Chapter 1
Drainage Policy

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1.0 Policies and Principles

Photograph 1-1. Local grass channel after 35 years of service. Ann Spirn of the Massachusetts Institute of Technology refers to this channel as "urban poetry" in her publications.

Adequate drainage for urban areas is necessary to preserve and promote the general health, welfare, and economic well-being of the region. Drainage is a regional phenomenon that affects all governmental jurisdictions and all parcels of property. This characteristic of drainage makes it necessary to formulate a program that balances both public and private involvement (Wright-McLaughlin Engineers 1969). Overall, the governmental entities most directly involved must provide coordination and master planning, but drainage planning must also be integrated on a regional level (FEMA 1995).

The underlying principles in this chapter provide direction for planning drainage facilities. These principles are made operational through a set of policy statements. The application of the policy is, in turn, facilitated by technical drainage criteria, which are the focus of this manual. When considered in a comprehensive manner, at a regional level and with public and private involvement, drainage facilities can enhance the general health and welfare of the region and assure optimum economic and social relationships while avoiding uneconomic flood losses and disruption (White 1945).

Urban Storm Drainage Criteria Manual (1969 – present)

> "The time is ripe in the Denver Region for implementation of a new and more thorough approach to storm drainage as it relates to urban problems. This manual was written in an attempt to provide the various techniques, methodology, and guidelines to achieve that objective." --Kenneth Wright, March 15, 1969

> "To the best of our knowledge, the USDCM is the first such standard prepared for implementation throughout an American metropolitan area. Its adoption will permit consistent reactions to basic problems that are independent of political subdivision boundaries. Its philosophy provides for flexible approaches to realization of necessary drainage control and total water resources objectives, and at the same time encourages improved sensitivity to the total ecology. We believe these approaches will save your region many millions of dollars through the years to come by reducing drainage construction costs and flood hazard exposure, at the same time enhancing the quality of urban life." --D. Earl Jones, U.S. Department of Housing and Urban Development (HUD), February 10, 1970

All residents of the area have benefited significantly from the pioneering vision of those who were responsible for the original (1969) version of the Urban Storm Drainage Criteria Manual, including Kenneth R. Wright, P.E., D. Earl Jones, Jr., P.E., Dr. Jack Schaeffer, Joe Shoemaker, and Dr. Gilbert White. The vast majority of the policies, principles, and criteria in the 1969 manual were retained in the 2001 and 2016 updates—a true testament to the wisdom of these leaders. This 2016 update builds upon the foundation that they provided more than 40 years ago.

UDFCD's principles and policies for urban storm drainage and floodplain management are briefly summarized in this section, followed by discussion of these policies in the remainder of the chapter.

1.1 Principles

Since 1969, UDFCD has embraced principles of drainage planning that guide the criteria in this manual. When these principles are followed, drainage planning and decisions are made in a consistent manner, considering both public safety and environmental protection. These time-tested principles include:

1. **Drainage is a regional phenomenon that does not respect the boundaries between government jurisdictions or between properties.** This makes it necessary to formulate programs that include both public and private involvement. Overall, the governmental entities most directly involved must provide coordination and master planning, but drainage planning must be integrated on a regional level if optimum results are to be achieved. The manner in which proposed drainage systems fit into existing regional systems must be quantified and discussed in the master plan.

2. **A storm drainage system is a subsystem of the total urban water resource system.** Stormwater system planning and design for any site must be compatible with comprehensive regional plans and should be coordinated with planning for land use, open space and transportation. Erosion and sediment control, flood control, site grading criteria, and water quality all closely interrelate with urban stormwater management. Any individual master plan or specific site plan should normally address all of these considerations.

3. **Every urban area has an initial (i.e., minor) and a major drainage system, whether or not they are actually planned and designed.** The initial drainage system, sometimes referred to as the "minor system," is designed to provide public convenience and to accommodate moderate, frequently occurring flows. The major system carries more water and operates when the rate or volume of runoff exceeds the capacity of the minor system. Both systems should be carefully considered.

4. **Runoff routing is primarily a space allocation problem.** The volume of water present at a given point in time in an urban region cannot be compressed or diminished. Channels and storm drains serve both conveyance and storage functions. If adequate provision is not made for drainage space demands, stormwater runoff will conflict with other land uses, result in damages, and impair or disrupt the functioning of other urban systems.

5. **Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.** Urbanization tends to increase downstream peak flow by increasing runoff volumes and velocities. Stormwater runoff can be stored and slowly released via detention facilities to manage peak flows, thereby reducing the drainage capacity required immediately downstream.

6. **An urban storm drainage strategy should be a multi-objective and multi-means effort.** The many competing demands placed upon space and resources within an urban region argue for a drainage management strategy that meets a number of objectives, including water quality enhancement, groundwater recharge, recreation, wildlife habitat, wetland creation, protection of landmarks/amenities, control of erosion and sediment deposition, and creation of open spaces.

7. **Design of the storm drainage system should consider the features and functions of the existing drainage system.** Every site contains natural features that may contribute to the management of stormwater without significant modifications. Existing features such as natural streams, depressions, wetlands, floodplains, permeable soils, and vegetation provide for infiltration, help control the velocity of runoff, extend the time of concentration, filter sediments and other pollutants, and recycle

nutrients. Each development plan should carefully map and identify the existing natural system. Techniques that preserve or protect and enhance the natural features are encouraged. Good designs improve the effectiveness of natural systems rather than negate, replace or ignore them.

8. **In conjunction with new development and redevelopment, coordinated efforts should be made to minimize increases in, and reduce where possible, stormwater runoff volumes, flow rates, and pollutant loads to the maximum extent practicable.** Key practices include:

   - The perviousness of the site and natural drainage paths should be preserved to the extent feasible. Areas conducive to infiltration of runoff should be preserved and integrated into the overall runoff management strategy for the site.

   - The rate of runoff should be slowed. Preference should be given to stormwater management systems that maximize vegetative and pervious land cover. These systems will promote infiltration, filtering and slowing of the runoff. It should be noted that, due to the principle of mass conservation, it is virtually impossible to prevent increases in post-development runoff volumes for all storm events when an area urbanizes. Existing stormwater regulations typically require control of peak flows to predevelopment levels to the maximum extent practicable, and increasingly, regulatory agencies are implementing requirements focused on the control of runoff volumes for smaller, frequently occurring events. Increased flow volumes may not cause flooding problems if a watershed has a positive outfall to a stream or river; however, increases in runoff volumes may cause problems for small, enclosed watersheds (i.e. draining to a lake) or into streams of limited capacity. Increases in runoff volumes, if not appropriately managed, can also adversely affect stream stability.

   - Pollution control is best accomplished by implementing a series of measures, which can include source controls, minimizing directly connected impervious area, and construction of on-site and regional facilities to control both runoff and pollution. Implementing measures that reduce the volume of runoff produced by frequently occurring events through infiltration and disconnection of impervious areas is one of the most effective means for reducing the pollutant load delivered to receiving waters.

