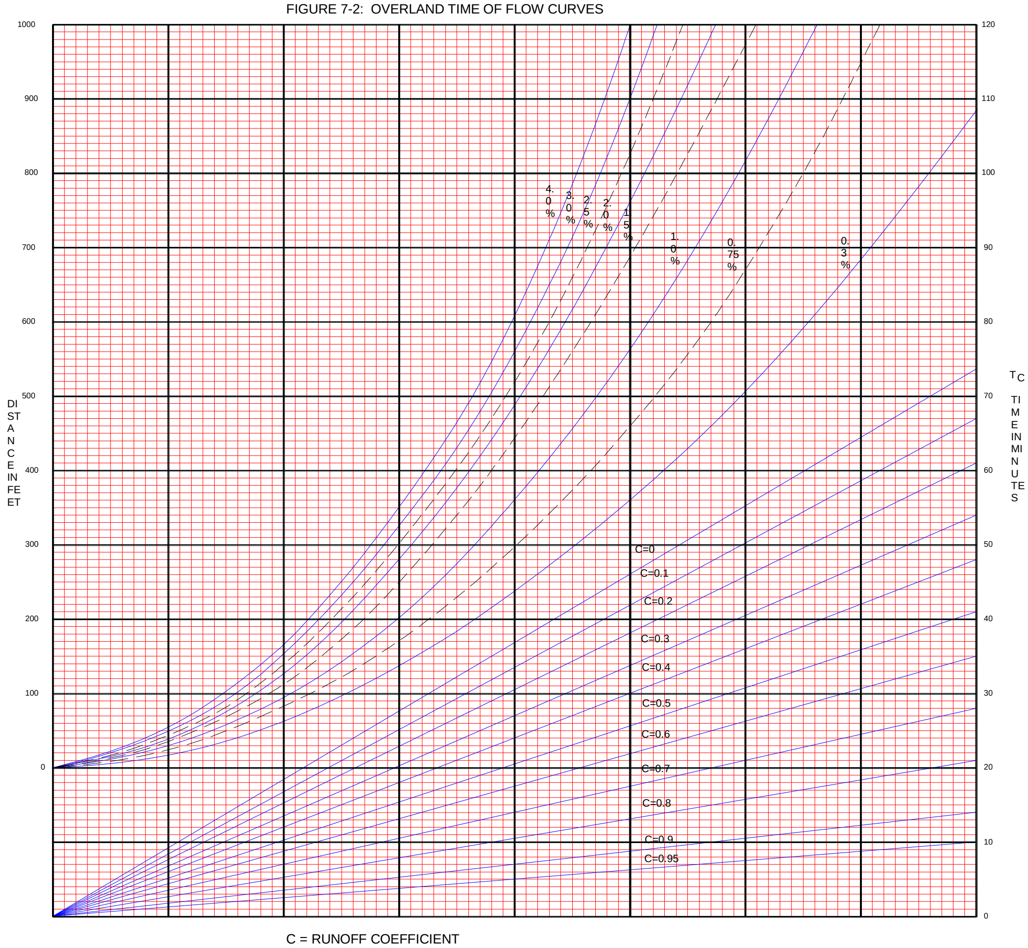
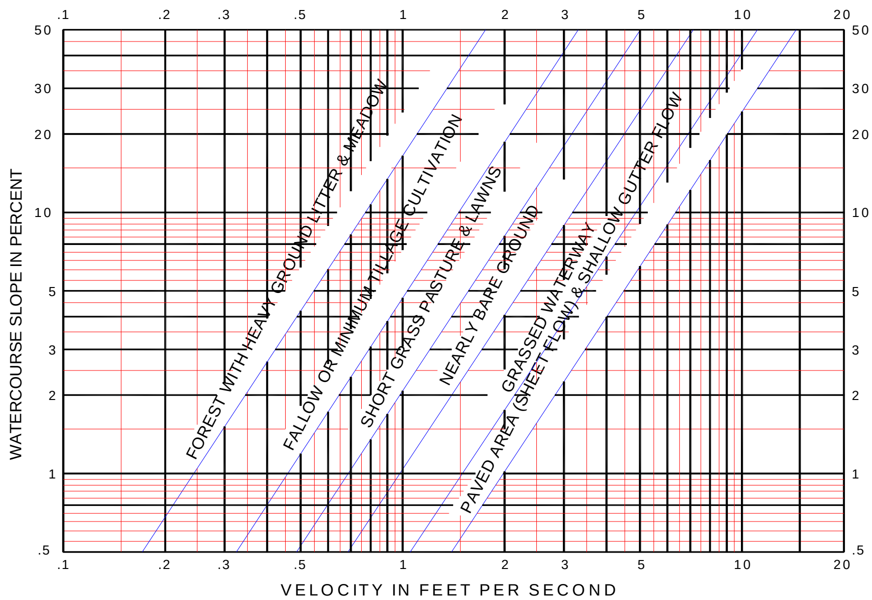


FIGURE 7-3: TIME OF TRAVEL



ESTIMATE OF AVERAGE FLOW VELOCITY FOR USE WITH THE RATIONAL METHOD

7.06 Materials and Installation

Construction of storm water-related public improvements shall be in compliance with these Standards. All pipe and structures shall be of adequate strength to support trench and AASHTO HS-20 highway loadings. The type of pipe and structures to be installed shall comply with these Standards, and shall be based upon applicable design flows, site conditions, and maintenance requirements.

7.07 Open Drainageways

(A) General

(1) **Designated Major Drainageways:** The following list identifies designated major drainageways in the City for primary storm water conveyance:

Designated Major Drainageways		
Bear Canyon Creek	Four Mile Canyon Creek	South Boulder Creek
Bluebell Canyon Creek	Goose Creek	Sunshine Canyon Creek
Boulder Creek	Gregory Canyon Creek	Two Mile Canyon Creek
Boulder Slough	King's Gulch	Viele Channel
Elmer's Two Mile Creek	Skunk Canyon Creek	Wonderland Creek
Dry Creek Ditch No. 2		

(2) **Design Approach:** Design of public improvements for local drainageways shall ensure opportunities to provide for open conveyance corridors that may serve multiple functions, including without limitation, storm water drainage and flood conveyance, wetlands and water quality enhancement, environmental protection and preservation, open space and wildlife areas, and recreational activities and trail corridors. Storm water improvements impacting local drainageways shall be designed and constructed to respect, restore and enhance these functions in order to maintain a natural ecology, environment and aesthetic value of such drainageways.

(B) Drainageway Types

(1) **Definition:** Drainageways in the City are defined as natural or artificial channels as follows:

(a) Natural channels include naturally developed creeks, streams and thalwegs, which have been geologically created through the erosion process over time. Boulder Creek is considered a natural channel.

(b) Artificial channels include those that are designed, constructed, or developed by human effort. Artificial channels may be unlined or lined (where non-erosive conditions for unlined design cannot be met). Artificial channels also include irrigation ditches, roadside ditches, and drainage swales.

(2) **Natural Drainageways**

(a) The hydraulic properties of natural drainageways vary along each stream reach and are to be maintained in a naturally occurring and environmental form. Natural drainageways typically have mild slopes, are reasonably stable, and are not in a state of serious degradation or aggradation.

(b) Where unstable conditions are created through the introduction of urbanized storm water runoff, which alters the nature of flow peaks and volumes and may cause erosion, mitigation measures may be proposed in the natural drainageway to maintain a stabilized and naturally occurring condition. A detailed analysis will be required for all development proposals affecting natural drainageways in order to identify the impacts of changes in flow characteristics, erosion and sedimentation, wetland losses and water quality conditions.

(c) Analyses of natural drainageways shall be provided for each project or development application affecting the drainageway. When performed, the Engineer is to prepare cross sections of the drainageway, define water surface profile for the existing and proposed minor and major storm events, investigate the bed and bank material to determine erosion and sediment transport tendencies, identify impacts on the naturally occurring conditions and ecology and study the bank slope and stream bed stability. An analysis shall include engineering calculations to ensure that supercritical flow conditions do not result from proposed project or development activities. Natural channel improvements that would cause supercritical flow conditions shall not be permitted.

(3) **Unlined Artificial Drainageways**

(a) Unlined artificial drainageways provide improved channel bottoms that are covered with wetlands, grass, or other vegetation, and may be used where naturally occurring drainageways are not present or as proposed under an adopted storm water master plan. Designs for unlined drainageways shall comply with these Standards and the UDFCD Drainage Criteria Manual.

(b) Unlined artificial drainageways are to provide conditions for slower flow velocities, reduced flow energy, increased flow retardance, and increased channel storage. The wetlands, grass, or other vegetation along stream beds and banks are intended to stabilize the channel, consolidate the soil mass of the bed, mitigate erosion, and control soil particles transport along the drainageway. Design of these improvements shall also consider opportunities for accommodating multiple functions along the drainageway, providing for a natural ecology, environment and aesthetic value.

(c) Structural measures such as rock linings used for revetments, drop structures, scour aprons, or trickle channels may be approved as a means of controlling erosion for unlined artificial drainageways.

(4) **Lined Artificial Channels**

(a) Where conditions for natural or unlined artificial drainageways are not available, including situations where limited right- of-way, supercritical velocities, or extremely erosive conditions exist, lined artificial channels may be constructed, subject to conformance with adopted storm water master plans and the review, discretion, and approval of the City. Designs for lined artificial channels shall comply with these Standards and the UDFCD Drainage Criteria Manual. Lined artificial channels typically include rock-lined, grouted rip-rap, and concrete-lined stream beds and banks.

(b) Rock-lined (rip-rapped) or grouted rip-rap channels are generally discouraged, but are much preferred to concrete lined channels. A rock-lined or grouted rip-rap channel may typically be steeper and narrower, due to the higher friction factors of rock, and may include steeper banks or side slopes. The lining shall be capable of withstanding all hydraulic and hydrodynamic forces 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. If project constraints suggest the use of a rock-lined or grouted rip-rap channels, the Engineer shall present the justification and design concept to the City for consideration.

(c) Concrete-lined channels are least desirable, and may only be approved under severely restrictive circumstances. The concrete lining shall withstand all hydraulic and hydrodynamic forces 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. If project constraints suggest the use of a concrete lined channel, the Engineer shall present the justification and design concept, including a discussion of non-concrete-lined alternatives and why they are not feasible, to the City for consideration.

