DRAINAGE POLICY

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1.0 STATEMENT OF POLICY

1.1 Policy

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 feature 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 agencies most directly involved must provide coordination and master planning, but drainage planning must also be integrated on a regional level (FEMA 1995).

When planning drainage facilities, certain underlying principles provide direction for the effort. These principles are made operational through a set of policy statements. The application of the policy is, in turn, facilitated by technical drainage criteria and data. When considered in a comprehensive manner—on a regional level with public and private involvement—drainage facilities can be provided in an urban area in a manner that will avoid uneconomic water losses and disruption, enhance the general health and welfare of the region, and assure optimum economic and social relationships (White 1945).

Photograph DP-1—Denver grass-lined channel after 35 years of service. Ann Spirn of the Massachusetts Institute of Technology refers to this channel as "urban poetry" in her publications. Spirn appreciates the soft natural lines.

The principles and policies for urban storm drainage are summarized below.

1.2 Principles

- **Drainage is a regional phenomenon that does not respect the boundaries between government jurisdictions or between properties.**
- **A storm drainage system is a subsystem of the total urban water resource system.**
- **Every urban area has an initial and a major drainage system, whether or not they are actually planned and designed.**
- **Runoff routing is primarily a space allocation problem.**
- **Planning and design of stormwater drainage systems generally should not be based on the premise that problems can be transferred from one location to another.**
- **An urban storm drainage strategy should be a multi-objective and multi-means effort.**
- **Design of the stormwater drainage system should consider the features and functions of the existing drainage system.**
- **In new developments, attempts should be made to reduce stormwater runoff rates and pollutant load increases after development to the maximum extent practicable.**
- **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 stormwater management system should receive regular maintenance.**
- **Floodplains need to be preserved whenever feasible and practicable.**
- **Reserve sufficient right-of-way to permit lateral channel movement whenever the floodplain is contained within a narrow natural channel.**

1.3 Basic Knowledge

A program for collecting and analyzing storm runoff and flood data should be maintained in order that intelligent and orderly planning may be undertaken in regard to storm drainage facilities.

A program should be maintained to delineate flood hazard areas along all waterways in the region which are urbanized or which may be 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. This information should be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, and the occurrence of extraordinary hydrologic events.

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.

1.4 Planning

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 in the Denver region. 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 assist in the solution of drainage problems.

Natural drainageways should be used for storm runoff waterways wherever feasible. Major consideration must be given to the floodplains and open space requirements of the area (White 1945).

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

Stormwater runoff can be stored in detention and retention reservoirs. Such storage can reduce the drainage conveyance capacity required immediately downstream. Acquisition of open space having a relationship to drainageways will provide areas where storm runoff can spread out and be stored for slower delivery downstream.

1.5 Technical Issues

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

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 planned, properly 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*.

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. Urban drainage design should have as an objective reduction of street repair and maintenance costs to the public.

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 for mitigating upstream runoff.

Proper design and construction of stormwater detention and retention basins are necessary to minimize future maintenance and operating costs and to avoid public nuisances and health hazards. This is particularly important, given the many detention and retention facilities in the Denver region.

The various governmental agencies within the Denver region have adopted and need to maintain their floodplain management programs. Floodplain management must encompass comprehensive criteria designed to encourage, where necessary, the adoption of permanent measures which 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.

1.6 Flood Insurance

Flood insurance is an integral part of the strategy to manage flood losses. The Denver region should encourage continued participation in the National Flood Insurance Program, set forth in the National Flood Insurance Act (NFIA) of 1968, as amended.

1.7 Implementation

This *Manual* should continue to be adopted by all governmental agencies operating within the region. Each level of government is encouraged to participate in a successful drainage program.

Problems in urban drainage administration encountered by any governmental agency can be reviewed by the Urban Drainage and Flood Control District (District) to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments (Figure DP-1).

The financing of 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.