9. **The stormwater management system should be designed beginning with the outlet or point of outflow from the project, giving full consideration to downstream effects and the effects of off-site flows entering the system.** The downstream conveyance system should be evaluated to ensure that it has sufficient capacity to accept design discharges without adverse upstream or downstream impacts such as flooding, stream bank erosion, and sediment deposition. In addition, the design of a drainage system should take into account the runoff from upstream sites, recognizing their future development runoff potential (e.g., imperviousness).

10. **The stormwater management system requires regular maintenance.** Failure to provide proper maintenance reduces both the hydraulic capacity and pollutant removal efficiency of the system. The key to effective maintenance is clear assignment of responsibilities to an established entity and a regular schedule of inspections to determine maintenance needs and to ensure that required maintenance is conducted. Local maintenance capabilities should be a consideration when selecting specific design criteria for a given site or project.

11. **Floodplains should be preserved whenever feasible and practicable.** Nature has claimed a prescriptive easement for floods, via its floodplains, that cannot be denied without public and private cost. Floodplain encroachment must not be allowed unless competent engineering and planning have proven that flow capacity is maintained, risks of flooding are defined, and risks to life and property are strictly minimized. Preservation of floodplains is a policy of UDFCD to manage flood hazards,

preserve habitat and open space, create a more livable urban environment, and protect the public health, safety, and welfare (White 1945).

12. **Reserve sufficient right-of-way for lateral movement of incised floodplains.** Whenever an urban floodplain is contained within a narrow non-engineered channel, its lateral movement over time can cause extensive damage to public and private structures and facilities. For this reason, whenever such a condition exists, it is recommended that, at a minimum, the channel be provided with grade control structures and a right-of-way corridor be preserved of a width corresponding to normal depth calculations for the future stable channel geometry, plus maintenance access requirements.

1.2 Basic Hydrologic Data Collection Policies

1. A program for collecting and analyzing storm runoff and flood data should be maintained so that intelligent and orderly planning may be undertaken for storm drainage facilities.

2. A program should be maintained to delineate flood hazard areas along all waterways in urbanized areas and in areas that may be urbanized in the future. This program should make full use of the information and data from the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), private consulting engineers, and the Colorado Water Conservation Board (CWCB). This information should be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, climate change, and the occurrence of extraordinary hydrologic events.

3. Before commencing design of any drainage project, comprehensive facts and data should be collected and examined for the particular watershed and area under consideration, and the basis for the design should then be agreed upon by the governmental entities affected.

1.3 Planning Policies

1. Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design must be compatible with comprehensive regional plans. A master plan for storm drainage should be developed and maintained in an up-to-date fashion at all times for each urbanizing drainage watershed.

2. The planning for drainage facilities should be coordinated with planning for open space and transportation. By coordinating these efforts, new opportunities may be identified that can help solve drainage problems. Natural streams should be used to convey storm runoff wherever feasible. Major consideration must be given to the floodplains and open space requirements of the area (White 1945).

3. Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.

4. Storage of runoff in detention and retention reservoirs can reduce the drainage conveyance capacity

Accessing UDFCD Hydrologic Data, Floodplain Maps and Flood Alert System

Much of the hydrologic data originally envisioned in the 1960s is now readily available on the UDFCD website (www.udfcd.org) and is accessible for developers, engineers, local governments, and the general public.

requirement immediately downstream. Acquisition of open space adjacent to streams provides areas where storm runoff can spread out and be stored for slower delivery downstream.

5. Runoff from small, frequently occurring storms should be managed to reduce runoff peak flows, volumes (where feasible) and pollutant loading to streams. Management of these frequently occurring events helps to protect beneficial uses of streams and promotes channel stability.

1.4 Technical Criteria

- Storm drainage planning and design should follow the criteria developed and presented in this Urban Storm Drainage Criteria Manual (USDCM).

- Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. To provide for orderly urban growth, reduce costs to future generations and avoid loss of life and major property damage, both systems must be properly planned, engineered and maintained.

- The determination of runoff magnitude should be by the Rational Formula, the Colorado Urban Hydrograph Procedure (CUHP), or statistical analyses based on an adequate record of actual measured flood occurrences as set forth in the Runoff chapter of this manual. The method of statistical analysis is very problematic for watersheds that lack stationarity, (i.e., have been altered via urbanization or other physical changes over the record of measured floods).

- Use of streets for urban drainage should fully recognize that the primary use of streets is for traffic. Streets should not be used as floodways for initial storm runoff. Usability of the street during minor storms and reduction of street maintenance costs should be objectives of urban drainage design.

- Irrigation ditches should not be used as outfall points for initial or major drainage systems, unless such use is shown to be without unreasonable hazard, as substantiated by thorough hydraulic engineering analysis, and written approval of the ditch owner(s) is obtained. In addition, irrigation ditches cannot be relied on to mitigate upstream runoff.

- Proper design and construction of stormwater detention basins and retention ponds is necessary to minimize future maintenance and operating costs and to avoid public nuisances, health hazards, and safety hazards. This is particularly important, given the many detention and retention facilities in an urban area.

- Management of runoff from frequently occurring storm events should include four steps: 1) employing runoff reduction practices, 2) implementing best management practices (BMPs) that provide a water quality capture volume with slow release and/or infiltration, 3) stabilizing streams and 4) implementing site-specific and other source control BMPs, as needed. See Chapter 1, Volume 3 of the USDCM for additional information on the four-step process.

- The various governmental entities within the UDFCD boundary have adopted floodplain management programs, which must be maintained over the long-term. Floodplain management must encompass comprehensive criteria designed to encourage the adoption of permanent measures that will lessen the

- Exposure of life, property and facilities to flood losses, improve the long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned and economically unjustifiable future development in such areas.

1.5 Flood Insurance Policy

Flood insurance is an integral part of the strategy to manage flood losses. UDFCD encourages the continued participation of local governments in the National Flood Insurance Program, as set forth in the National Flood Insurance Act (NFIA) of 1968, as amended.

1.6 Levee Policy

1. UDFCD strongly discourages local governments from authorizing or permitting the use of levees in regard to new development in flood hazard areas.

2. UDFCD will consider levees to protect existing development only as a last resort when no other mitigation option is feasible.

1.7 Criteria Implementation Policies

1. The USDCM should continue to be adopted by all governmental entities operating within the UDFCD boundary (Figure 1-1).

2. Each level of government is encouraged to participate in a successful drainage program.

3. Problems in urban drainage administration encountered by governmental entities can be reviewed by UDFCD to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments. The financing of storm drainage improvements is fundamentally the responsibility of the affected property owners—both those directly affected by the water and those from whose land the water flows.