(5) **Roadside Ditches and Drainage Swales:** Roadside ditches and drainage swales are open drainage systems that are not part of the major drainageway system, and are used to convey minor and major storm water runoff in projects and developments and along rural-type streets. The design of these drainage swales is similar to the design of unlined artificial drainageways on a reduced scale.

(C) Drainageway Flow Computation

Uniform flow and critical flow computations for drainageways shall be performed in accordance with Sections 2.2.3 and 2.2.4, "Major Drainage," UDFCD Drainage Criteria Manual.

(D) Drainageway Design Standards

The design standards for drainageways involve a wide range of options intended to create safe, environmental, multipurpose, and aesthetic improvements. The following planning, evaluation, and design standards shall be applied:

(1) **Natural Drainageways**

(a) The drainageway and overbank areas necessary to pass 100-year storm runoff are to be reserved for storm water purposes.

(b) Naturally occurring drainageway velocities are to be preserved at 5 feet per second or less, having a calculated Froude number of 0.8 or less, unless greater velocities given existing conditions or velocity increases due to development are approved by the City in conformance with these Standards.

(c) Water surface profiles shall be defined to identify floodplain conditions.

(d) Flood fringe filling along naturally defined drainageways, which reduces drainageway flood storage capacity and increases downstream runoff peaks, is to be avoided unless approved as part of an adopted City storm water master plan.

(e) Roughness factors (n), which are representative of unmaintained channel conditions, shall be used for the analysis of water surface profiles and to determine velocity limitations

(f) The Director may allow the placement of erosion control structures, such as drop structures, check dams, revetments, and scour aprons, where they may be necessary to maintain stabilized drainageway conditions, subject to the design requirement that the drainageway conditions remain as near natural as possible.

(g) Design parameters applicable to artificial drainageways, including without limitation, freeboard height, bed and bank slopes, and curvature, may not necessarily apply to natural drainageways. Significant site planning advantages may be realized by maintaining the natural drainageway, without structured improvements, by allowing drainageway overtopping onto reserved flooding areas designated as open space and wetlands and maintaining irregular waterway features that naturally control flow conditions, improve water quality, preserve stream ecology and enhance community and aesthetic values.

(2) **Unlined Artificial Drainageways:** Where not specified in these Standards, the design of unlined artificial drainageways shall conform with the UDFCD Drainage Criteria Manual.

(a) **Flow Velocities:** Maximum normal depth velocity for the major (100-year) storm shall be 5 feet per second in sandy soils, and 7 feet per second where soil conditions permit, as demonstrated through geotechnical analysis. Additionally, the Froude number shall be less than 0.8.

(b) **Longitudinal Channel Slopes:** Channel slopes are dictated by velocity and Froude number requirements. Where natural slopes exceed design slopes, drop structures shall be provided to maintain design velocities and Froude numbers. Normally, grass lined channels will have slopes of 0.2 percent to 0.6 percent.

(c) **Side Slopes:** Maximum side slopes shall be no steeper than 4:1, unless specific drainageway conditions warrant steeper side slopes as determined by the Director.

(d) **Depth:** Maximum depth of flow, outside of any low flow or trickle channel, shall be 5 feet. Critical depth shall be determined for both the major and initial storms in order to ensure that supercritical flows do not occur.

(e) **Bottom Width:** Bottom width shall be consistent with the maximum depth and velocity standards, and shall accommodate low flows and the development of wetland and water quality enhancement systems.

(f) **Freeboard:** The minimum depth of freeboard above normal depth flows for the major storm is to be 1 foot, or adequate to provide additional capacity for one third of the major storm design flow.

(g) **Horizontal Curvature:** The center line curvature shall have a design radius twice the top width for design flow conditions, but not less than 50 feet.

(h) **Roughness Coefficient:** Meaning's "n," as adjusted by channel bottom conditions outlined in the UDFCD Drainage Criteria Manual, shall be applied.

(i) **Cross Sections:** Drainageway cross-sections may be almost any type suitable to the location and to the environmental conditions, subject to conformance with these Standards. Cross sections simulating naturally occurring drainageway corridors are strongly recommended.

(j) **Channel Bottom:** The channel bottom is to be designed to convey low flows and enhance water quality in conformance with environmental concerns and regulations. Acceptable channel bottoms, subject to City approval for specific site applications, may include without limitation wetlands or natural vegetation and low flow channels conveying a minimum 3 percent of the design storm flow.

(k) **Easement/Right-of-Way:** The minimum drainageway easement/right of way width shall include the bank to bank dimension of the drainageway section, including the normal flow depth and freeboard areas, and adequate maintenance access.

(l) **Maintenance Access:** Maintenance access shall be provided along the entire length of all major drainageways and shall connect with a public street to allow access by medium and large scale construction and maintenance equipment. An access road shall be at least 12 feet wide and designed to adequately support the loads of expected maintenance equipment. The maintenance road may be shared as a greenway trail, subject to approval by the City.

(m) **Water Surface Profiles:** Water surface profiles shall be determined for all drainageway designs using standard backwater methods, taking into consideration losses due to velocity changes produced by changing channel sections, drops, waterway openings, or obstructions. The water surface and energy gradient profiles shall be shown on the construction plans.

(3) **Lined Artificial Channels:** Where allowed by the City, lined artificial channels shall be designed in accordance with these Standards and the UDFCD Drainage Criteria Manual, including the following:

(a) **Easement/Right-of-Way:** The minimum drainageway easement/right of way width shall include the bank to bank dimension of the drainageway section, including the normal flow depth and freeboard areas, and adequate maintenance access.

(b) **Maintenance Access:** Maintenance access shall be provided along the entire length of all major drainageways and shall connect with a public street to allow access by medium and large scale construction and maintenance equipment. An access road shall be at least 12 feet wide and designed to adequately support the loads of expected maintenance equipment. The maintenance road may be shared as a greenway trail, subject to approval by the City.

(c) **Water Surface Profiles:** Water surface profiles shall be determined for all drainageway designs using standard backwater methods, taking into consideration losses due to velocity changes produced by changing channel sections, drops, waterway openings, or obstructions. The water surface and energy gradient profiles shall be shown on the construction plans.

(4) **Roadside Ditches and Drainage Swales:** The design of roadside ditches and drainage swales is similar to the standards for unlined channels with modifications for application to minor storm drainage. The standards are as follows:

(a) **Capacity:** Roadside ditches and drainage swales shall have a minimum capacity for the 10-year design storm.

(b) **Flow Velocity:** The maximum velocity for the design storm runoff peak is not to exceed 5 feet per second. The Froude number shall be less than 0.8.

(c) **Longitudinal Slope:** The slope shall be limited by flow velocity of the design storm. Swale widening or check drops may be required to control velocities.

(d) **Freeboard:** Freeboard above the design flow depth shall be at least 6 inches.

(e) **Curvature:** The minimum radius of curvature shall be 25 feet.

(f) **Roughness Coefficient:** Manning's "n," as adjusted by channel bottom conditions outlined in the UDFCD Drainage Criteria Manual, shall be applied.

(g) **Depth:** A drainage swale shall be at least 1 foot deep. A maximum depth for drainage swales shall not exceed 5 feet, and shall be dictated by the design flow and cross-sectional standards.

(h) **Side Slopes:** Side slopes shall be no greater than 3:1; however, 4:1 side slopes or flatter are recommended for landscaped areas and to enhance water quality.

(i) **Driveway Culverts:** Along roadside ditches, driveway culverts shall be sized to pass the design storm flow without overtopping the driveway, having a minimum culvert diameter size of 12 inches in height with at least 6 inches of cover. Flared end sections or headwalls with appropriate erosion protection shall be provided. Given the depth constraints along roadside ditches, more than one culvert may be required to pass the design flow. Maintenance of all driveway culverts shall be the responsibility of the property owner served by the driveway.

(j) **Major Drainage Capacity:**

(i) The major drainage (100-year storm) capacity of roadside ditches is restricted by the maximum flow depth allowed at the street crown or by the ground surface at the edge of the street right-of-way.

(ii) The major drainage capacity of drainage swales is restricted to the maximum flow that can be passed without inundation to and damage of downstream properties.

(E) Hydraulic Structures

(1) **Where Required:** Hydraulic structures are used in open storm water systems to control the flow of the runoff. The energy associated with flowing water has the potential to create damage to the drainage system, especially in the form of erosion. Hydraulic structures are intended to control the energy of storm water flow and minimize the damage potential of storm water runoff. Typical hydraulic structures may include without limitation the following:

(a) Channel drop and check structures,

(b) Rip rap and rock linings,

(c) Energy dissipaters and stilling basins,

(d) Channel rundowns,

(e) Bridges and culverts,

(f) Irrigation ditch crossings,

(2) **Design Standards:** The standards to be used in the design of hydraulic structures shall be in accordance with these Standards and the UDFCD Drainage Criteria Manual.

7.08 Storm Sewers

(A) System Design

(1) **Where Required:** Storm sewers shall be required when the other parts of the minor storm water system, primarily streets, curbs, gutters, and roadside ditches, no longer have the capacity for additional runoff in the initial storm event.

(2) **Gravity Flow Conditions:** Storm sewers shall be designed for gravity (open) flow conditions, using a "Manning's" roughness coefficient from Table 7-3, "Manning's "n" for Storm Sewers."

Table 7-3: Manning's "n" for Storm Sewers

Sewer Type	Manning's "n"
Concrete	0.015
Plastic	0.013
Corrugated Metal	0.013

(3) **Flow Depth:** Storm sewers are to be designed to carry peak flows at full pipe depth.

(4) **Pressure Flow Prohibited:** Pressurized surcharged or depressed (inverted siphon) storm water mains are prohibited in the City's storm water system.

(B) Location

All storm sewer mains shall be installed in public rights-of-way or easements, in conformance with Section 4.03, "Utilities Easements," of these Standards.

(C) Depth

The cover for all storm sewer mains shall be at least 18 inches deep, measured from the top of pipe to the final surface grade, and shall be capable of withstanding AASHTO HS-20 highway traffic loadings.

(D) Size

Storm sewer mains shall be at least 18 inches in diameter, and storm sewer laterals shall be at least 12 inches in diameter.

(E) Slope

(1) **Minimum and Maximum:** Minimum allowable slope shall provide flow velocities of at least 2-feet per second and maximum allowable slope shall provide flow velocities no greater than 10feet per second during peak flow conditions.