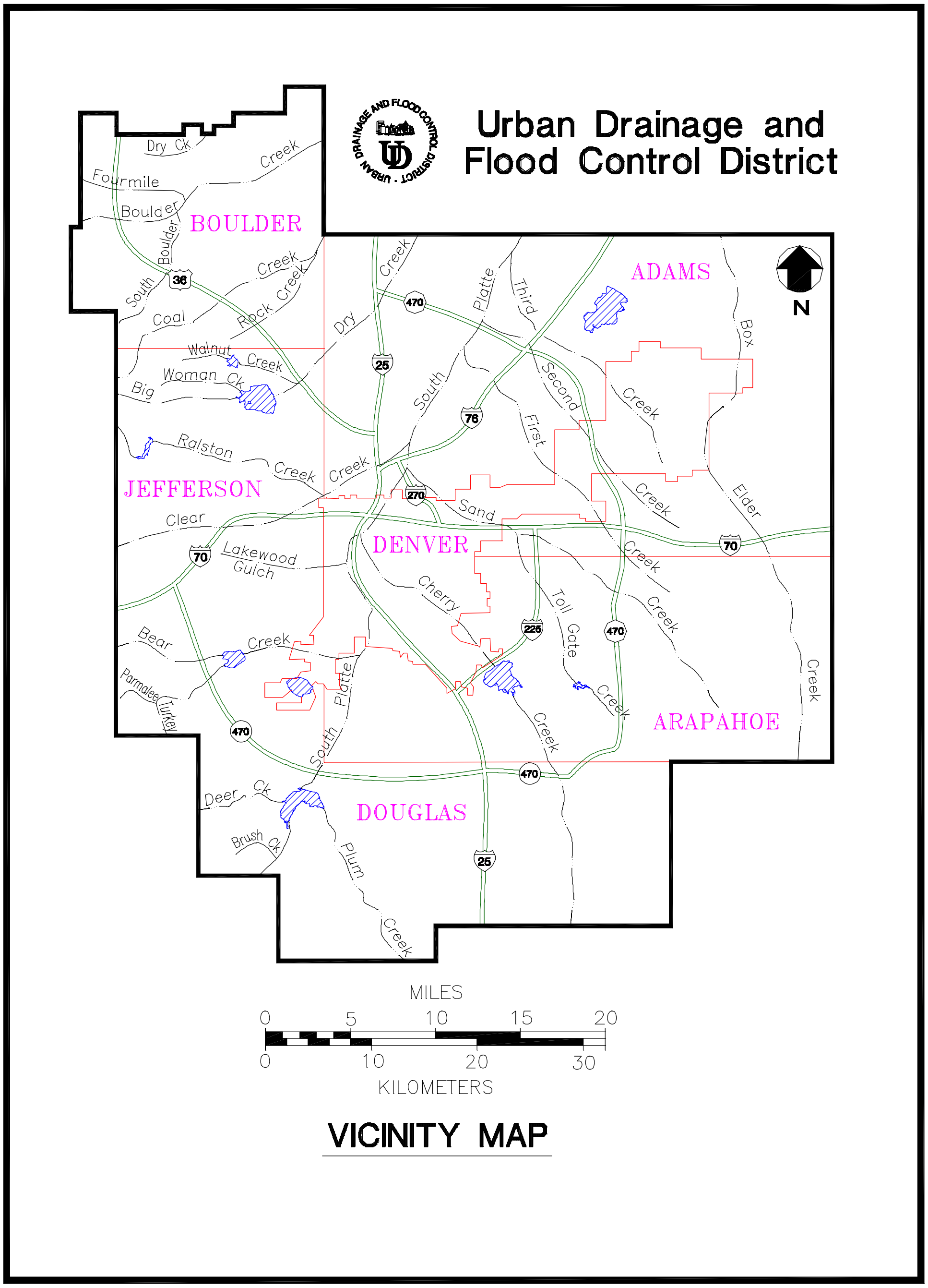

Figure DP-1—Urban Drainage and Flood Control District Boundaries

2.0 PRINCIPLES

2.1 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 agencies 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 ways in which proposed drainage systems fit existing regional systems must be quantified and discussed in the master plan.

2.2 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, particularly with planning for land use, open space and transportation. Erosion and sediment control, flood control, site grading criteria, and regional water quality all closely interrelate with urban stormwater management. Any individual master plan or specific site plan should normally address all of these considerations.

2.3 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 a “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.

2.4 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 sewers serve both conveyance and storage functions. If adequate provision is not made for drainage space demands, stormwater runoff will conflict with other land uses, will result in damages, and will impair or even disrupt the functioning of other urban systems.