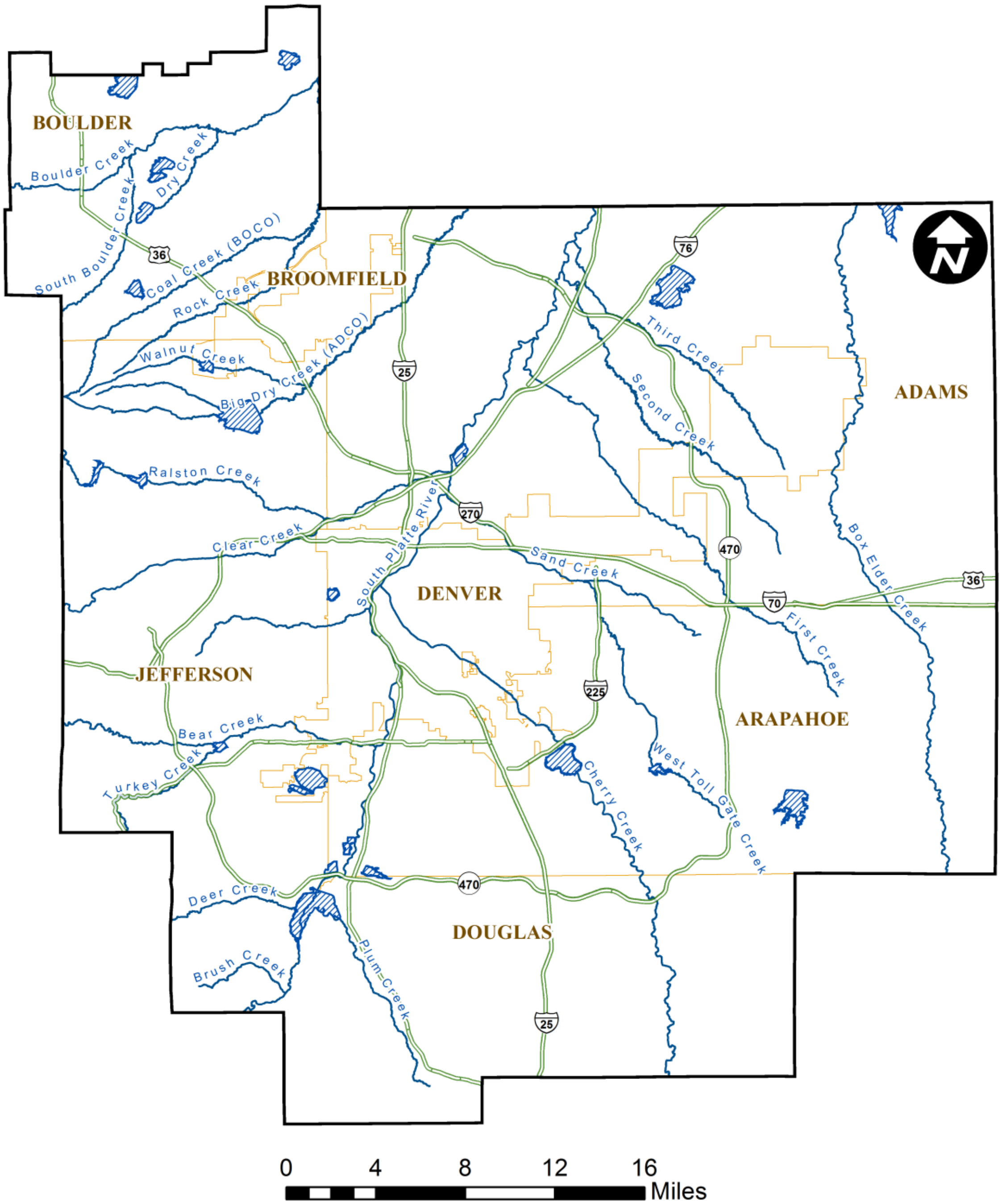

Figure 1-1. Urban Drainage and Flood Control District (UDFCD) boundary

2.0 UDFCD Hydrologic Data Collection

A well developed and systematic inventory of basic hydrologic data and knowledge provides the foundation for sound decision making that protects the public health, safety and welfare and results in effective use of public funds. Prior to the commencement of any drainage project, comprehensive facts and data are collected and examined for the particular watershed and area under consideration. The following key information leads to scientifically-based and cost-effective drainage planning:

- **Data Collection Program**. An important step in a drainage program is to get the facts. A program for collecting and analyzing storm runoff and flood data is maintained to promote intelligent and orderly planning (Jones 1967).

- **Storm Runoff and Flood Damage Data**. Storm runoff and flood damage data should be collected in a systematic and uniform manner.

- **Rainfall-Runoff Characterization**. A program is maintained to collect and analyze rainfall-runoff relationships in urbanized portions of the UDFCD boundary.

- **Inventory of Successful Projects**. Some drainage projects function better than others. It is important to determine why, so that key features may be identified for use on future projects.

- **Publically Accessible UDFCD Library**. As a key component of UDFCD's education and outreach program, UDFCD actively maintains an electronic library of drainage master planning studies, as-built drawings, maps, hydrologic data and guidance documents, which is available for use by all governmental entities, planners, and engineers. The public is encouraged to access this library through the UDFCD website (www.udfcd.org). Additionally, archived material (hydrologic and hydraulic models, master planning study technical appendices, etc.) may be made available by email request to udfcd@udfcd.org.

- **Runoff Magnitude Records**. Where practical, the magnitude of computed and measured runoff peaks is tabulated for UDFCD streams and gulches so that comparisons may be readily made between watersheds and erroneous values may be more easily identified.

- **Floodplain Data**. A program to delineate flood hazard areas along all waterways within the UDFCD boundary is maintained by UDFCD. This program makes full use of UDFCD's Flood Hazard Area Delineation (FHAD) studies, FEMA Flood Insurance Studies, Natural Resources Conservation Service and USGS data, and floodplain studies by others. This information is regularly reviewed and updated to reflect changes due to urbanization, changed stream conditions, and the occurrence of extraordinary hydrologic events.

    - **Small Streams**. Small streams and other waterways, which are often overlooked, have a large damage potential. These waterways should receive early attention in areas subject to urbanization. Floodplain information should be shown on preliminary and final subdivision plats, including the areas inundated by major storm runoff and areas of potential erosion.

    - **Central UDFCD Database**. Floodplain data and mapping is stored in a central UDFCD depository available to all planners, developers, and engineers. All floodplain mapping, master planning documents, and FHADs, as well as many, design reports, as-builts and other UDFCD documents, are now available online in a database that is searchable by waterway, document type, keywords, etc.

- **Floodplains**. Floodplain management efforts should focus on developing information in areas that have a one percent chance of being inundated in any given year—that is, the 100-year floodplain. Local governmental entities may choose to regulate floodplains for other frequencies of flooding; however, the 100-year floodplain based on runoff from the projected fully urbanized watershed must be defined and is the minimum basis for regulation.

- **Priority for Data Acquisition**. UDFCD has established priorities for data acquisition because it recognizes that not all of the desired data can be collected at one time. When setting priorities, consideration is given to 1) areas of rapid urban growth, 2) drainage problem areas, 3) local interest and capabilities in floodplain management, and 4) the potential for developing high-quality, robust data sets.

3.0 Planning

3.1 Total Urban System

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design should be compatible with comprehensive regional plans. Master plans for storm drainage have been developed and are maintained in an up-to-date fashion for most of the watersheds in the UDFCD region. An effort to complete the coverage of master plans for yet unplanned areas of UDFCD should be continued until full coverage is achieved.