(2) **Constant Slope:** All storm sewer mains shall be laid at a constant slope between manholes.

(F) Alignment

(1) **Straight Alignment:** All storm sewer mains shall be laid in a straight alignment between manholes.

(2) **Curvilinear Mains Prohibited:** Curvilinear storm sewer mains shall not be allowed.

(G) Separations and Crossings

All collection main separations and crossings of other City utilities shall be designed in compliance with Section 4.05, “Separation of Utilities,” of these Standards.

(H) Taps

All taps approved onto an existing storm sewer main shall be made by the City of Boulder Utilities Division, and shall be paid for by the applicant.

(I) Ground Water Barriers

(1) **Required:** Where the possibility exists that ground water may be diverted by the construction of new storm sewer mains, ground water barriers shall be constructed within the storm sewer main trench to prevent ground water migration or diversion along the main.

(2) **Placement:** The Engineer shall determine the location and number of ground water barriers that will be necessary to mitigate any ground water impacts, subject to review and approval by the Director. Any necessary support material required to address ground water concerns, such as soils investigations, engineering calculations and design details, shall be provided by the Engineer.

(J) Extensions

Where required as part of any adopted City master plan or to satisfy storm water design requirements as part of any proposed project or development, storm sewer mains shall be extended downstream to the major drainageway, upstream to the far edge of the property being served, to ensure perpetuation of the storm water collection system.

(K) Manholes

(1) **Location:** Manholes shall be provided at each storm sewer main connection with another storm sewer main or lateral line, at all changes in grade, slope, alignment and pipe size, and at distances not greater than the following:

(a) 400 feet, for mains 36 inches in diameter or less, and

(b) 500 feet, for mains greater than 36 inches in diameter.

(2) **Size**

(a) Table 7-4, “Required Manhole Sizes,” indicates required manhole sizes.

Table 7-4: Required Manhole Sizes

Sewer Main Diameter	Manhole Diameter
12 - 18 Inches	4 Feet
21 - 42 Inches	5 Feet
48 - 54 Inches	6 Feet
60 Inches and Larger	Special Detail

(b) **Special Provisions:** Larger manhole diameters or a junction structure may be required when sewer alignments are not straight through or more than one sewer line passes through a manhole.

(3) **Maintenance Access:** Direct access by maintenance vehicles shall be provided to each manhole. The access drive shall be an all-weather surface, such as asphalt or concrete paving, adequate gravel base or turf block, and shall be capable of supporting maintenance vehicles weighing up to 14 tons.

(4) **Covers**

(a) Manholes that are not located within a public street, alley or driveway section shall be installed with a bolting-type cover, to ensure safety and prevent vandalism.

(b) Manholes located within the 100-year floodplain, or in a location where runoff may accumulate and pond, shall be installed with a bolting-type cover, to prevent loss of the cover. The manhole ring shall be bolted to the manhole cone to prevent possible damage due to surcharge.

(L) Hydraulic Design

(1) **Rational Method for Sizing Storm Sewer System:** This method is outlined in the UDFCD Drainage Criteria Manual. The following step-by-step procedure should be used in conjunction with Figure 7.4, "Typical Form for Storm Drainage System Design Data," of these Standards. This procedure is for the average design situation and variations may be necessary to accommodate actual field conditions.

(a) **Column 1:** Determine design point locations and list. This design point should correspond to the sub-basin illustrated on the preliminary layout map.

(b) **Column 2:** List basins contributing runoff to this point that have not previously been analyzed.

(c) **Column 3:** Enter the length of the flow path between previous design point and design point under consideration.

STORM DRAINAGE SYSTEM DATA DESIGN																						
Location of Design Point	Basins	Length Ft.	Inlet Time min.	Flow Time		Time of Concentration min.	Pipe min.	Intensity "I" in/hr.	Area "A" acre	Direct Runoff cfs	Other Runoff cfs	Summation Runoff cfs	Street		Pipe			Street		Pipe		Remarks
				Street min.	Pipe min.								Slope %	Allowable Capacity cfs	Slope %	Size Line	Capacity cfs	Design cts	Velocity tps	Design cfs	Velocity tps	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

(d) **Column 4:** Determine the inlet time for the particular design point. See the runoff part of this criteria for methods to determine inlet time.

(i) For the first design point on a system, inlet time will be equal to the time of concentration.

(ii) For subsequent design points, inlet time should also be tabulated to determine if it may be of greater magnitude than the accumulated time of concentration from upstream basins.

(iii) If the inlet time exceeds the time of concentration from the upstream basin, and the area tributary to the inlet is of sufficient magnitude, the inlet time should be substituted for time of concentration and used for this and subsequent basins.

(e) **Column 5:** Enter the appropriate flow time between the previous design point and the design point under consideration. The flow time of the sheet should be used if a significant portion of the flow from the basin is carried in the street.

(f) **Column 6:** Pipe flow time should generally be used unless there is significant carry-over from above basins in the street.

(g) **Column 7:** The time of concentration is the summation of the previous design point time of concentration and the intervening flow time.

(h) **Column 8:** Rational Method Runoff Coefficient, “C,” for the basins listed in Column 2 should be determined and listed. The “C” value should be weighted if the basins contain area with different “C” values.

(i) **Column 9:** The intensity to be applied to the basins under consideration is obtained from the Rainfall Intensity Duration Curves (see Figure 7.05-1). The intensity is determined from the time of concentration and the frequency of design for this particular design point.

(j) **Column 10:** The area in acres of the basins listed in Column 2 is tabulated here. Subtract ponding areas that do not contribute to direct runoff .

(k) **Column 11:** Direct runoff from the tributary basins listed in Column 2 is calculated and tabulated hereby multiplying Columns 8,9, and 10 together.

(l) **Column 12:** Runoff from other sources, such as controlled releases from rooftops, parking lots, base flows from groundwater, and any other source, are listed here.

(m) **Column 13:** The total of runoff from the previous design point summation plus the incremental runoff listed in Columns 11 and 12 is listed here.

(n) **Column 14:** The proposed street slope is listed in this column.

(o) **Column 15:** The allowable capacity for the street is listed in this column. Allowable capacities should be calculated in accordance with procedures set forth in Section 7.10, “Streets,” of these Standards.

(p) **Column 16**: List the proposed pipe grade.

(q) **Column 17:** List the required pipe size to convey the quantity of flow necessary in the pipe.

(r) **Column 18:** List the capacity of the pipe flowing full with the slope expressed in Column 16.

(s) **Column 19:** Tabulate the quantity of flow to be carried in the street.

(t) **Column 20:** List the actual velocity of flow for the volume of runoff to be carried in the street.

(u) **Column 21:** List the quantity of flow determined to be carried in the pipe.

(v) **Column 22:** Tabulate the actual velocity of flow in the pipe for the design Q.

(w) **Column 23:** Include any remarks or comments that may affect or explain the design. The allowable quantity of carryover across the street intersections should often be listed for the initial design storm. When routing the major storm through the system, required elevations for adjacent buildings can often be listed in the column.

(2) **Hydraulic and Energy Grade Line, and Design Losses:** Storm sewers shall be designed to convey the initial storm flow peaks without surcharging the sewer, and the final energy grade line shall be at or below the proposed ground surface. To ensure that this objective is achieved, the hydraulic and energy grade line shall be calculated by accounting for pipe friction losses and pipe form losses. Total hydraulic losses will include frictions, expansion, contraction, bend, and junction losses. The methods for estimating these losses are presented in the following sections.

(a) **Pipe Friction Losses:** The Manning's "n" values to be used in the calculation of storm sewer capacity and velocity are presented in Table 7-3, "Manning's "n" for Storm Sewers," of these Standards.

(b) **Pipe Form Losses:** Generally, between the inlet and outlet the flow encounters a variety of configurations in the flow passageway such as changes in pipe size, branches, bends, junctions, expansion, and contractions. These shape variations impose losses in addition to those resulting from pipe friction. Pipe form losses are the result of fully developed turbulence and can be generally expressed as follows:

$$H_L = K(V^2/2g)$$

Where H_L = Head Loss (feet)

K = Loss Coefficient

$V^2/2g$ = Velocity Head (feet)

g = Acceleration of Gravity (32.2 ft/sec^2)

Separate form losses attributable to pipe expansions and contractions, junctions and manholes, and at pipe outlets may be more specifically calculated in the following equations:

(i) **Expansion Losses:** Expansion in a storm sewer conduit will result in a shearing action between the incoming high velocity jet and the surrounding sewer boundary. Much of the kinetic energy is therefore dissipated by eddy currents and turbulence. The loss of head can be calculated as follows:

$$H_L = K_e (V_1^2/2g) [1 - (A_1/A_2)]^2$$

Where H_L = Head Loss (Feet)

K_e = Loss Coefficient (1.0, Sudden Expansion, 0.17, Gradual 10% Taper, Refer to Figure 7-5, "Storm

(Expansion/Contraction)," of these Standards)

V_1 = Pipe Velocity Upstream of Expansion (feet per second)

A_1 = Pipe Cross-Sectional Area Upstream of Expansion (ft^2)

A_2 = Pipe Cross-Sectional Area Downstream of Expansion (ft^2)

(ii) **Contraction Losses:** The form loss of head due to contraction can be calculated as follows:

$$\mathbf{H_L = K_c\ (V_2 2/2g)\ [1 - (A_2/A_1)]^2}$$

Where H_L = Head Loss (Feet)

K_c = Loss Coefficient (0.5, Sudden Contraction, 0.1, Gradual Contraction, Refer to Figure 7-5, "Storm Sewer Energy Loss Coefficient (Expansion/Contraction)," of these Standards)

V2 = Outfall Velocity (feet per second)

A_1 = Pipe Cross-Sectional Area Upstream of Expansion (ft^2)

A_2 = Pipe Cross-Sectional Area Downstream of Expansion (ft^2)

(iii) **Junction and Manhole Losses:** A junction occurs where one or more branch sewers enter a main sewer, usually at manholes. The hydraulic design of a junction is in effect the design of two or more transitions, one for each flow path. Allowances should be made for head loss due to the impact at junctions. The head loss for a straight through manhole or at an inlet entering the sewer may be calculated from the general form loss equation, $H_L = K(V^2/2g)$, presented at the beginning of this paragraph. The form loss of head at a junction can be calculated as follows:

$$\mathbf{H_L = V_2^2/2g - K_j\ V_1^2/2g}$$

Where HL = Head Loss (Feet)

V2 = Outfall Velocity (Feet Per Second)

Kj = Loss Coefficient (Refer to Figure 7-6," Manhole and Junction Losses," of these Standards

V_1 = Inlet Velocity (Feet Per Second)

(3) **Storm Sewer Outlet Losses:** When the storm sewer system discharges into an open channel, additional losses occur at the outlet in the form of expansion losses. For a headwall and no wingwalls, the loss coefficient Ke = 1.0 and for a flared-end section the loss coefficient is approximately 0.5 or less.