2.5 Planning and Design of Stormwater Drainage Systems Generally 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 the speed of runoff. Stormwater runoff can be stored in detention facilities, which can reduce the drainage capacity required immediately downstream.

2.6 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.

Photograph DP-2—An urban storm drainage strategy should be a multi-objective and multi-means effort.

2.7 Design of the Stormwater 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 drainageways, 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.

2.8 In New Developments, Attempts Should Be Made to Reduce Stormwater Runoff Rates and Pollutant Load Increases After Development to the Maximum Extent Practicable

1. The perviousness of the site should be maintained, to the extent feasible.

2. The rate of runoff should be slowed. Preference should be given to stormwater management systems that use practices that maximize vegetative and porous 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 when an area urbanizes. However, existing stormwater regulations can require control of peak flows to predevelopment levels to a maximum extent achievable. Increased flow volumes may present no flooding problems if the watershed has a positive outfall to a stream or river; however, these volumes may cause problems for a small, enclosed watershed draining to a lake or into streams of limited capacity.

3. Pollution control is best accomplished by implementing a series of measures, which can include source control, minimization of directly connected impervious areas, and construction of on-site and regional facilities, to control both runoff and pollution.

2.9 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 backwater 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 urban development potential.

2.10 The Stormwater Management System Should Receive 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 agency and a regular schedule of inspections to determine maintenance needs and to ensure that required maintenance is done. Local maintenance capabilities should be a consideration when selecting specific design criteria for a given site or project.

2.11 Floodplains Need to 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. Floodplains often provide a natural order to the land surface with drainageways that serve as outfalls for urban drainage, bottomland for wildlife habitat, riparian corridors, and specialized vegetation. Floodplain encroachment can occur only after competent engineering and planning have been conducted to assure 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 the District 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).

Photograph DP-3—National Medal of Science winner, Dr. Gilbert White, recommends natural-like floodplains because they save people from damages and are good for the economy.

2.12 Reserve Sufficient Right-of-Way for Lateral Movement of Incised Floodplains

Whenever a floodplain is contained within a narrow (i.e., degraded) channel, its lateral movement over time can cause extensive damages 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 equivalent to the cross section recommended for a grass-lined channel, including a maintenance access roadway.

3.0 BASIC KNOWLEDGE

3.1 Data Collection

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

3.1.1 Storm Runoff and Flood Damage

Storm runoff and flood damage data should be collected in a systematic and uniform manner.

3.1.2 Rainfall-Runoff Relationships

A program should be maintained to collect and analyze rainfall-runoff relationships in urban areas of the Denver region.

3.1.3 Inventory of Successful Projects

Some drainage projects function better than others. It is important to determine why, so that key features may be inventoried for use on other succeeding projects.

3.1.4 Library

The District should acquire and actively maintain a library, which should be available for use by all governmental agencies, practicing planners, and engineers. The public should be encouraged to use the library as part of the District's educational and outreach programs.

3.1.5 Runoff Magnitudes

Where practical, the magnitude of computed and measured runoff peaks should be tabulated for Denver region streams and gulches so that comparisons may be readily made between watersheds and erroneous values may be more easily identified.

3.2 Floodplain Data

The program to delineate flood hazard areas along all waterways in the region should be maintained. This program should make full use such sources as the District's Flood Hazard Area Delineation studies, the FEMA Flood Insurance Studies, data from the Natural Resources Conservation Service, the USGS, and floodplain studies by private consulting engineers. This information should be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, and the occurrence of extraordinary hydrologic events.

3.2.1 Small Waterways

Small gulches 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.

3.2.2 Data Inventory

The information collected should be stored in a central District depository available to all planners, developers, and engineers.

3.2.3 Floodplains

This effort should be aimed towards developing information on those areas that have a one percent chance of being inundated in any given year—that is, the 100-year floodplain. Local governmental agencies 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 in addition to being the minimum basis for regulation.

3.2.4 Priority for Data Acquisition

The District will establish priorities for acquisition of data because it is recognized that not all of the data can be collected at one time. When setting priorities, consideration should be given to:

a. Areas of rapid urban growth

b. Drainage problem areas

c. Local interest and capabilities in floodplain management

d. Potential for developing significant information

3.3 Data Use

Prior to the commencement of any drainage project, comprehensive facts and data should be collected and examined for the particular watershed and area under consideration.