Evolution of UDFCD Master Planning Program

"Initially, master planning was aimed at reducing flood potential in areas already developed. Now, much of our time is also spent on growth areas, working to prevent flood problems from ever occurring."

—Ben Urbonas, UDFCD Master Planning Program Manager from 1976 to 2008.

3.1.1 Planning Process Elements

Good urban drainage planning is a complex process. Fundamentals include:

1. **Major Drainage Planning:** Local and regional planning should consider the major drainage system necessary to manage the 100-year runoff; that is the runoff having a one percent probability of occurrence in any given year. Implementation of major drainage plans will reduce loss of life and major damage to the community and its infrastructure.

2. **Outfall System Planning:** Outfall system planning efforts identify detention, water quality and conveyance practices within a watershed that ultimately discharges to a receiving stream. Outfall system plans typically address storm drain improvements, stream crossing improvements, stream enlargement, stabilization, and floodplain preservation.

3. **Initial Drainage System Planning:** All local and regional planning should consider the initial drainage system to transport the runoff from 2-year to 5-year storms; these storms have a 50% to 20% respective probability of occurrence in any given year. The planner of an initial system must strive to minimize future drainage problems from these more frequently occurring storms.

4. **Water Quality and Environmental Design:** All planning efforts should address stormwater quality treatment requirements, opportunities for the development to mimic natural hydrology and preserve natural features, enhance habitat, and evaluate impacts of new facilities. When convened early in the planning and design process, a multi-disciplinary design team can help to ensure that the benefits to total urban systems are considered in the drainage planning effort.

5. **Long-term Maintenance and Operation**: Future operation and maintenance by private and public entities needs to be considered during the planning stages to ensure that the facility functions as designed over the long-term.

3.1.2 Master Planning

Drainage design does not lend itself to a piecemeal approach; therefore, master plans for drainage should be prepared on a prioritized basis. Such plans already cover most of the developed watersheds within in the UDFCD boundary. Additional plans will be developed for areas yet unplanned. In addition, existing master plans will be updated as needed to reflect conditions that change over time.

Initial steps include the planning of major drainage systems from the point of outfall, proceeding in an upstream direction. Major drainage systems, which are defined as servicing an area of at least 130 acres, are typically well defined and often dictate the design of the initial drainage system, including storm drains, detention facilities, and stormwater quality BMPs.

Master planning must be based upon potential future upstream development, taking into consideration both upstream and downstream existing and future regional publicly owned and operated (or controlled) detention and retention storage facilities. Assurances for construction and perpetual operation and maintenance of detention and retention facilities must be provided for the effects of the facilities to be considered in master planning. In the absence of such detention and retention facilities, the basis of design for both the initial and major systems is fully developed upstream conditions without storage.

Each municipality and county within UDFCD’s boundary is responsible for master planning urban storm drainage facilities within its jurisdiction. UDFCD can help to coordinate efforts. Cooperation between governmental entities is needed to solve drainage problems, and joint city, county and UDFCD efforts are encouraged. Master planning is best accomplished on a systematic priority basis so that the most demanding problems, such as areas of rapid urbanization, are addressed first.

UDFCD has established a standard format for master plan reports and drawings so that a uniform planning approach and coordination of efforts can occur more easily. Master planning should be completed in adequate detail to provide a clear drainage framework for future development in a particular watershed. Generalized concepts based on rough hydrological analyses should not be used as master plans; a more rigorous analysis is necessary.

3.1.3 Floodplain Easements

A master plan should be prepared prior to development in a watershed. Where development occurs in a watershed in advance of a master plan, flood easements should be retained for the 100-year floodplain. If available the future conditions 100-year floodplain should be used for this purpose. Where an existing master plan recommends the preservation of a defined floodplain, every effort should be made to acquire and/or preserve an easement or property right (ownership) for such a floodplain.

Photograph 1-2. National Medal of Science winner, Dr. Gilbert White, recommended naturalistic floodplains because they save people from damages and are good for the economy and the environment.

On any floodplain, nature possesses an

intrinsic easement for intermittent occupancy by runoff waters. Humans can deny this easement only with difficulty. Encroachments upon, or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during nature's inevitable periodic occupancy of this easement. Floodplain regulations, therefore, must define natural easements and boundaries and must delineate floodplain and floodways that are consistent with the overall public interest.

3.1.4 Local and Regional Planning

Local and regional planning, whether performed under federal or state assistance programs or under completely local auspices, should consider and evaluate opportunities for multi-objective water resources management.

3.1.5 Development and Site Planning

All land development proposals should receive full site planning and engineering analyses. In this regard, professional consideration must be given to the criteria outlined in this manual. Development of an area without the provision of adequate drainage multiplies the cost to the public because the drainage problem must be corrected later, usually at public expense. Where flood hazards are involved, local planning boards should consider proposed land use so that it is compatible with the flood hazard risks involved with the property, and appropriate easements should be provided to preclude encroachment upon waterways or flood storage areas.

A development plan should consider broad goals such as:

- Drainage and flood control problem alleviation,
- Economic reasonableness,
- Broader regional development context,
- Environmental preservation and enhancement, considering water quality and stream stability,
- Social and recreational objectives.

Photograph 1-3. An urban storm drainage strategy should be a multi-objective and multi-means effort.

These goals have the potential to influence the type of drainage subsystem selected. Planning for drainage facilities should be related to the goals of the urban region, should be looked upon as a subsystem of the total urban system, and should not proceed independent of these considerations (Wright 1967).

3.1.6 Managing Runoff from Frequently Occurring Storms

Protecting and enhancing the water quality of streams is an important objective of drainage planning. Erosion control, maintaining stream stability, and reducing pollutant loading from stormwater runoff must be considered. Volume 3 of the USDCM provides criteria for stormwater runoff BMPs that help to reduce runoff volumes for frequently occurring storm events and provide treatment of the water quality capture volume (WQCV), which is based on the 80th percentile runoff-producing event.

The first step in managing runoff from frequently occurring storms is implementing runoff reductions

Common Stormwater Quality Terms and Concepts

Best Management Practice (BMP): A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters. (Some entities use the terms "Stormwater Control Measure" or "Stormwater Control.")

Low Impact Development (LID): LID is a comprehensive land planning and engineering design approach to managing stormwater runoff with the goal of mimicking the pre-development hydrologic regime. LID emphasizes conservation of natural features and use of engineered, on-site, small-scale hydrologic controls that infiltrate, filter, store, evaporate, and detain runoff close to its source.

Minimizing Directly Connected Impervious Area (MDCIA): MDCIA includes a variety of runoff reduction strategies based on reducing impervious areas and routing runoff from impervious surfaces over grassy areas to slow runoff and promote infiltration. MDCIA is recommended as a key technique for reducing runoff peaks and volumes for frequently-occurring storms following urbanization. MDCIA is a key component of LID.