FIGURE 7-5

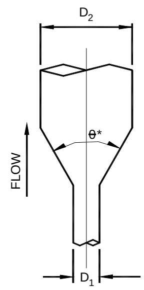
STORM SEWER ENERGY LOSS COEFFICIENT

(EXPANSION, CONTRACTION)

(A) EXPANSION (K_e)

θ*	$\frac{D_2}{D_1} = 3$	$\frac{D_2}{D_1} = 1.5$
10	0.17	0.17
20	0.40	0.40
45	0.86	1.06
60	1.02	1.21
90	1.06	1.14
120	1.04	1.07
180	1.00	1.00

* THE ANGLE θ IS THE ANGLE IN DEGREES BETWEEN THE SIDES OF THE TAPERING SECTION.



(B) PIPE ENTRANCE FROM RESERVOIR

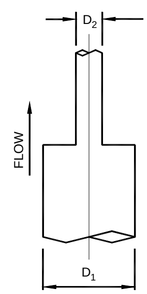
BELL-MOUTH $H_L = 0.04 \frac{V^2}{2g}$

SQUARE-EDGE $H_L = 0.5 \frac{V^2}{2g}$

GROOVE END U/S FOR CONCRETE PIPE $H_L = 0.2 \frac{V^2}{2g}$

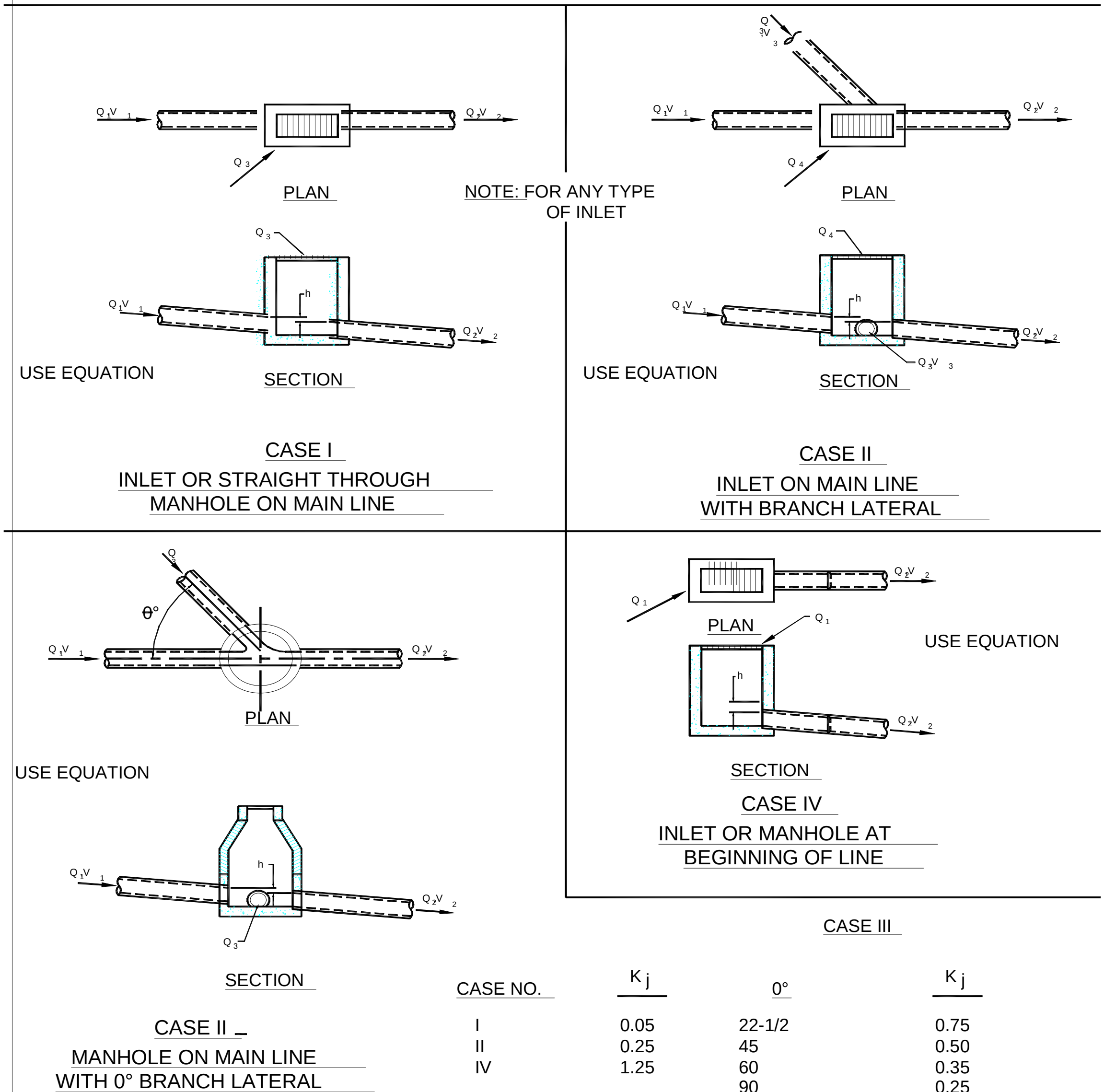
(C) CONTRACTIONS (K_c)

$\frac{D_2}{D_1}$	K_c
0	0.5
0.4	0.4
0.6	0.3
0.8	0.1
1.0	0



REFERENCE: LINSLEY AND FRANZINI "WATER RESOURCES ENGINEERING" MC GRAW-HILL, 1964

FIGURE 7-6: MANHOLE AND JUNCTION LOSSES



CASE III

CASE NO.	K_j	0°	K_j
I	0.05	22-1/2	0.75
II	0.25	45	0.50
IV	1.25	60	0.35
		90	0.25
		NO LATERAL	SEE CASE I

REFERENCE: APWA SPECIAL REPORT NO. 49, 1981

7.09 Inlets

(A) Specifications

(1) **Required:** Storm inlets shall be provided where sump (low-spot) conditions exist or street runoff-carrying capacities are exceeded.

(2) **Inlet Classification:** Inlets are classified as a sump or continuous grade condition. Sump inlets are inlets located in a low spot or submerged condition. Continuous grade inlets are inlets located along a continuous grade curb and gutter section where bypass flows may occur, and not in a low point.

(3) **Standard Inlets:** Table 7-5, "Standard Inlets," indicates the standard inlets permitted for use in the City.

Table 7-5: Standard Inlets

Inlet Type	Drainage Condition	Permitted Use	Percentage of Theoretical Capacity Allowed
Curb Opening Inlet - Type "R"	Continuous Grade or Sump	All Curb and Gutter Street Types	80% (5 Foot Length) 85% (10 Foot Length) 90% (15 Foot Length)
Combination (Curb Opening/Grated) Inlet - Type "A"	Continuous Grade or Sump	Director Approval Required	66%
Grated Area Inlet - Type 13	Sump	Parking Lots, Alleys	60%

(4) **Reduction Factors:** In order to account for inlet capacity reductions caused by debris plugging, pavement overlaying, parked vehicles, and other blockage factors, inlet design shall be based on the "percentage of theoretical capacity allowed" as outlined in Table 7-5, "Standard Inlets," in these Standards.

(5) **Inlet Spacing**

(a) Spacing of storm inlets is dependent upon traffic requirements, contributing land use, street slope and distance to the nearest outfall system. The recommended sizing and spacing of the inlets is based upon the interception rate of 70 percent to 80 percent, which has been found to be more efficient than spacing using 100 percent interception rate.

(b) Using recommended inlet spacing, only the most downstream inlet is designed to intercept 100 percent of the flow. In addition to recommended interception rates, considerable improvements in overall inlet system efficiency can be achieved if the inlets are located in the sumps created by street intersections.

(6) **Inlet Grates:** All inlet grates located in a street, alley, parking lot travel lane, bike path, or sidewalk, shall utilize a safety grate approved for bicycle traffic.

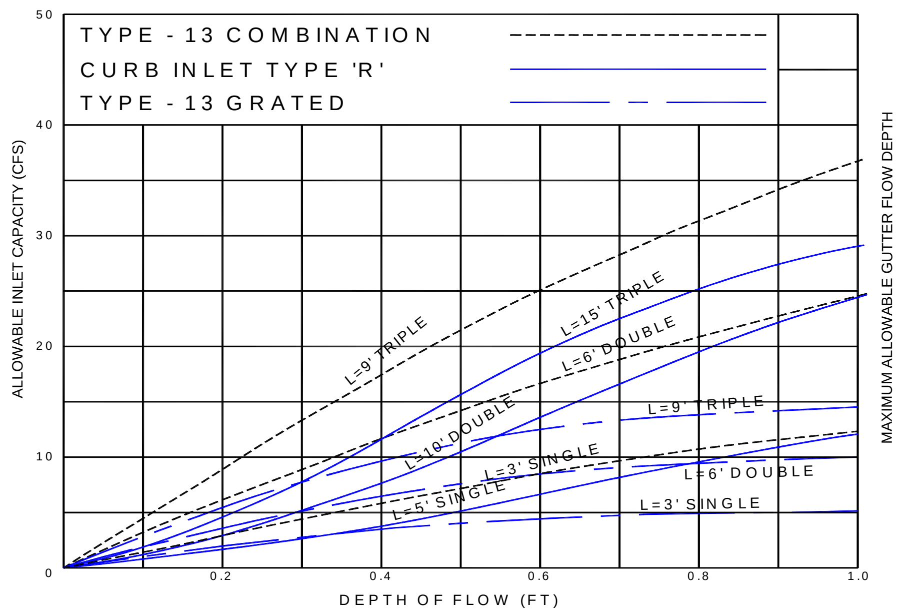
(7) **Additional Standards:** Except as modified in these Standards, storm sewer inlet design shall conform with the standards in the UDFCD Drainage Criteria Manual.