3.3.1 Master Plan

Drainage design does not lend itself to a piece-meal approach; therefore, master plans for drainage should be prepared on a priority basis. Such plans already cover most of the developed major drainageways in the District. Additional plans will be developed for areas yet unplanned. In addition, existing master plans will be updated as needed to reflect changed conditions that take place over time.

3.3.2 Public Cost

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.

3.3.3 Easements

Where construction occurs along a waterway not yet developed downstream or upstream, and where a master plan is not yet available, flood easements should be left which will include the future development 100-year floodplain. 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.

On any floodplain, nature possesses by prescription an easement for intermittent occupancy by runoff waters. Man 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 the inevitable periods of nature's easement occupancy.

Floodplain regulation, then, must define natural easements and boundaries and must delineate floodplain occupancy that will be consistent with total public interests.

4.0 PLANNING

4.1 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 maintained in an up-to-date fashion for most of the watersheds in the Denver region. An effort to complete the coverage of master plans for yet unplanned areas of the District should be continued until full coverage is achieved.

4.1.1 Development Plan

A development plan should be given direction by broad, general framework goals. Examples of such goals are:

1. Drainage and flood control problem alleviation
2. Economic efficiency
3. Regional development
4. Environmental preservation and enhancement
5. Social and recreational need fulfillment

These goals, or combinations of these goals, as they are pursued within an urban region, have the potential to influence greatly 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).

4.1.2 Master Plan

Each municipality and county in the Denver region is responsible for master planning for urban storm drainage facilities within its boundaries and environs. The District can help to coordinate efforts. Cooperation between governmental agencies is needed to solve drainage problems and joint city, county and District efforts are encouraged. Carrying forward master planning is best accomplished on a priority-phased basis so that the most demanding problems, such as areas of rapid urbanization, may be addressed at an early date.

Early work includes the planning of major drainageways from the point of outfall, proceeding in an upstream direction. The major drainageways are generally well defined and often dictate the design of the initial drainage system, including storm sewers, detention facilities, and water quality systems.

The District has established a suitable format for master plan reports and drawings so that a uniform planning approach and coordination of efforts can more easily be made. Master planning should be done in enough detail and with adequate thoroughness to provide a ready drainage development guide for the future in a particular watershed. Generalized concepts based on rule-of-thumb hydrological analyses should not be used as master plans; a more rigorous analysis is necessary.

4.1.3 Planning Process Ingredients

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

1. Major Drainage Planning. All local and regional planning must take into consideration the major drainage system necessary to manage the runoff that is expected to occur once every 100 years. The major drainage system plans will reduce loss of life and major damage to the community and its infrastructure.

2. Initial Drainage System Planning. All local and regional planning must take into consideration the initial drainage system to transport the runoff from storms expected to occur once every 2 to 10 years. The planner of an initial system must strive to minimize future drainage complaints.

3. Environmental Design. Environmental design teams involving a range of disciplines should be convened whenever desirable to ensure that the benefits to total urban systems receive consideration in the drainage planning work. Planning should address water quality enhancements and include evaluation of the impacts of new facilities, as well as future operation and maintenance by private and public bodies.

4.1.4 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.

4.1.5 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 the *Manual*. Where flood hazards are involved, the local planning boards should take into consideration proposed land use so that it is compatible with the flood hazard risks involved with the property, and appropriate easements need to be provided to preclude encroachment upon waterways or flood storage areas.

4.1.6 Water Quality

Protecting and enhancing the water quality of public streams is an important objective of drainage planning. Erosion control, maintaining stream channel stability, sediment and debris collection, and pollutant removal from stormwater runoff must be taken into account by using the stormwater runoff best management practices (BMPs) described in Volume 3 of this *Manual*.

Sanitary sewerage systems that overflow or bypass untreated sewage into surface streams should not be permitted in the Denver region. Existing systems that discharge sewage should be adjusted by their owners to eliminate this problem.

Full cooperation should be extended to planners and designers of sanitary sewerage works to minimize the hazards involved with the flooding of sanitary sewers by urban storm runoff. Drainage planning should include means to prevent inflow to sanitary sewers because of street flow and flooding of channels.