Green Infrastructure: Planning and design of systems intended to benefit from the services and functions provided in the natural environment. In regard to wet weather management, and on a regional scale, preservation of riparian floodplains and channel stabilization that allows for vital habitat and wildlife passage through techniques similar to those found in nature, preserves ecological function and creates balance between built and natural environments. On an urban level, wet weather management practices that include infiltration, evapotranspiration, and reuse to help restore natural hydrology.

Water Quality Capture Volume (WQCV): This volume represents runoff from frequent storm events such as the 80th percentile runoff-producing event. The volume varies depending on local rainfall data. Within the UDFCD boundary, the WQCV is based on runoff from 0.6 inches of precipitation.

Excess Urban Runoff Volume (EURV): EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff (generally greater than the 2-year event for pervious land surfaces). The EURV is relatively constant for a given imperviousness over a wide range of storm events.

Full Spectrum Detention: This practice utilizes capture and slow release of the EURV. UDFCD has found this method better replicates historic peak discharges for the full range of storm events compared to multi-stage detention practices.

practices, also known as *minimizing directly connected impervious area* (MDCIA), which reduces the amount and connectivity of impervious surfaces in a development. This can be accomplished through a variety of techniques such as functional grading, wide and shallow surface flow sections, disconnection of hydrologic flow paths, and the use of bioretention and permeable pavements. The extent to which MDCIA and runoff reduction can be implemented on a development site is dependent on the site conditions (e.g., soil type, groundwater depth, depth to bedrock) and development type (e.g., new development, redevelopment, ultra urban, infill,). Opportunities for runoff reduction should be evaluated in each development. Once this step has been completed, then BMPs designed to treat the remaining WQCV can be implemented. An alternative to treating the WQCV is use of an integrated detention and water quality detention facility based on capture and treatment of the Excess Urban Runoff Volume (EURV). Design criteria for these facilities, described as full spectrum detention facilities, are provided in the *Storage* chapter.

3.1.7 Separation of Stormwater and Sanitary Flows

Sanitary sewage systems that overflow or bypass untreated sewage into surface streams are not permitted in Colorado. Drainage planning should prevent inflow to sanitary sewers resulting from street flow and channel flooding. In cases where sanitary sewers are flooded by urban storm runoff, engineers and planners should work together to correct these problems. Additionally, illegal connections of sanitary sewers to the storm drain system or conditions where storm drains intercept flows from leaking sanitary sewers must be corrected to protect public health.

3.2 Multiple-Objective Considerations

Planning for drainage facilities should be coordinated with planning for open space, recreation and transportation. By coordinating these efforts, new opportunities can be identified which can assist in the solution of drainage problems (Heaney, Pitt and Field 1999).

1. **Lower Drainage Costs**. Planning drainage works in conjunction with other urban needs results in more orderly development and lower costs for drainage and other facilities.

2. **Open Space**. Open space provides significant urban social and environmental benefits. Use of stabilized, natural streams is often less costly than constructing artificial channels. Combining the open space needs of a community with the major drainage system is a desirable combination of uses that reduces land costs and promotes riparian zone protection and establishment over time.

3. **Transportation**. Design and construction of new streets and highways should be fully integrated with drainage needs of the urban area for better streets and highways and better drainages and to avoid creation of flooding hazards. The location of borrow pits needed for road construction should be integrated with broad planning objectives, including storm runoff detention.

4. **Natural Channels**. Natural streams should be used in lieu of storm drains for stormwater runoff wherever practical. Preservation and protection of natural streams are encouraged; however, significant consideration must be given to their stability as the tributary area urbanizes.

5. **Channelization**. Natural streams within an urbanizing area are often deepened, straightened, lined, and sometimes put underground. A community loses a natural asset when this happens. Channelizing a natural waterway usually speeds up the flow, causing greater downstream flood peaks and higher drainage costs, and does nothing to enhance the environment. Natural streams within an urbanizing area require stabilization, not channelization.

6. **Channel Storage**. Streams having "slow-flow" characteristics, vegetated bottoms and sides, and wide water surfaces provide significant floodplain storage capacity. This storage is beneficial because it reduces downstream runoff peaks and provides an opportunity for groundwater recharge. Wetland channels, wide natural streams, and adjacent floodplains provide urban open space.

Photograph 1-4. Streams having "slow-flow" characteristics with vegetated bottoms and sides can provide many benefits.

7. **Major Runoff Capacity**. Streams and their residual floodplains should be capable of carrying the 100-year storm runoff, which can be expected to have a one percent chance of occurring in any given year.

8. **Maintenance and Maintenance Access**. Urban streams require both scheduled and unscheduled maintenance activities such as removal of sediment, debris and trash; mowing, and repair of hydraulic structures. Assured long term maintenance is essential, and it must be addressed during planning and design. UDFCD assists with drainage facility maintenance, provided that the facilities are designed and constructed in accordance with the UDFCD's Maintenance Eligibility Guidelines. The most current version of these guidelines may be obtained from UDFCD's website (www.udfcd.org). Designers are strongly encouraged to adhere to the design criteria listed in the Maintenance Eligibility Guidelines. Waterways, detention facilities, and other drainage facilities must have permanent access for routine and major maintenance activities.

3.3 Avoiding Transfer of Problems

Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another. Both intra-watershed and inter-watershed transfers

Multi-purpose Values of Urban Stream Corridors

"Urban stream corridors provide many critical functions in the life of a community. During storm events, they function as conveyance systems for storm runoff. Floodplain managers have a keen interest in making this function as reliable and safe as possible. But, urban stream corridors are much more. Their linear nature is well suited to trails and a variety of recreational activities. Human beings are naturally drawn to water and the natural environment. Moreover, Coloradoans seek an active outdoor lifestyle and value natural areas for beauty and the appreciation of wildlife. Urban streams also provide an immense ecological resource and are central to the natural processes that support the environment. Thus, thoughtful treatment of these natural systems creates community assets that are important to local governments and developers as they plan new projects and especially to the future residents. Therefore, trails, recreational activities, floodplain, wetland, and riparian preservation are critical community values."

—Bill DeGroot, UDFCD Floodplain Management Program Manager (1974- 2014) should be avoided and appropriate assumptions should be made during master planning to avoid transfer of problems. Key principles include:

1. **Intra-Watershed Transfer**: Channel modifications that create unnecessary problems downstream should be avoided, both for the benefit of the public and to avoid damage to private parties. Problems to avoid include land and channel erosion and downstream sediment deposition, increase of runoff peaks, and debris transport, among others.

2. **Inter-Watershed Transfer:** Diversion of storm runoff from one watershed to another introduces significant legal and social problems and should be avoided unless specific and prudent reasons justify and dictate such a transfer and no measurable damages occur to the natural receiving water or urban systems or to the public.

3.4 Detention and Retention Storage

Stormwater runoff can be stored in detention basins and retention ponds. Such storage, when properly designed, constructed, and maintained with adequate assurances for the long-term, can reduce the peak flow drainage capacity required, thereby reducing the land area and expenditures required downstream. Retention ponds, both on and off-line, require a legal right to store water in Colorado. Consultation with the State Engineer’s Office is needed in such cases.

