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Stream Protection in Urban Watersheds Through Master Planning

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Abstract
Major changes to the landscape and the water environment occur when land urbanize simply because stormwater runoff differs significantly in quantity and quality from the runoff that occurs before urbanization takes place. Streams, rivers, lakes, estuaries and other receiving water bodies experience the changes to runoff frequencies and volumes and react accordingly. The forces behind the observed changes in the receiving waters are discussed in this paper and suggestions are made on how to plan to deal with them. Master planning of urban watershed and their waterway can help guide decision makers to mitigate, in large part, the impacts imposed on these waters by land-use changes. Although each watershed is unique, some general principles are suggested to deal with these emergent problems.

INTRODUCTION

Urbanization has the potential to significantly degrade streams, rivers, lakes, and other surface water bodies and to change the community structure of aquatic and terrestrial life that these waters support. However, streams and their adjacent floodplains are natural resources in urban areas worthy of protection. The primary cause of stream degradation is the increased runoff from increases in impervious surfaces as lands urbanize. The increased runoff results in channel incision or widening and higher loads of suspended sediment and other pollutants in stream flow. Designing stormwater systems that reduce runoff rates and volumes, reduce channel erosion, include water-quality enhancement features and provide aquatic habitat can minimize the degradation of urban streams and the associated ecological features. As an example, the preservation of floodplains can protect riparian habitat and preserve open spaces, thus creating a community asset in the urban environment (White, 1945; Buie, 1970; UDFCD, 1969, 2001).

URBAN STORMWATER PROBLEMS IN SEMI-ARID REGIONS

Increased Runoff

Urbanization of a watershed changes the hydrologic regime by increasing peak flow, increasing volume, increasing the frequency of runoff, and increasing flow duration. The two principal factors governing flow regimen are the percentage of area made impervious and the efficiency at which surface runoff is transmitted across the land to stream channels (Leopold, 1968).

Figure 1 illustrates the ratio of pre-development to post-development peak flow rate as land changes from native grassland to single-family residential in the Denver area (Urbonas and Glidden, 1981). Peak flow rates increase 40 to 50 times for the 2-year storm. The shift is more dramatic for smaller storms as virtually no runoff is generated from native grasslands. The average annual number of runoff events increase from less than one to 30 (UDFCD, 1999), and mean annual runoff volume increases from 13 mm (0.5 inches) to 90 mm (3.6 inches), a seven-fold increase (Urbonas, 2003). Increased runoff from urbanization would imply a proportional decrease in groundwater recharge to supply base flows during dry weather (Dunne and Leopold, 1978). Actual data, however, demonstrate that this effect is rare (ASCE and WEF, 1992; Schueler, 1994). Visual observations in Colorado's eastern plains suggest that native watersheds of 100 hectares (250 acres) and larger develop a perennial base flow, rather than a decrease in base flow, after they become urbanized. The likely source of most of this water is intensive lawn irrigation (ASCE and WEF, 1992).

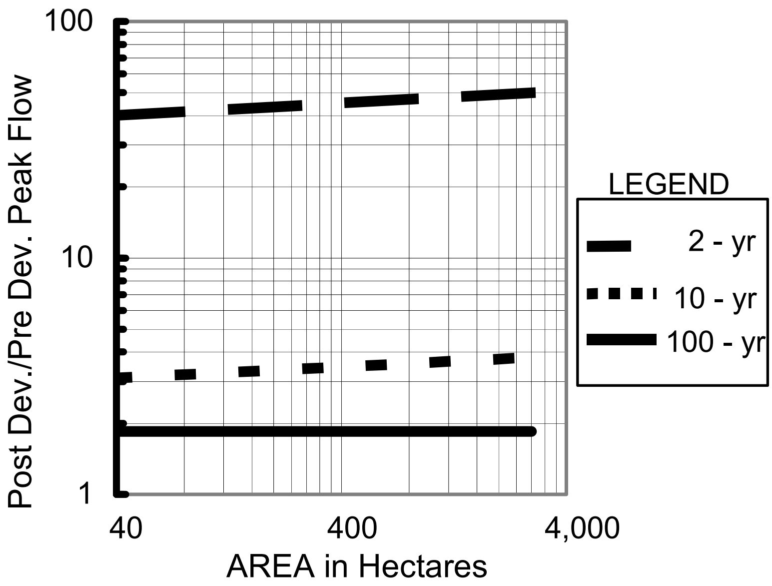

Figure 1. Change in runoff peaks from natural grassland to single-family residential development as compared to pre-developed landscape (Urbonas and Glidden, 1981).