4.2 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).

4.2.1 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.

4.2.2 Open Space

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

4.2.3 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.

4.3 Natural Channels

Natural drainageways should be used for storm runoff waterways wherever practical. Preservation and protection of natural drainageways are encouraged; however, major consideration must be given to their stability as the area urbanizes.

4.3.1 Channelization

Natural drainageways 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.

4.3.2 Channel Storage

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

Photograph DP-4—Drainageways having "slow-flow" characteristics, with vegetated bottoms and sides can provide many benefits.

4.3.3 Major Runoff Capacity

Drainageways and their residual floodplains should be capable of carrying the major storm runoff, which can be expected to have a one percent chance of occurring in any single year.

4.3.4 Maintenance and Maintenance Access

Waterways will require both scheduled and unscheduled maintenance for a wide array of activities such as sediment, debris and trash removal, mowing, and repair of hydraulic structures. Assured long term maintenance is essential, and it must be addressed during planning and design. The District assists with drainage facility maintenance, provided that the facilities are designed in accordance with the District's Maintenance Eligibility Guidelines. The June 2001 version of these guidelines are available on the CD version of this *Manual*, and updates to these guidelines should be obtained from the District's Web site at www.udfcd.org. Designers are strongly encouraged to adhere to the design criteria listed in the Maintenance Eligibility Guidelines. Waterways, detention structures and other facilities must have permanent access for routine and major maintenance activities.

4.4 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.

4.4.1 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.

4.4.2 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.

4.4.3 Watershed Planning

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 detention and retention storage facilities. Such facilities must be assured of construction, perpetual operation and maintenance. Urban development causes a major increase in the volume of runoff, even though the peak flows for certain return floods might be managed to simulate those of undeveloped historic conditions. 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.

4.5 Detention and Retention Storage

Stormwater runoff can be stored in detention and retention reservoirs. Such storage can reduce the peak flow drainage capacity required, thereby reducing the land area and expenditures required downstream. (However, see limitation in 4.4.3 regarding taking credit for detention.) In some instances of stormwater retention and detention, there may be water rights implications, and in those instances, the State Engineer's Office should be consulted.

4.5.1 Upstream Storage

Storage of storm runoff close to the points of rainfall occurrence includes use of parking lots, ball fields, property line swales, parks, road embankments, borrow pits, and on-site basins and ponds.

Large parking lots, like those at shopping centers, create more runoff volume than before with high runoff discharge rates. The same is true for many small parking lots. Parking lots should be designed to provide for storage of runoff during infrequent events except where clearly shown that such storage is impractical. Wherever reasonably acceptable from a social standpoint, parks should be used for short-term detention of storm runoff to create drainage benefits. Such use may help justify park and greenbelt acquisition and expenditures.

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 virtual impossibility of assurance of their continued long-term performance or existence (Debo 1982; Prommersberger 1984) requires the District to recognize in its floodplain management only regional, publicly owned facilities. Nevertheless, upstream storage is encouraged, such as with the "Blue-Green" concept first described in *Civil Engineering* magazine (Jones 1967).

4.5.2 Minimized Directly Connected Impervious Area Development

The “minimized directly connected impervious area” (MDCIA) concept (refer to Volume 3 of this *Manual*) provides an approach to upstream stormwater management that reduces the amount of impervious surfaces in a development and their connection to the initial drainage system. In addition, it includes functional grading, wide and shallow surface flow sections, disconnection of hydrologic flow paths, and the use of porous landscape detention and porous pavement areas. Details for its use are presented in Volume 3 of this *Manual*. The technique of MDCIA is also referred to as “low impact development” (LID). Other references include Heaney, Pitt and Field (1999) and Prince George’s County, Maryland (1999).

4.5.3 Downstream Storage

The detention and retention of storm runoff is desirable in slow-flow channels, in storage reservoirs located in the channels, in off-stream reservoirs, 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. This should be achieved via numerous and varied techniques.

4.5.4 Reliance on Non-Flood-Control Reservoirs

Privately owned non-flood-control reservoirs cannot be used for flood mitigation purposes in master planning because their perpetuity cannot be reasonably guaranteed. Publicly owned water storage reservoirs (city, state, water district, irrigation company, etc.) should be assumed to be full for flood planning purposes and, therefore, only the detention storage above the spillway crest can be utilized in regard to the determination of downstream flood peak flows.