(B) Inlet Hydraulics

Inlets are to be designed based on the theoretical flow capacity, considering the runoff volume and depth of flow in the gutter, as adjusted by applying a reduction factor to account for variable "in field" conditions which would limit optimal theoretical performance.

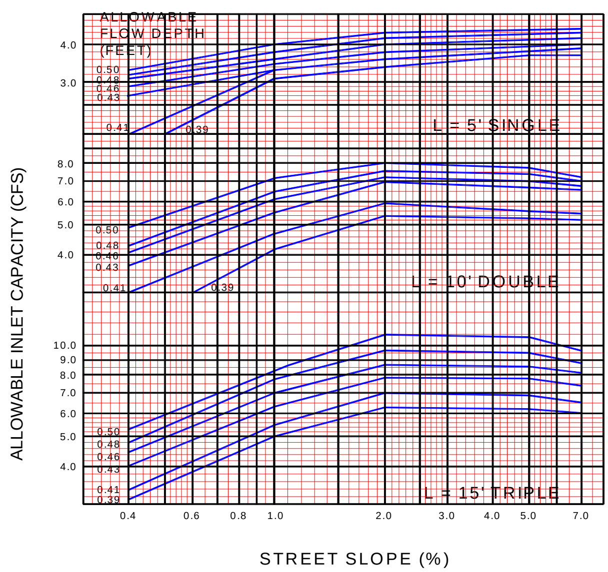
(1) **Sump Inlet Condition:** Sump inlet capacity shall be determined by the depth of ponding above the inlet and the size and shape of the inlet opening. The theoretical capacity of a Type R, Combination Type A or Grated Type 13 inlet in a sump condition is to be determined from Figure 7-7, "Allowable Inlet Capacity, Sump Conditions - All Inlets," of these Standards. Design capacity is then calculated by applying the "percentage of theoretical capacity allowed" factor outlined in Table 7-5, "Standards Inlets," of these Standards.

FIGURE 7-7: ALLOWABLE INLET CAPACITY
SUMP CONDITIONS - ALL INLETS



(2) **Continuous Grade Inlet Condition:** Continuous grade inlet capacity is to be determined based upon gutter slope, depth of flow in the gutter, length and height of the curb opening, street cross slope, and the amount of depression at the inlet. In addition, continuous grade conditions limit the potential to intercept all gutter flow without very long and expensive inlet construction. Given this, continuous grade inlets are to be designed considering "inlet carryover" which includes an evaluation of the flow interception percentage at each inlet and the amount of carryover to be included at the next inlet stage.

FIGURE 7-8: ALLOWABLE INLET CAPACITY
TYPE 'R' CURB OPENING ON A CONTINUOUS GRADE



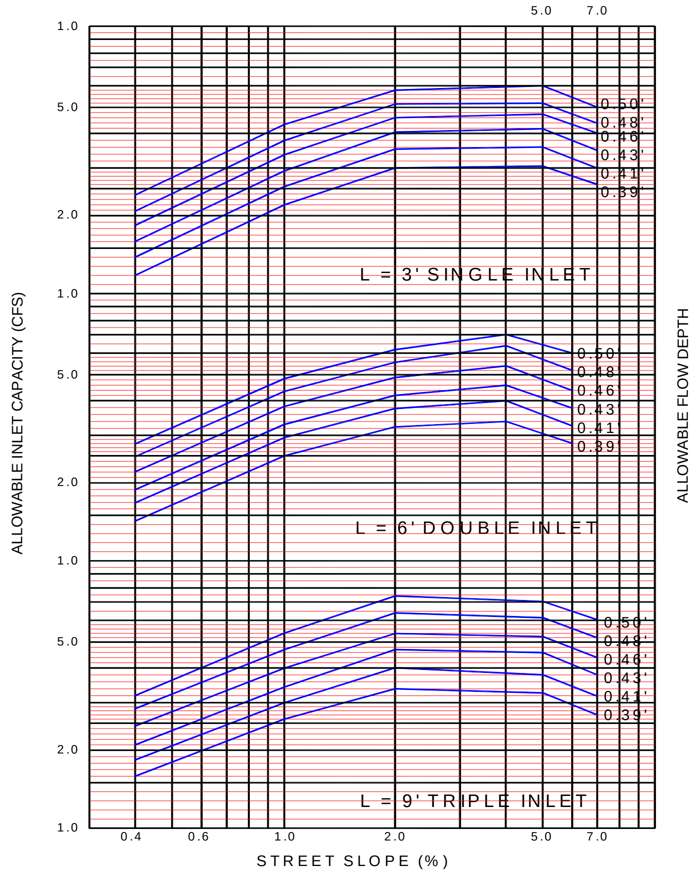
NOTES:

1. MAXIMUM INLET CAPACITY AT MAXIMUM ALLOWABLE FLOW DEPTH. PROPORTIONALLY REDUCE FOR OTHER DEPTHS.
2. ALLOWABLE CAPACITY =
   88% (L = 5')
   92% (L = 10') — OF THEORETICAL CAPACITY
   95% (L = 15')
3. INTERPOLATE FOR OTHER INLET LENGTHS.

(a) **Type R Inlet:** The theoretical capacity of a Type R inlet in a continuous grade condition is to be determined from Figure 7.8, “Allowable Inlet Capacity, Type “R” Curb Opening on a Continuous Grade,” of these Standards. Design capacity is then calculated by applying the “percentage of theoretical capacity allowed” factor outlined in Table 7-5, “Standards Inlets,” of these Standards.

(b) **Combination Type A Inlet:** The theoretical capacity of a Type A inlet in a continuous grade condition is to be determined from Figure 7-9, “Allowable Inlet Capacity, Type “A” Combination on a Continuous Grade,” of these Standards. Design capacity is then calculated by applying the “percentage of theoretical capacity allowed” factor outlined in Table 7-5, “Standards Inlets,” of these

FIGURE 7-9: ALLOWABLE INLET CAPACITY
TYPE "A" COMBINATION ON A CONTINUOUS GRADE



NOTES:

1. ALLOWABLE CAPACITY = 66% THEORETICAL CAPACITY
2. MAXIMUM INLET CAPACITY AT MAXIMUM ALLOWABLE FLOW DEPTH. PROPORTIONALLY REDUCE FOR OTHER DEPTHS.

Standards.

7.10 Street Drainage

(A) Function of Streets in the Drainage System

(1) **Primary Function of Streets:** Streets provide an integral part of the storm water system and are intended to transport local storm runoff within reasonable limits. However, the primary function of streets is for transportation, and storm water conveyance shall not be the major function of the street. Street runoff shall be analyzed for the initial and major storm events, and necessary storm drainage facilities shall be designed in conformance with these Standards. When street runoff exceeds allowable limits, a storm sewer system or an open drainageway is required to convey the excess flows.

(2) **Allowable Storm Water Conveyance:** Allowable storm water conveyance on public streets is based upon a reasonable frequency and level of traffic interference. Depending on the character of the street, certain traffic lanes may be fully or partially inundated during storm events. During less intense storms, streets should be designed to efficiently convey minor and nuisance runoff to the storm sewer or open drainage system without interference to traffic movements. During major storm events, streets are needed to provide an emergency passageway for the flood flows with minimal damage to urban environment.

(B) Street Classification and Allowable Runoff Encroachment

(1) **Street Classification:** City streets are classified according to the average daily traffic carried and travel routes they provide. Higher category streets, such as arterials and collectors, are required to provide a greater level of access and through travel for emergency purposes during major storm events than lower category streets.

(2) **Allowable Runoff Encroachment:** A storm drainage system (storm sewer or open drainageway) shall be provided where the gutter runoff encroachment reaches the limits outlined in Table 7-6, "Allowable Street Drainage Encroachment."

Table 7-6: Allowable Street Drainage Encroachment

Street Classification	Minor Storm Maximum Encroachment	Major Storm Maximum Encroachment
Residential and Local Streets	No curb overtopping. Flow may spread to street crown.	Depth at flowline shall not exceed 18 inches.
Collector Streets	No curb overtopping. A minimum one travel lane width shall remain free of drainage encroachment.	Depth at flowline shall not exceed 18 inches.
Arterial Streets	No curb overtopping. A minimum two travel lanes width shall remain free of drainage encroachment.	Depth at crown shall not exceed 6 inches. Depth at flowline shall not exceed 18 inches.
Freeways	No flow encroachment is allowed.	Refer to CDOT Roadway Design Manual

NOTE: Flow encroachment shall not extend beyond property lines.

(C) Hydraulic Street Capacity

(1) Allowable Capacity - Minor Storm

(a) The allowable minor storm capacity of each street section is to be calculated using the modified Manning's formula as follows:

$$Q = (0.56)\ (z/n)S^{1/2}\ y^{8/3}$$

Where Q = Discharge in Cubic Feet Per Second

z = $1/S_x$ Where S_x is the Cross Slope of the Pavement (ft/ft)

y = Depth of Flow at Face of Curb (Feet)

S = Longitudinal Grade of Street (ft/ft)

n = Manning's Roughness Coefficient

(b) A nomograph for this equation has been developed and is included in Figure 7-10, “Nomograph for Flow in Triangular Gutters,” of these Standards. The graph is applicable for all gutter configurations.

(c) An “n” value of 0.016 shall be used for all calculations involving street runoff. The allowable gutter capacity shall be adjusted by applying a reduction factor to account for various street conditions that decrease the street capacity. These conditions include street overlays, parked vehicles, debris and hail accumulation, and deteriorated pavement. The reduction factor also is used to minimize damaging gutter flow velocities. These factors are determined by the curves in Figure 7-11, “Gutter Capacity Reduction Curves,” of these Standards. The allowable gutter flow calculated with the reduction factor shall be used in the drainage system design calculations.

(d) The allowable gutter capacity was computed using a symmetrical street section. Therefore, the allowable gutter capacity will need to be reduced for non-symmetrical street sections. If critical capacity areas exist on a non-symmetrical street, then individual street capacity calculations of these areas shall be submitted as part of the system design.