Photograph 1-5. Retention ponds with permanent ponding have many benefits, including flood reduction, water quality and land values.

3.4.1 Upstream Storage

Provide temporary storage of storm runoff close to the points of rainfall occurrence to the extent practical. Opportunities for storage include on-site detention basins and retention ponds, parking lots, ball fields, property line swales, parks, road embankments, and borrow pits. Wherever reasonably acceptable from a social standpoint, parks should be used for short-term detention of storm runoff. Such use may help justify park and greenbelt acquisition and expenditures. This "Blue-Green" concept was introduced in the 1960’s (Jones 1967) and remains an effective strategy in drainage planning.

Parking lots create more runoff volume and higher runoff rates than natural conditions. Where practical, parking lots should be designed to provide temporary storage of runoff during infrequent events (e.g., 5-year or greater).

Due to the difficulty in quantifying the cumulative effects of very large numbers of small (i.e., on-site) detention/retention facilities (Malcomb 1982; Urbonas and Glidden 1983) and the challenge of assurance of their continued long-term performance or existence (Debo 1982; Prommersberger 1984), UDFCD recognizes only regional, publicly owned (or controlled) facilities in its floodplain management program.

3.4.2 Downstream Storage

Detention and retention of storm runoff is desirable in slow-flow channels, in storage facilities located in the stream, in off-line facilities, and by using planned channel overflow ponding in park and greenbelt areas. Lengthening the time of concentration of storm runoff to a downstream point is an important goal of storm drainage and flood control strategies.

3.4.3 Reliance on Privately Controlled Facilities and Water Storage Reservoirs

Privately controlled facilities cannot be used for flood mitigation purposes in master planning because their perpetuity cannot be reasonably guaranteed. Additionally, publicly owned water storage reservoirs (city, state, water district, irrigation company, etc.) should be assumed to be full for flood planning purposes and only the detention storage above the spillway crest considered in the determination of downstream flood peak flows. Exceptions may occur where legal agreements are in place ensuring flood storage in perpetuity.

3.4.4 Reliance on Embankments

The detention of floodwaters behind embankments created by railroads, highways or roadways resulting from hydraulically undersized culverts or bridges should not be utilized for flood peak mitigation when determining the downstream flood peaks for channel capacity purposes unless such detention has been established in perpetuity through a legally binding agreement.

4.0 Technical Criteria

4.1 Intended Use of Design Criteria

Storm drainage planning and design should adhere to the criteria developed and presented in this manual. The design criteria presented herein represent current best engineering practice, and their use in the region is recommended. The criteria are not intended to be an ironclad set of rules that the planner and designer must follow; they are intended to establish guidelines, standards and methods for sound planning and design. UDFCD revises and updates the criteria as necessary to reflect advances in the field of urban drainage engineering and urban water resources management.

Governmental entities and engineers should utilize the USDCM in planning new facilities and in their reviews of proposed works by developers, private parties, and other governmental entities, including the Colorado Department of Transportation and other agencies of the state and federal governments.

4.2 Initial and Major Drainage Criteria

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. Both systems must be planned and properly engineered to provide for orderly urban growth, reduce costs to future generations, and avoid loss of life and major property damage.

4.2.1 Design Storm Return Periods for Initial and Major Drainage Systems

Storm drainage planning and design should fully recognize the need for two separate and distinct storm drainage systems: the initial drainage system and the major drainage system. Recommended design storms for the initial and major drainage systems are specified in Table 1-1. Local governments should not be tempted to specify larger than necessary design runoff criteria for the initial drainage system because of the direct impact on the cost of urban infrastructure.

Normally, the initial drainage system cannot economically carry major storm runoff, though the major drainage system can provide for the initial runoff. A well-planned major drainage system will reduce or eliminate the need for storm drain systems (Jones 1967). Systems consisting of underground pipes are a part of initial storm drainage systems.

Table 1-1. Design storms and purposes of initial and major drainage systems

Drainage System	**Design Storm**	**Purposes**
Initial Drainage System	2- to 5-year floods (depends on local criteria)	Reduce the frequency of street flooding and maintenance costs, provide protection against regularly recurring damage from storm runoff, help create an orderly urban system, and provide convenience to urban residents.
Major Drainage System	100-year flood (1% probability of occurrence for any given year)	Avoid major property damage and loss of life for the storm runoff expected to occur from an urbanized watershed.

There are many developed areas within the UDFCD boundary that predate and do not fully conform to the drainage standards in Table 1-1. Flooding problems experienced in such areas were a key reason for the original development of the USDCM. UDFCD recognizes that upgrading already developed areas to conform to all of the policies, criteria, and standards contained in the USDCM will be difficult, if not impractical to obtain, short of complete redevelopment or renewal. However, flood risk management techniques can be applied to these areas.

Strict application of the USDCM in the overall planning of new development is practical and economical; however, when planning drainage improvements and designating floodplains for developed areas, the use of the policies, criteria, and standards contained in the USDCM should be adjusted to provide for economical and environmentally sound solutions consistent with other goals of the area. Where the 100-year storm is not chosen for design purposes, the residual impact of the 100-year storm should be investigated and made known.

4.2.2 Critical Facilities

Drainage engineers and planners should consider that certain critical facilities may need a higher level of flood protection. For instance, hospitals, police, fire stations and emergency communication centers should be designed in a manner so that their functioning will not be compromised, even during a 100-year flood. The use of a 500-year flood level for such facilities may be justified (and required by State floodplain regulations) in many instances.

4.2.3 Runoff Computations

The determination of runoff magnitude should be made using the techniques described in the *Runoff* chapter.

> **Master Plan Hydrology**
>
> Published peak flows should only be changed when it is clear either an error was made or a recalibration of the regional hydrologic model impacts the area of study and, in either case, when continued use of the published flows is not in the public's interest.

The peak discharges determined by any method are approximations. Rarely will drainage works operate at the design discharge. In actual practice, flow will always be more or less, as the hydrograph rises and falls during a storm event. Thus, the engineer should not overemphasize the detailed accuracy and precision of computed discharges but should emphasize the design of practical and hydraulically balanced drainage infrastructure based on sound logic and engineering, as well as dependable hydrology. The use of more than three significant figures for estimating peak discharges conveys a false sense of precision and should be avoided.

Because of the public's reliance on published peak flow estimates, these values should be changed only when it is clear either an error was made or a recalibration of the regional hydrologic model impacts the area of study and, in either case, when continued use of the published flows is not in the public's interest.

4.2.4 Joint Probability Computations

The depth of flow in the receiving stream must be taken into consideration for backwater computations for both the initial and major storm runoff. An analysis of the joint probability of occurrence may be warranted. FEMA recommends modeling a 10-year water surface in the receiving stream for a 100-year tributary discharge. HEC-22 also provides guidance based on the ratio of main stream watershed area to that of the tributary stream.