4.5.5 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 by the drainage engineer for flood peak mitigation when determining the downstream flood peaks for channel capacity purposes unless such detention has been covered by a binding agreement approved by the District.

5.0 TECHNICAL CRITERIA

5.1 Design Criteria

Storm drainage planning and design should adhere to the criteria developed and presented in this *Manual* maintained by the District.

5.1.1 Design Criteria

The design criteria presented herein represent current good engineering practice, and their use in the Denver 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.

5.1.2 Criteria Updating

The criteria contained in this *Manual* should be revised and updated as necessary to reflect advances in the field of urban drainage engineering and urban water resources management.

5.1.3 Use of Criteria

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

5.2 Initial and Major Drainage

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 planned and properly engineered.

5.2.1 Design Storm Return Periods

Storm drainage planning and design should fully recognize the need for considering two separate and distinct storm drainage systems: the initial drainage system and the major drainage system. 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.

There are many developed areas within the Denver urban region that do not fully conform to the drainage standards projected in this *Manual*. The multitude of problems associated with these areas historically provided the emphasis required to proceed with development of this *Manual*. It is recognized that upgrading these developed areas to conform to all of the policies, criteria, and standards contained in this *Manual* will be difficult, if not impractical, to obtain, short of complete redevelopment or renewal. However, flood-proofing techniques can be applied to these areas.

Strict application of this *Manual* in the overall planning of new development is practical and economical; however, when planning drainage improvements and the designation of floodplains for developed areas, the use of the policies, criteria, and standards contained in this *Manual* 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 impact of the 100-year storm should be investigated and made known.

5.2.2 Initial Storm Provisions

The initial storm drainage system, capable of safely handling 2- to 10-year floods depending on local criteria, is necessary to reduce the frequency of street flooding and maintenance costs, to provide protection against regularly recurring damage from storm runoff, to help create an orderly urban system, and to provide convenience to urban residents. Normally, the initial drainage system cannot economically carry major runoffs, 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 sewer systems (Jones 1967). Storm sewer systems consisting of underground pipes are a part of initial storm drainage systems.

5.2.3 Major Storm Provisions

In addition to providing the storm drainage facilities for the initial storm runoff, provisions should be made to avoid major property damage and loss of life for the storm runoff expected to occur from an urbanized watershed once every 100 years on average (i.e., one percent probability of occurrence any given year). Such provisions are known as the major drainage system.

5.2.4 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, even during a 100-year flood, their functioning will not be compromised. The use of a 500-year flood level for such facilities may be justified in many instances.

5.2.5 Major Drainage Channels

Open channels for transporting major storm runoff are more desirable than closed sewers in urban areas, and use of such channels is encouraged. Open channel planning and design objectives are often best met by using natural-type vegetated channels, which characteristically have slower velocities and large width-to-depth ratios. Additional benefits from open channels can be obtained by incorporating parks and greenbelts with the channel layout. When evaluating existing natural water courses (perennial, intermittent and ephemeral), it is desirable to minimize straightening, fill placement, and other alterations. Alterations such as these should be very carefully evaluated. Normally, however, some structural stabilization will be necessary to address the increased effects on stream stability caused by increased flows due to urbanization. For example, grade control structures and structural protection at the channel toe and on outer banks are normally required.

The filling, straightening or altering of natural water courses, perhaps wet only during and after large rainstorms, is discouraged. 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 must be made to reduce flood peaks and control erosion so that the natural channel regime is preserved as much as practical. Buffer zones can be used to account for future channel meandering and bank sloughing, at least in part.

Use of open channels should receive early attention when planning a new development, along with other storm runoff features.

5.2.6 Tailwater

The depth of flow in the receiving stream must be taken into consideration for backwater computations for either the initial or major storm runoff.

5.3 Runoff Computation

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

5.3.1 Accuracy

The peak discharges determined by any method are approximations. Rarely will drainage works operate at the design discharge. Flow will always be more or less in actual practice as it rises and falls during a storm event. Thus, the engineer should not overemphasize the detailed accuracy of computed discharges but should emphasize the design of practical and hydraulically balanced works based on sound logic and engineering, as well as dependable hydrology. The use of more than three significant figures for estimating the flood magnitudes conveys a false sense of accuracy and should be avoided. Because of the public's reliance on published peak flow estimates, they should only be changed when it is clear that an original error has been made and that continuing their use would not be in the public's interest.