(2) **Allowable Capacity - Major Storm:** The allowable street capacity for the major storm shall be calculated using Manning's formula, dividing the street cross section into the pavement area and sidewalk/grass area, and computing individual flow contributions. An “n” value of 0.016 for pavement and 0.035 for the sidewalk/grass area shall be used.

(D) Cross Street Flow

The standards outlined in Table 7-7, “Allowable Cross Street Flow,” of these Standards, shall be used for allowable cross-street flow, where flow passes from one side of the street to the other. The allowable cross-street flow shall be determined using the methods prescribed in the preceding sections, based on the design storm being considered; however, the gutter slope variable should be replaced with the cross-street water surface slope.

FIGURE 7.10

NOMOGRAPH FOR FLOW IN TRIANGULAR GUTTERS

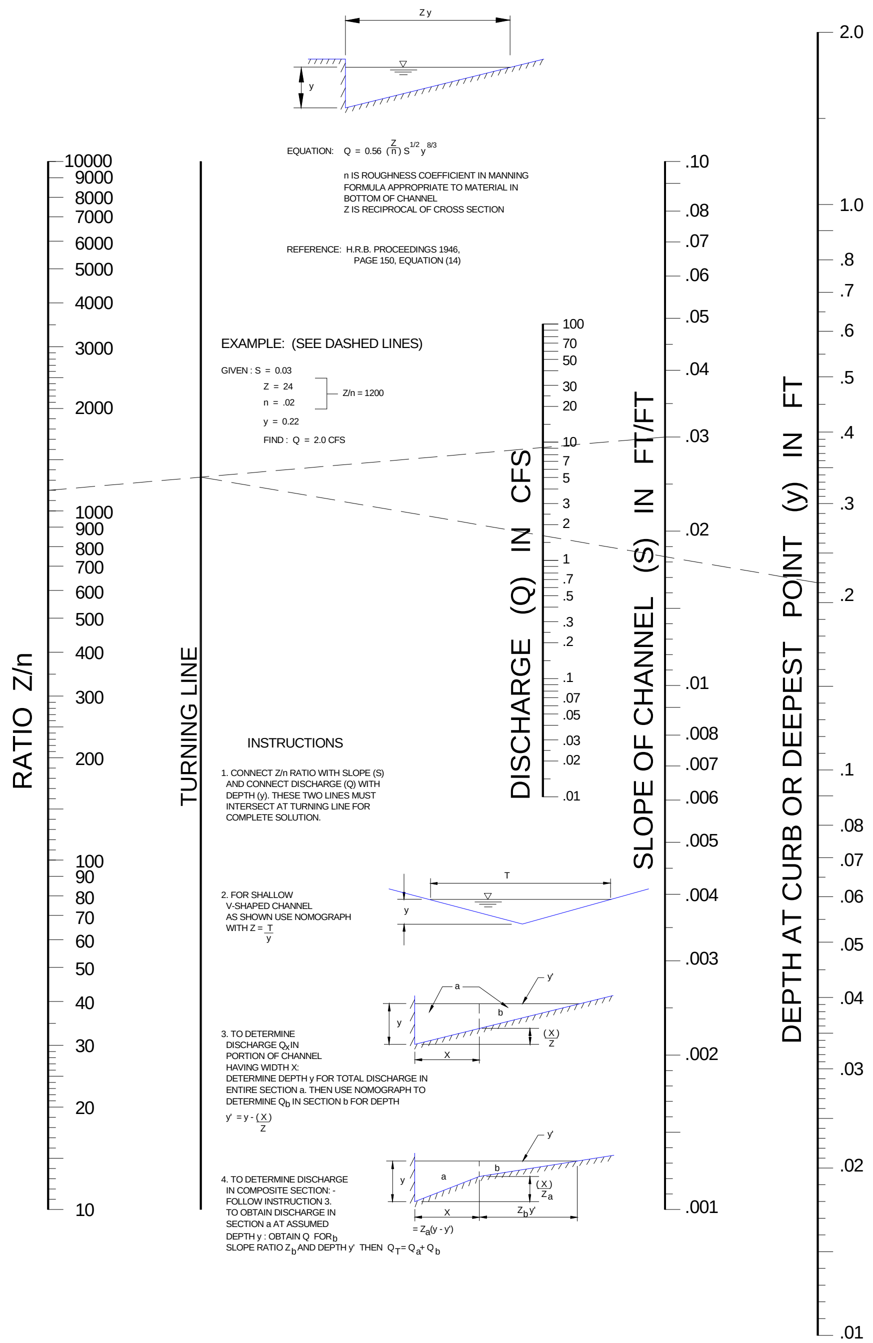
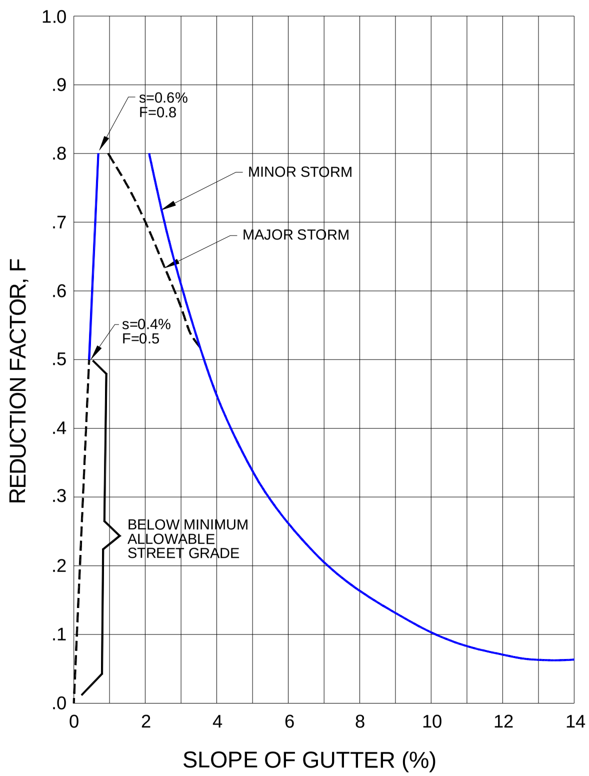
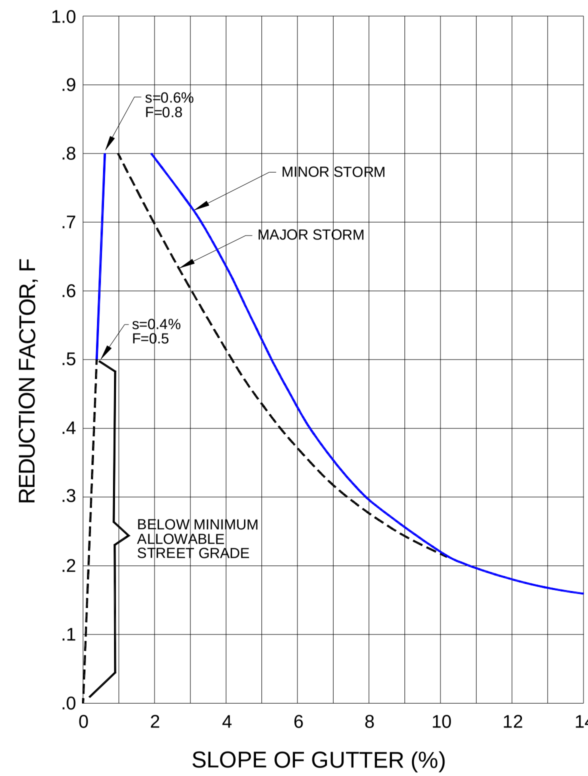


FIGURE 7-11
GUTTER CAPACITY REDUCTION CURVES



REDUCTION FACTOR FOR ALLOWABLE GUTTER CAPACITY
WHEN APPROACHING AN ARTERIAL STREET

APPLY REDUCTION FACTOR FOR APPLICABLE SLOPE TO THE THEORETICAL GUTTER CAPACITY TO OBTAIN ALLOWABLE GUTTER CAPACITY APPROACHING ARTERIAL STREET



REDUCTION FACTOR FOR ALLOWABLE GUTTER CAPACITY
LOCAL AND COLLECTOR STREETS

APPLY REDUCTION FACTOR FOR APPLICABLE SLOPE TO THE THEORETICAL GUTTER CAPACITY TO OBTAIN ALLOWABLE GUTTER CAPACITY APPROACHING ARTERIAL STREET

Table 7-7: Allowable Cross Street Flow

Street Classification	Minor Storm Runoff	Major Storm Runoff
Residential and Local Street	Maximum Depth of 6 Inches in Cross Pan	Maximum Depth of 18 Inches Above Flowline
Collector Street	Where Allowed, Maximum Depth of 6 Inches in Cross Pan	Maximum Depth of 18 Inches Above Flowline
Arterial	Not Allowed	Maximum Depth of 6 Inches Over Street Crown

7.11 Culverts

(A) System Design

(1) **Required:** Culverts shall be provided for the conveyance of storm water runoff under a roadway, railroad, driveway, or other crossings of an open drainage system (such as a drainageway or roadside swale). The size, shape, and type of culvert crossings shall be based on the projected runoff volumes, as well as existing topographic conditions. All culvert designs are subject to approval by the Director.

(2) **Culvert Types:** Typical culvert types include circular, elliptical, or arch pipe sections, and reinforced concrete box culverts.

(B) Hydraulic Design

All culverts shall be designed using the form presented in Figure 7-12, "Design Computation Form for Culverts," of these Standards. The procedures and basic design methods to be applied are in accordance with the UDFCD Drainage Criteria Manual. All culvert designs are to include an analysis to determine whether inlet or outlet control conditions govern for both major and minor storm runoff conditions. The following procedure is to be applied:

(1) Compile design data, including design discharge, allowable headwater, and proposed culvert cross section (to determine slope, length, flowline and velocity).

(2) Design culvert assuming inlet control, using trial culvert type and size. Apply the proper design nomographs and repeat until the allowable headwater condition is achieved.

(3) Design culvert assuming outlet control, beginning with the adequate culvert design for inlet control. Compute H (Head) from the proper design nomograph and TW (Tail Water) from open channel hydraulics to determine HW (Headwater). The HW must satisfy the allowable headwater conditions.

(4) Design appropriate outlet protection based on outlet velocity and tail water depth.