4.2.5 Open Channels for Major Drainage

Open channels for transporting major storm runoff are more desirable than underground conduits, and use of such is encouraged. Open conveyance planning and design objectives are often best met by using naturalized streams (as described in the *Open Channels* chapter), which characteristically have slower velocities and large width-to-depth ratios. Additional benefits can be obtained by incorporating parks and greenbelts with the naturalized stream layout. Use of naturalized streams (and other storm runoff features) should be considered in the early planning stages of a new development.

When evaluating existing natural water courses (perennial, intermittent and ephemeral), straightening, fill placement, and other alterations should be minimized and carefully evaluated. Such actions tend to reduce flood storage and increase the velocity to the detriment of those downstream of and adjacent to the channel work. Effort should be made to reduce flood peaks and control erosion so that the natural channel regime is preserved as much as practical. Some type of structural stream stabilization is almost always necessary to stabilize the stream against increased flows associated with urbanization. For example, grade control structures and structural protection at the stream toe and on the outer banks at bends are normally required. Riparian buffer zones can be used to accommodate future meandering and bank sloughing, at least in part.

4.3 Use of Streets

Streets are a significant component of the urban drainage system, and use of streets for storm runoff should be made within reasonable limits, recognizing that the primary purpose of streets is for traffic. Reasonable limits of the use of streets for conveyance of storm runoff should be governed by design criteria summarized in Table 1-2 for initial storm runoff, Table 1-3 for major storm runoff and Table 1-4 for allowable maximum cross-street flow for initial and major design storm runoff. These criteria are consistent with the intent that major storm runoff will be removed from public streets at frequent and regular intervals and routed into streams, as well as the recognition that runoff tends to follow streets and roadways; therefore, streets and roadways may be aligned to provide a specific runoff conveyance function.

Table 1-2. Reasonable use of streets for initial storm runoff in terms of pavement encroachment

Street Classification	Maximum Encroachment
Local	No curb overtopping. Flow may spread to crown of street.
Collector	No curb overtopping. Flow spread must leave at least one lane free of water.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction but should not flood more than two lanes in each direction.
Freeway	No encroachment is allowed on any traffic lanes.

Table 1-3. Major storm maximum street ponding depth

Street Classification	Maximum Ponding Depth
Local and Collector	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water over the gutter flow line should not exceed 12 inches for local and collector streets.
Arterial and Freeway	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 inches.

Table 1-4. Maximum allowable cross-street flows

Street Classification	Initial Design Runoff	Major Design Runoff
Local	6 inches of depth in cross pan	12 inches of depth above gutter flow line.
Collector	Where cross pans allowed, depth of flow should not exceed 6 inches	12 inches of depth above gutter flow line.
Arterial/Freeway	None	No cross flow. 12 inches of maximum depth at upstream gutter or roadway. edge

Initial and major drainage planning should go hand-in-hand. When maximum allowable street encroachment will be exceeded, a storm drain system based on the initial storm should be planned. Development of a major drainage system that can also drain the initial runoff from the streets is encouraged; this enables the storm drain system to commence further downstream.

Other design criteria for use of streets include:

- An arterial street crossing will generally require a storm drain system.
- Bubblers (inverted siphons which convey flows beneath roadways) are discouraged because of plugging with sediment and difficulty in maintaining them. Additionally, these serve as a breeding ground for bacteria and mosquitos.
- Collector streets should have cross pans only at infrequent locations as specified by the governing entity and in accordance with good traffic engineering practices.
- The local street criteria for overtopping also apply to any private access road that serves commercial areas or more than one residence, for emergency access and safety reasons.
- Drainage design objectives for streets should include reducing street repair and maintenance costs, minimizing nuisance to the public, and minimizing frequent disruption of traffic flow.

4.4 Use of Irrigation Ditches

Use of irrigation ditches for collection and transport of either initial or major storm runoff should be prohibited unless specifically provided in a UDFCD master plan or approved by UDFCD and the ditch owner, following adequate hydraulic engineering analysis that demonstrates such use is without unreasonable hazard.

Irrigation ditches are typically characterized by flat slopes and limited carrying capacity. Experience and hydraulic calculations demonstrate that these physical limitations generally preclude use of ditches as an outfall point for the initial storm drainage system. Exceptions to the rule can occur when the capacity of the irrigation ditch is adequate to carry the normal ditch flow plus the initial storm runoff with adequate freeboard to avoid creating a hazard to those below the ditch. In such cases, written approval must be obtained from the ditch owner stating that the owner understands the physical and legal (i.e., liability) consequences of accepting such runoff.

Irrigation ditches are not suitable as an outfall for the major storm runoff. Without major reworking of irrigation ditches to provide major carrying capacity without undue hazard to those downstream or below the ditch, the ditches are almost always totally inadequate for such a use and should not be used as an outfall. Moreover, because ditches are normally privately owned, one cannot assume the perpetual existence or function of a ditch.

Other irrigation ditch-related considerations include:

- Land planners downhill from a ditch should ignore the effects of the ditch in hydrologic calculations, but should also plan for continued ditch seepage.
- Irrigation ditches are sometimes abandoned in urban areas after the agricultural land is no longer farmed. Provisions must be made for a ditch’s perpetuation, defined as continued operation,

capacity, and serviceability, prior to its being chosen and used as an outfall for urban drainage.

4.5 Water Quality Treatment

Stormwater quality BMPs are designed based on either the Water Quality Capture Volume (WQCV) or the Excess Urban Runoff Volume (EURV):

- **WQCV**: The WQCV, as described in detail in Volume 3 of the USDCM, corresponds to approximately the 80th percentile runoff event and is used in BMPs designed for water quality purposes only. It is appropriate to size BMPs for the entire area tributary to the BMP. The release rate for the WQCV varies based on the type of BMP.

- **EURV**: The EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff (generally greater than the 2-year event from pervious land surfaces). The EURV is relatively constant for a given imperviousness over a wide range of storm events. The EURV is a greater volume than the WQCV and is detained over the minimum time necessary to allow for the recommended drain time of the WQCV, and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with Full Spectrum Detention, a simplified sizing method for both water quality and flood control detention. EURV calculation procedures are provided in the *Storage* Chapter.

4.6 Maintenance of Storage and Water Quality Facilities

Long-term maintenance provisions must be arranged for storage and water quality facilities. Maintenance of detention or retention facilities includes the removal of debris, excessive vegetation from the embankment, and sediment. Maintenance requirements for water quality facilities (BMPs) vary, depending on the BMP type, as described in Chapter 6, Volume 3 of the USDCM. Without maintenance, detention, retention, and water quality facilities will become unsightly social liabilities and eventually become ineffective for their intended functions.

5.0 Floodplain Management

5.1 Purpose

Governmental entities within the UDFCD area should continue to implement floodplain management programs. Floodplain management includes comprehensive criteria designed to encourage, where necessary, the adoption of permanent state or local measures which will lessen exposure of life, property and facilities to flood losses, improve long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned future development in such areas.