5.4 Streets

5.4.1 Use of Streets

Streets are significant and important in urban drainage, and full use should be made of streets for storm runoff up to reasonable limits, recognizing that the primary purpose of streets is for traffic. Reasonable limits of the use of streets for transportation of storm runoff should be governed by reasonable design criteria as summarized in Table DP-1. Urban drainage design should have as objectives reduction of street repair, maintenance costs, nuisance to the public, and disruption of traffic flow.

Table DP-1—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.

When maximum allowed encroachment is present, the storm sewer system design based on the initial storm should commence. Development of a major drainage system that can often drain the initial runoff from the streets is encouraged, thus making the point at which the storm sewer system should commence further downstream. Initial and major drainage planning should go hand-in-hand.

While it is the intent of this policy to have major storm runoff removed from public streets at frequent and regular intervals and routed into major drainageways, it is recognized that water will often tend to follow streets and roadways and that streets and roadways often may be aligned so they will provide a specific runoff conveyance function. Planning and design objectives for the major drainage system with regard to public streets should be based upon following the limiting criteria summarized in Table DP-2.

Table DP-2—Major Storm Runoff Recommended Maximum Street Inundation

Street Classification	Maximum Depth and Inundated Areas
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 18 inches for local and 12 inches for 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.

The allowable flow across a street should be within the criteria presented in Table DP-3.

Table DP-3—Allowable Maximums for Cross-Street Flow

Street Classification	Initial Design Runoff	Major Design Runoff
Local	6 inches of depth in cross pan	18 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

An arterial street crossing will generally require that a storm sewer system be commenced, unless the topography is such that day-lighted inlet culverts or other suitable means can transport the initial storm runoff under the arterial street or water can be routed to a major drainage facility. Bubblers (inverted siphons which convey flows beneath roadways) are not encouraged in the Denver region because of possible plugging with sediment and difficulty in maintaining them. Collector streets should have cross pans only at infrequent locations as specified by the governing agency 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.

5.5 Irrigation Ditches

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 substantiated by adequate hydraulic engineering analysis and approval of the owner of the ditch.

5.5.1 Use of Ditches

The irrigation ditches coursing through urban areas are laid out on flat slopes and with limited carrying capacity. Based on experience and hydraulic calculations, irrigation ditches cannot, as a general rule, be used as an outfall point for the initial storm drainage system because of physical limitations. 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. Written approval must be obtained from the ditch owner stating that the owner understands the physical and legal (i.e., liability) consequences of accepting said runoff.

If there is a question about the use of irrigation ditches as outfalls for initial storm runoff, there is no question about their unsuitability 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. Land planners downhill from a ditch should plan for pre-ditch drainage conditions as well as continued ditch seepage.

5.5.2 Ditch Perpetuation

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

5.5.3 Conformance With Master Plan

Use of irrigation ditches for collection and transport of either initial or major storm runoff should be prohibited unless specifically provided in a District's master plan or approved by the District and the ditch owner.

5.6 Detention and Retention Facilities Maintenance

The significant cost of handling stormwater runoff, coupled with the social benefits to be derived from proper storm drainage facilities, points towards the use of detention and retention basins for storage of stormwater runoff in the Denver region. Maintenance provisions must be arranged. Maintenance of detention or retention facilities includes the removal of debris, excessive vegetation from the embankment, and sediment. Without maintenance, a detention/retention facility will become an unsightly social liability and eventually become ineffective.

5.6.1 Water Quality

Detention and retention facilities provide an opportunity to improve the quality of stormwater runoff before it reaches streams. Water quality BMPs will add an additional level of maintenance obligation because they are designed to remove, among other things, solid constituents from urban runoff.

Photograph DP-5—Detention basins with permanent ponding help in many ways, including flood reduction, water quality and land values.

6.0 FLOODPLAIN MANAGEMENT

6.1 Purpose

Various governmental agencies within the Denver region should initiate 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 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.