PROJECT:

DESIGNER: ______________

DATE: ______________

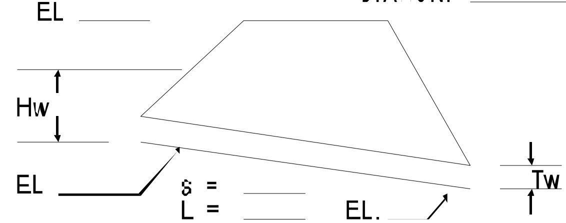
HYDROLOGIC AND CHANNEL INFORMATION

Q_1 = ____ TAILWATER ELEVATION = ______

Q_1 = ____ TAILWATER ELEVATION = ______

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}
Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH
STATION: ______



MEAN STREAM VELOCITY = ______ $\frac{L}{100s}$ = ______
MAX. STREAM VELOCITY = ______

CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION											CONTROLLING Hw	OUTLET VELOCITY	COST	COMMENTS
			INLET CONT		OUTLET CONTROL $HW = H + h_o - L_s$							CHART					
			$\frac{Hw}{D}$	Hw	K_e	H	d_c	$\frac{d_c + D}{2}$	ho	Ls	Hw	No.	Hw				

SUMMARY & RECOMMENDATIONS:

FIGURE 7-12: DESIGN COMPUTATION FORM FOR CULVERTS

(C) Structural Design

The structural design of culverts shall conform to accepted structural engineering practices, the Colorado Department of Transportation design standards and standard specifications, any methods and criteria recommended by the manufacturer for a specific culvert type, and for conditions found at the construction site. As a minimum, all culverts shall be designed to withstand an AASHTO HS-20 traffic loading.

(D) Specifications

(1) **Size**

(a) Culvert design size shall be based upon the following:

(i) Runoff volumes for the appropriate design storm.

(ii) Required capacity based on roadway classification and allowable street overtopping, as prescribed in Section 7.10, "Street Drainage," of these Standards

(b) Culverts shall be at least 18 inches in diameter or height, with the exception of driveway culverts along roads with roadside drainage swales, which shall be at least 12 inches in diameter or height.

(2) **Inlet and Outlet Sections**

(a) All culverts shall be designed with headwalls and wingwalls, or flared end sections at the inlet and outlet. Flared end sections are allowed only on pipe culverts with diameters of 42 inches (or equivalent) or less.

(b) Erosion protection, such as rip-rap, boulder energy dissipators, or adequate vegetation, shall be provided at the inlet or outlet where required to mitigate potential scouring or erosive flow conditions. The Engineer shall propose the erosion protection to be used, subject to approval by the Director.

(3) **Slope and Velocity**

(a) Culvert slopes shall be designed so that neither silting nor excessive velocities resulting in scour can occur. The minimum design velocity for minor storm conditions shall be 2 feet per second, to provide for self-cleansing of the culvert.

(b) The maximum culvert velocity is dictated by the channel conditions at the outlet, and the amount of erosion protection or energy dissipation that can be provided to prevent scour or damage.

(4) **Allowable Headwater**

(a) The maximum headwater / diameter (HW/D) ratio for the 100-year design flows shall be 1.5, and 1.0 for the 10-year design flow. These HW/D ratios are to be applied to culverts at street crossings, and should not be applied to outlets from detention ponds or private driveways.

(b) Ponding above the top of a culvert is not permitted if such ponding could potentially cause property or roadway damage, culvert clogging, saturation of critical embankments, detrimental debris deposition, erosion, or inundation of existing or future utilities, structures, or buildings.

(5) **Trash Racks**

(a) The installation of a trash rack over a culvert entrance shall be provided as required by the Director where there exists the potential for debris clogging of the culvert or where there is a safety hazard concern for the possibility of people (especially children) being carried into the culvert.

(b) Trash racks shall be designed to maintain adequate culvert hydraulics, considering the potential for debris buildup and blockage which may render the culvert ineffective. Careful design considerations are to be applied, including without limitation application of the following standards:

(i) Materials: All trash racks shall be constructed with smooth steep pipe, having an outside diameter of at least 1 ¼ inches. Trash rack ends and bracing shall be constructed with steel angle sections. All trash rack components shall have a corrosion protective finish.

(ii) Design: Trash racks shall be designed without cross-braces, to minimize debris clogging, and be able to withstand the full hydraulic load of a completely plugged trichroic based on the highest anticipated depth of ponding. The trash rack shall be hinged and removable for maintenance purposes.

(iii) Bar Spacing: Bar spacing shall provide a maximum clear opening of 6 inches. The longitudinal slope of the trash rack shall be no steeper than 3:1, horizontal to vertical. The entire trash rack shall have a clear opening at least three times the culvert opening area.

(c) Hydraulics: Use the following equation to compute hydraulic losses through trash racks:

$$H_T = 0.11 * (TV/D)^2 * (\sin A)$$

Where: H_T = Head Loss through the Trichroic (feet)

T = Thickness of Trichroic Bar (inches)

V = Velocity normal to Trichroic (fps)

D = Center-to-Center Spacing of Bars (inches)

A = Angle of Inclination of Trichroic with Horizontal

The velocity normal to the trichroic shall be computed considering the rack to be 50 percent plugged.

7.12 Detention

(A) System Design

(1) **Intent:** Detention ponding facilities are intended to store increased runoff from developed property and release this runoff at the historic rate that existed prior to development or redevelopment. By providing detention ponding, increased runoff impacts on downstream facilities may be controlled and minimized to reduce potential damages and the need for greatly expanded storm water conveyance facilities.

(2) **Required:** Detention ponding for storm water shall be provided for all new development or redevelopment, other than single-family lots that are not part of a larger development and subdivisions of one single-family lot into two single-family lots where the runoff coefficient for the site is increased, unless runoff for the initial and major storm events

from the entire tributary basin can be conveyed directly to the major drainage system without adverse impact on upstream, surrounding, or downstream properties and facilities and storm water detention to meet water quality mitigation measures is not required.

(3) **Maintenance:** The property owner shall be responsible for maintaining storm water detention facilities.

(B) Design Frequency, Release Rates, and Storage Requirements

(1) **Design Storms:** Detention ponds shall be designed for the initial and major design storms, as a combined facility, and shall satisfy the separate storage and release conditions for each storm event. The design release rates shall be restricted such that runoff from the entire parcel and tributary basin to be developed or redeveloped does not exceed the maximum runoff, or historic runoff, for the initial and major storm that occurred prior to the proposed development or redevelopment. Where existing downstream facilities have been designed for a storm with a lesser frequency than required by this document, additional storage may be required to maintain historic release rates during that lower frequency storm event.

(2) **Storage Volume:** The storage volume of runoff to be detained on-site shall be sized to contain 110 percent of the difference between the historic runoff and the initial and major storm runoff projected for the ultimate developed conditions of the entire parcel and tributary basin to be developed or redeveloped.

(C) Hydraulic Design

(1) **Required Storage Analysis – Basins Under 160 Acres:** An analysis of the storage required for each detention pond shall be performed using a routed hydrograph method. Simplified routing techniques using the Rational Method, such as the triangular hydrograph, trapezoidal hydrograph, or the procedure presented in “Airport Drainage,” prepared by the Federal Aviation Agency, and outlined in Section 5.1, “Rational Method Analysis,” UDFCD Storm Drainage Criteria manual, are to be used for all basins smaller than 160 acres.

(2) **Required Storage Analysis – Basins Over 160 Acres:** The CUHP method, outlined in Section 5.2, “CUHP Storage Analysis,” UDFCD Storm Drainage Criteria manual, is to be used for basins 160 acres or larger.

(3) **Single or Multiple Pond Design:** The routed hydrograph method allows for designing detention systems as single ponds, multiple ponds, or multiple consecutive ponds for the entire parcel and tributary basin. Where multiple consecutive ponds are designed, flexibility may be applied to upper stage ponds in sizing and release rates to address site constraints, creative storm system layouts, and reductions in size of the final stage detention pond, subject to restricting the release rate from the final stage pond to the historic runoff rate for the entire parcel and tributary basin to be developed or redeveloped.

(4) **Undetained Site Releases:** On certain parcels to be developed or redeveloped where runoff from portions of the site can not be detained due to topography or site conditions, free release of runoff may be approved with compensating detention storage design subject to the following conditions:

(a) Total maximum runoff from the entire parcel and tributary basin to be developed or redeveloped shall not exceed the historic runoff,

(b) Release rates from the detention ponds shall be reduced by the developed runoff rate from the undetained drainage area,

(c) The undetained drainage area may not exceed five percent of the entire parcel and tributary basin to be developed or redeveloped, and

(d) The release rate from the undetained area may not exceed 25 percent of the historic release rate from the entire parcel and tributary basin to be developed or redeveloped.

(D) Pond Design

(1) **Surface Ponding Required:** All detention ponds shall be provided as open, surface grade improvements. Underground, enclosed, or roof top detention ponds shall not be permitted unless unusual site conditions and adequate detention performance and maintenance conditions are approved by the Director.

(2) **Location:** Detention ponds shall be located wherever possible in open, pervious landscaped areas to enhance site drainage and soil percolation, and to improve water quality. Detention ponds located in parking lots are not encouraged given the potential for inconveniences, hazards, and damages resulting from possible water and ice buildup in public parking areas. Where detention ponding is provided in parking areas, signs meeting the standards for traffic signage shall be posted to notify users that the area is subject to ponding during rainfall events. Detention ponding provided in parking lots shall be designed so as not to exceed a depth of 12 inches.

(3) **Side Slopes:** Side slopes for detention ponds shall be designed to provide for ease of maintenance and access. Landscaped side slopes are not to exceed 4:1, and vertical or steep walls used as side slopes are to be constructed of durable natural materials, such as rock or timber, with heights no greater than 30 inches to reduce safety hazards.

(4) **Pond Bottoms:** Pond bottoms are to be pervious and sloped to prevent the collection of standing water, unless a permanent pond or wetland bottom is provided for water quality enhancements. Hard-lined trickle channels are not to be constructed in detention ponds unless approved by the Director to address specific drainage problems or safety and environmental hazards.