Floodplain Management

"Preventing new flood damage potential is not only a critical function of any total flood control program, it is typically the surest, most cost-effective way to reduce total annual losses from flooding. Prevention requires adhering to a well-documented, well-understood drainage philosophy that encourages utilization of non-structural methods of flood damage mitigation. Sensible land use regulations coupled with defined floodplains and drainage master plans keep new flood damage potential from being introduced into the 100-year floodplains."—Bill DeGroot, UDFCD Floodplain Management Program Manager (1974 to 2014)

5.2 Goals

Floodplain management includes these two primary goals:

1. **Reduce the vulnerability of residents to the danger and damage of floods**. The dangers of flooding include threats to life, safety, public health, and mental well-being, as well as damage to properties and infrastructure and disruption of the economy. Protection from these hazards should be provided, by whatever measures are suitable, for floods having a one percent recurrence probability in any given year (100-year floods), at a minimum, based on projected build-out in the watershed. Protection from the effects of greater, less frequent flooding is also needed for critical facilities where such flooding would cause service interruptions or unacceptable damages.

2. **Preserve and enhance the natural values of the floodplain**. Natural floodplains serve society by providing floodwater storage, groundwater recharge, water quality enhancement, passive recreation, and habitat for plants and animals. Many floodplains also have cultural and historical significance. It is in the public's interest to avoid development that destroys these values or, in instances where the public good requires development, to ensure that measures are taken to mitigate the floodplain loss through replacement of floodplain functions or other means.

These two goals are achievable through coordinated floodplain management and drainage planning conducted in a coordinated manner by local governments and other entities.

5.3 National Flood Insurance Program

Flood insurance should be integral part of a strategy to manage flood losses. The cities and counties in the UDFCD area are encouraged to continue to participate in the National Flood Insurance Program (NFIP) set forth in the NFIA of 1968, as amended. A prerequisite for participation is the adoption of a floodplain management program by the local government that, where necessary, includes adoption of permanent state or local regulatory measures that will lessen the exposure of property and facilities to flood losses. Property owners should be encouraged to buy flood insurance, even outside the designated floodplain, to protect against local flooding where such potential exists.

5.4 Floodplain Management

The objectives of floodplain management are to:

1. Adopt effective floodplain regulations.

2. Improve local land use practices, programs, and regulations in flood-prone areas.

3. Provide a balanced program of measures to reduce losses from flooding.

4. Reduce the need for reliance on local and federal disaster relief programs.

5. Minimize adverse water quality impacts.

6. Foster the creation/preservation of greenbelts, with associated societal, water quality, wildlife and other ecological benefits, in urban areas.

The most successful and sustainable way to accomplish all of the above listed objectives is do so while promoting the natural and beneficial uses of the floodplain. The natural and beneficial uses of the floodplain hold political, social, and economic value. Although hydrologic data are critical to the development of a floodplain management program, a successful program is largely dependent on a series of policy, planning, and design decisions. These area-wide decisions provide the setting for floodplain usage and, when combined with hydrologic considerations and augmented by administrative and other implemention devices, constitute a floodplain management program. The program must give high priority to both flood danger and public programs, such as urban renewal, open space, etc. See the Floodplain Preservation Brochure available at www.udfcd.org for additional discussion and good examples of developments designed and constructed with value placed on the natural and beneficial functions of the floodplain.

> "Floods are acts of God, but flood losses are largely acts of man."
>
> –Gilbert White, June 1945

5.5 Floodplain Filling

While floodplain management allows some utilization of the flood fringe (i.e., areas outside of the formal floodway), the planner and engineer should proceed cautiously when planning facilities on lands below the expected elevation of the 100-year flood. Flood peaks from urbanized watersheds are high and short-lived, which makes storage in the flood fringe important and effective. Filling the flood fringe tends to increase downstream peaks.

5.6 New Development

When deciding whether to 1) construct a major flood control project to enable new development or 2) maintain an open area within an urban floodplain, the following factors should be considered:

- Relative costs of the respective alternatives (not only financial, but also non-financial economic costs such as opportunities foregone).
- Opportunities for flood proofing and other measures in relation to the extent of flood hazard.
- Availability of land in non-floodprone areas for needed development.
- Location of the high flood hazard areas, namely, defined floodways.
- Potential adverse effect on others in or adjacent to the floodplain.
- The fact that floods larger than the design flood can and will occur (i.e., some level of risk exposure will still exist, even with well-designed facilities).

5.7 Floodplain Management Strategies and Tools

FEMA has developed a variety of floodplain management strategies and tools, as summarized in Table 1-5. Other strategies and tools may also be used.

Table 1-5. Floodplain management strategies and tools

Strategy	**Brief Description**
Reduce Exposure to Floods	Reduce exposure to floods and disruptions by employing floodplain regulations and local regulations. The latter includes zoning, subdivision regulations, building codes, sanitary and well codes, and disclosure to property buyers.
Development Policies	Development policies that include design and location of utility services, land acquisition, redevelopment, and permanent evacuation (purchase of properties).
Disaster Preparedness	Disaster preparedness is an important tool for safeguarding lives and property, and disaster assistance will reduce the impact to citizens from flooding.
Flood Proofing	Flood proofing of buildings is a technique that is wise and prudent where existing buildings are subject to flooding. Flood proofing can help a proposed project achieve a better benefit-cost ratio.
Flood Forecasting	Flood forecasting and early warning systems are important means to reduce flood losses, safeguard health, protect against loss of life and generally provide an opportunity for people to prepare for a flood event before it strikes.
Flood Modification	The use of methods to modify the severity of the flood is a floodplain management tool. These include regional detention, channelization, minimizing directly connected impervious area, and on-site detention.
Modification of Flood Impacts	The impact of flooding can be mitigated (or modified) though the education, flood insurance, tax adjustments, emergency measures, and a good post-flood recovery plan that can be initiated immediately following a flood.

6.0 Implementation of Urban Storm Drainage Criteria

6.1 Adoption and Use of the USDCM and Master Plans

The USDCM should be adopted and used by local governments operating within the UDFCD boundary, as a resource that:

1. Gives direction to public entity efforts to guide private decisions.

2. Gives direction to public entity efforts to regulate private decisions.

3. Provides a framework for a public entity when it seeks to guide other public entities.

4. Provides a framework to assist in coordinating a range of public and private activities.

5. Provides direction for development of master plans and designs and for implementation of drainage facilities.

Drainage master plans should be completed following the criteria in the USDCM and be adopted and implemented by all governmental entities within the master plan boundaries.

6.2 Governmental Participation

Each level of government must participate if a drainage program is to be successful.

6.3 Amendments to Criteria

Problems in urban drainage administration encountered by any governmental entity should be reviewed by UDFCD to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments. UDFCD should continually review the needs of the region in regard to urban runoff criteria and should recommend changes as necessary to the USDCM.

6.4 Financing Drainage Improvements

Financing storm drainage improvements is fundamentally the responsibility of the affected property owners (both the persons directly affected by the water and the person from whose land the water flows) as well as the local government. Every effort should be made to keep the cost of drainage solutions reasonable. This will involve careful balancing of storage and conveyance costs and the integration of drainage with other activities such as open space and transportation efforts. Funding must be established, and budgets should be prepared to assure proper maintenance of all new drainage and storage facilities.

7.0 References

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