6.2 Goals

There are two goals in regard to floodplain management:

- *To reduce the vulnerability of Denver region 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 reoccurrence 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 in those places where such flooding would cause unacceptable or catastrophic damages.

- *To preserve and enhance the natural values of the region's floodplains.*

  Natural floodplains serve society by providing floodwater storage, groundwater recharge, water quality enhancement, aesthetic pleasure, 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 assure that measures are taken to mitigate the loss through replacement or other means.

These two goals are reconcilable and achievable through appropriate management shared by the agencies involved.

6.3 National Flood Insurance Program

Flood insurance should be an integral part of a strategy to manage flood losses. The cities and counties in the Denver region are encouraged to continue to participate in the federal flood insurance program set forth in the NFIA of 1968, as amended.

6.3.1 Participation

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.

6.4 Floodplain Management

The objectives of floodplain management are:

a. To adopt effective floodplain regulations.

b. To improve local land use practices, programs, and regulations in flood-prone areas.

c. To provide a balanced program of measures to reduce losses from flooding.

d. To reduce the need for reliance on local and federal disaster relief programs.

e. To minimize adverse water quality impacts.

f. To foster the creation/preservation of greenbelts, with associated wildlife and other ecological benefits, in urban areas.

Floodplain management practices must be implemented to be of value. Although hydrologic data are critical to the development of a floodplain management program, the program is largely dependent on a series of policy, planning, and design decisions. These decisions are essentially political, economic, and social in character and are developed on a geographic scale extending beyond the floodplain itself. These area-wide decisions provide the setting for floodplain usage and, when combined with hydrologic considerations and augmented by both administrative and implementing devices, constitute the floodplain management program. The program must give high priority to both flood danger and public programs, such as urban renewal, open space, etc.

6.5 Floodplain Filling

While floodplain management includes 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.

6.6 New Development

The decision as to whether or not a major flood control measure should be undertaken to permit intensive new urbanization or to maintain an open area within an urban floodplain or any intermediate use should be made on the basis of:

a. Relative costs of the respective alternatives (not only financial, but also non-financial economic costs such as opportunities foregone).

b. The opportunities for flood proofing and other measures in relation to the extent of flood hazard.

c. The availability of lands in non-floodplain areas for needed development.

d. The location of the high flood hazard areas, namely, defined floodways.

e. The potential adverse effect on others in or adjacent to the floodplain.

f. The fact that floods larger than the design flood will occur (i.e., exposure will still exist, even with well-designed facilities, for the one percent flood).

6.7 Strategies and Tools

The strategies and tools available to the drainage engineer for floodplain management are numerous and varied. The following menu is meant to be a list of strategies and tools available for floodplain management, but it should not be considered to be limiting (FEMA 1995).

6.7.1 Exposure to Floods

Reduce exposure to floods and disruptions by employing floodplain regulations and local regulations. The latter would include zoning, subdivision regulations, building codes, sanitary and well codes, and disclosure to property buyers.

6.7.2 Development Policies

Development policies include design and location of utility services, land acquisition, redevelopment, and permanent evacuation (purchase of properties).

6.7.3 Preparedness

Disaster preparedness is an important tool for safeguarding lives and property, and disaster assistance will reduce the impact to citizens from flooding.

6.7.4 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.

6.7.5 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.

6.7.6 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.

6.7.7 Impact of Modification

Using education, flood insurance, tax adjustments, emergency measures, and a good post-flood recovery plan that can be initiated immediately can modify the impact of flooding.

7.0 IMPLEMENTATION

7.1 Adoption of Drainage Master Plans

This *Manual* and master plans should be adopted and used by all governmental agencies operating within the District.

7.1.1 Manual Potential

From a broad perspective, this *Manual* on drainage disseminated by the District will have the potential to:

a. Give direction to public agency efforts to guide private decisions.

b. Give direction to public agency efforts to regulate private decisions.

c. Provide a framework for a public agency when it seeks to guide other public agencies.

d. Provide a framework to assist in coordinating the range of public and private activities.

e. Provide direction for development of master plans and designs and for implementation of drainage facilities.

7.2 Governmental Operations

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

7.3 Amendments

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

7.4 Financing

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) and the local governing body.

7.4.1 Drainage Costs

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.

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