(E) Outlet Design

(1) **Outlet Hydraulic Design**

Hydraulic design data for sizing detention ponding outlets is as follows:

(a) **Weir Flows**

(i) Weir flow outlet design is to be calculated using the following equation:

$$Q = CLH^{3/2}$$

Where: Q = Discharge (cubic feet per second)

C = Weir Coefficient (Refer to Figure 7.13, “Weir Flow Coefficients,” of these Standards)

L = Horizontal Length (feet)

H = Total Energy Head (feet)

(ii) A “V”-notch weir may also be used as calculated using the following equation:

$$Q = 2.5 \tan(A/2)\, H^{5/2}$$

Where: Q = Discharge (cubic feet per second)

A = Angle of the Notch at the Apex (degrees)

H = Total Energy Head (feet)

(iii) When designing or evaluating weir flow, the effects of submergence should be considered.

(b) **Orifice Flow:** Orifice flow outlet design is to be calculated using the following equation:

$$Q = C_d A\, (2gh)^{1/2}$$

Where: Q = Discharge (cubic feet per second)

C_d = Orifice coefficient (0.65 for "Square-Edged" entrance conditions)

A = Orifice Area (ft^2)

g = Gravitational Constant (32.2 ft/sec^2)

h = Head on Orifice measured form Centerline of Orifice (feet)

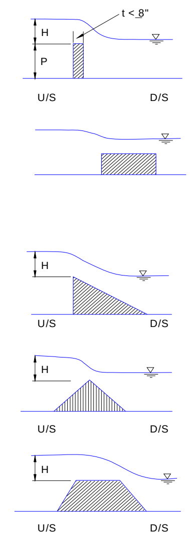
(2) **Placement:** All outlets for detention ponds, not including water quality ponds or portions of combined ponds, shall be placed at a location and elevation to ensure draining of the required detention storage volume within 24 hours of a storm event.

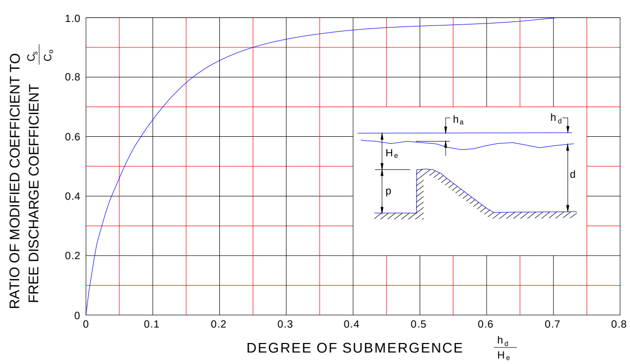
Overflow Release Feature: All detention ponds shall include an overflow release feature to spill during storm events larger than the major design storm or when release outlets fail. This feature shall be designed to release overflows in a direction and manner that will not adversely affect properties downstream of the detention pond.

FIGURE 7-13: WEIR FLOW COEFFICIENTS

SHAPE	COEFFICIENT	COMMENTS
SHARP CRESTED	-	
PROJECTION RATIO (H/P=0.4)	3.4	H<1.0
PROJECTION RATIO (H/P=2.0)	4.0	H>1.0
BROAD CRESTED	-	
W/SHARP U/S CORNER	2.6	MINIMUM VALUE
W/ ROUNDED U/S CORNER	3.1	CRITICAL DEPTH
TRIANGULAR SECTION	-	
A) VERTICAL U/S SLOPE	-	
1:1 D/S SLOPE	3.8	H>0.7
4:1 D/S SLOPE	3.2	H>0.7
10:1 D/S SLOPE	2.9	H>0.7
B) 1:1 U/S SLOPE	-	
1:1 D/S SLOPE	3.8	H>0.5
3:1 D/S SLOPE	3.5	H>0.5
TRAPEZOIDAL SECTION		
1:1 U/S SLOPE, 2:1 D/S SLOPE	3.4	H>1.0
2:1 U/S SLOPE, 2:1 D/S SLOPE	3.4	H>1.0
ROAD CROSSINGS		
GRAVEL	3.0	H>1.0
PAVED	3.1	H>1.0

SCHEMATIC





ADJUSTMENT FOR TAILWATER

REFERENCE: KING & BRATER, HANDBOOK OF HYDRAULICS, MC GRAW HILL BOOK COMPANY, 1963 - DESIGN OF SMALL DAMS, BUREAU OF RECLAM., 1977

7.13 Storm Water Quality Best Management Practices

(A) Required

All development is required to utilize storm water quality management practices to reduce the impacts on receiving waters. Additionally, the City is an operator of a Phase II regulated small Municipal Separate Storm Sewer System (MS4) and is required by the State of Colorado to hold a permit to discharge storm water. In order to comply with the permit, all development which disturbs 1 acre of land or more must meet additional requirements.

(B) Erosion Control Measures

(1) **Storm water Management Plan (SWMP):** Prior to any construction activity disturbing 1 acre of land or more, a City approved SWMP and a Storm Water Permit for Construction Activity application from the Colorado Department of Public Health and Environment (CDPHE) are required. The SWMP shall be prepared in accordance with the CDPHE requirements for "Contents of the Storm water Management Plan" and the UDFCD's Urban Storm Drainage Criteria Manual, Volume 3, "Best Management Practices" (UDFCD Drainage Criteria Manual). Storm water quality management and erosion control measures are to be constructed and maintained in accordance with the SWMP and the UDFCD Drainage Criteria Manual.

(a) The Operator will be required to have the SWMP on site at all times and shall be prepared to respond to maintenance of specific BMP's.

(b) The Operator shall inspect all BMP's at least every 14 days and within 24 hours after any precipitation or snow melt event that causes surface runoff. Effective **March 30, 2005**, inspections of BMP's shall be conducted by an individual who has successfully completed formal training in erosion and sediment control by an organization acceptable to the Director of Public Works. A certification of successful completion of such training shall be provided upon request.

(c) The Operator shall amend the SWMP whenever there is a change in design, construction, operation, or maintenance, which has an effect on the potential for discharge of pollutants to the MS4 or receiving waters, or if the SWMP proves to be ineffective in achieving the general objectives of controlling pollutants in storm water discharges associated with construction activities.

(d) Records of inspection are to be maintained on site with the SWMP. Inspection records are to be available at the project site at all times and shall be made available to the City upon request.

(e) Prior to commencement of work, all general contractors, subcontractors and utility agencies shall obtain and comply with the approved, current SWMP for the project.

(2) **Storm Water Quality and Erosion Control Plan:** The Director of Public Works may require the preparation of a Storm Water Quality and Erosion Control Plan in order to assess the impacts of any project or development not required to submit a SWMP. Best Management Practices (BMP's) in accordance with the UDFCD Drainage Criteria Manual shall be applied to ensure that downstream properties and drainage ways will not be adversely impacted by site development and construction activities.

(3) Preparation Standards: Design of both the SWMP in section (1) above and the Storm Water Quality and Erosion Control Plan in section (2) above shall include the following elements:

(a) Protection for adjacent properties (including public right-of-way) from erosion and/or sediment deposition.

(b) Protection for public streets from the deposit of sediment from runoff or vehicles tracking mud.

(c) Stabilization for all disturbed areas as defined in the UDFCD Drainage Criteria Manual.

(d) Protection for all storm sewer inlets from the entry of sediment-laden water.

(e) Long-term stability of cut and fill slopes and the successful establishment of permanent vegetative cover on exposed soil.

(f) The following standard notes:

(i) "All temporary erosion control facilities shall be installed before any construction activities take place".

(ii) "Solid waste, industrial waste, yard waste and any other pollutants or waste on any construction site shall be controlled through the use of BMP's. Waste and/or recycling containers shall be provided and maintained by the owner or contractor on construction sites where there is the potential for release of waste. Uncontained waste that may blow, wash or otherwise be released from the site is prohibited. Sanitary waste facilities shall be provided and maintained by the owner or contractor".

(iii) "Ready-mixed concrete, or any materials resulting from the cleaning of vehicles or equipment containing or used in transporting or applying it, shall be contained on construction sites for proper disposal. Release of these materials is prohibited".

(iv) "Cover shall be applied within 14 days to inactive soil stockpiles, and shall be maintained for stockpiles that are proposed to remain in place longer than 30 calendar days".

(v) "BMP's shall be implemented to prevent the release of sediment from construction sites. Vehicle tracking of mud shall not be allowed to enter the storm water system or waters of the State. Sediment tracked onto public streets shall be removed.

(vi) "Techniques shall be used to prevent dust, sediment or debris blowing from the site".

(vii) "Storm water discharges from construction activities shall not cause or threaten to cause pollution, contamination or degradation of waters of the State".

(viii) "All earth disturbances shall be designed, constructed and completed to limit the exposed area of any disturbed land to the shortest possible period of time".

(ix) "Bulk storage structures for petroleum products and other chemicals shall have adequate protection so as to contain all spills and prevent any spilled material from entering the storm water system or waters of the State".

(x) “Any disturbance to temporary and permanent BMP’s shall be repaired or replaced within 48 hours”.

(xi) “The property owner and subsequent property owners will be responsible for continued compliance with the requirements of this section, during construction activity on the site”.

(xii) “All temporary erosion and sediment control measures shall be removed and disposed within 30 days after final site stabilization is achieved, or after the temporary measures are no longer needed, whichever occurs first”.

(C) Permanent Storm Water Quality Management

The UDFCD Drainage Criteria Manual shall be applied to address permanent storm water quality management and erosion control for all proposed projects and developments.

(1) All proposed projects and developments, including single family residential homes shall “Minimize Directly Connected Impervious Areas” in accordance with the UDFCD Drainage Criteria Manual.

(2) All proposed projects and developments, other than single-family lots that are not part of a larger development, shall provide Water Quality Capture Volume and a Water Quality Outlet in accordance with the UDFCD Drainage Criteria Manual unless other storm water quality facilities are approved by the Director. Projects and developments that disturb less than 1 acre of land and do not increase the impervious area or runoff shall provide storm water quality facilities to the extent practicable.

(3) Where detention pond facilities for the major and minor storm event are designed as combined facilities, the total volume for the minor storm shall be the required minor storm volume plus the required Water Quality Capture Volume. The total volume for the major storm shall be the full 100-year detention volume plus one-half the Water Quality Capture Volume.

(4) All projects and developments shall utilize “Industrial and Commercial Best Management Practices” as defined in the UDFCD Drainage Criteria Manual.

(D) Maintenance

The property owner shall be responsible for maintaining permanent storm water quality facilities. Maintenance shall be as recommended by the UDFCD Drainage Criteria and shall be performed such that the design properties of the facility are preserved.