Urbanization also changes the duration of stormwater runoff. Nardi and Roesner (2003) estimate that a small non-urbanized watershed in Fort Collins, Colorado experiences runoff 120 hours per year on average. After urbanization, simulated annual duration of runoff attributed to wet weather increased to 245 hours, namely, twice the pre-development duration.

Channel Erosion
The profound changes in surface runoff resulting from urbanization that is experienced by the natural waterways cause major changes in the geomorphic patterns seen in these waterways. Accelerated channel erosion, incision and widening are the most evident changes seen in these streams, along with major changes to the aquatic and/or terrestrial habitat they support (Leopold and Miller, 1956; Harvey and Watson, 1986; MacRae, 1996; Sovern and Washington, 1996; Bledsoe, 2002). Aggradation of a channel can occur when there is an excess supply of sediment or reduction in transport capacity. Figure 2 illustrates one of many incising and eroding waterways within the District's boundaries.

Water Quality Degradation
Urban runoff has also been shown to adversely effect water quality of the receiving waters (U.S. EPA, 1983). Studies conducted by U.S. EPA (1983) and locally in the Denver area (Doerfer and Urbonas, 1993) show that concentrations of copper, lead, zinc, and sediment are somewhat greater, and that the concentrations of organic compounds and bacteria are at much greater levels in the surface runoff from urban areas than from natural watersheds. While concentrations of most constituents are not significantly higher, the annual loads being delivered by the increased volumes of runoff are significantly higher. However, the toxicity of the elevated concentration and loads to the aquatic organisms in this region's streams is still uncertain, while the effects on receiving lakes and reservoirs have been shown to be significant, mostly in the increased eutrophication of these standing bodies of water.

Figure 2. Stream degradation and erosion in Denver, USA area. Note the 2- to 3-meter incision, exposed utilities and head cutting that is undermining the bridge pier.

MASTER PLANNING FOR STREAM PROTECTION

Basic Principles

Drainage facilities in an urban watershed are viewed as a subsystem of a larger urban system (APWA, 1981; ASCE and WEF, 1992; UDFCD, 1969, 2001). Planning of urban stormwater management systems should be based on incorporating natural waterways into the urban fabric, along with other drainage works and urban infrastructure. Unlike planning for water, sewer and other utilities, successful planning for surface drainage must be integrated early into the urban layout and the community's fabric (UDFCD, 1969, 2001). Planning for stream protection as lands urbanize has to also recognize the potential for the problems that can develop as discussed above.

The underlying principles for planning to protect receiving waters center around four basic needs: (1) When lands urbanize or redevelop, employ runoff volume reduction designs as much as practicable; (2) Treat any residual runoff through the use of a clearly specified water quality capture volume (WQCV) sufficient in size to capture the most frequent storm events (Guo and Urbonas, 1996) and then release these volumes slowly to minimize the energy of flow in the receiving streams; (3) Stabilize the natural waterways that receive urban runoff through the use of grade controls and other means as needed; and, (4) Provide additional measures to prevent contaminated industrial/commercial runoff and to capture contaminated spills before they reach receiving waters.

Planning Process

Master planning of an urban watershed is a systematic procedure. Assuming a consultant has been hired to work with the stakeholders to develop the plan, for the majority, but not all of the planning projects, the following steps need to be taken:

- Collect information about the watershed's topography, geology, soils, impervious cover, urban land use and other anthropogenic features, environmental features, meteorology, etc.
- Develop hydrology, namely runoff volumes and flow rates for various return periods of flooding along the waterways.
- Define the nature and extent of existing and projected problems.
- Identify possible solutions to address identified current and projected problems.

- Involve the public. Share the findings and the identified potential solutions with the public. Be clear with the public that at this point in the planning process decisions have not been made on what the plan will contain or recommend.
- Narrow the possible solutions for detailed investigation to the ones that best fit the project's goals, community's needs and that best address the public's concerns. When appropriate, analyze benefits and costs of possible solutions.
- Prepare an interim report on the problems, possible solutions, their costs and quantifiable benefits (if possible) and the consultant's recommendations.
- Evaluate the consultant's recommendations and develop a draft "*selected plan*" that either accepts the consultant's recommendations or modifies them in light of the community's political and fiscal needs and realities.
- Present findings and the draft "*selected plan*" to the public and to the decision makers (governing boards, elected officials, etc.). Seek their guidance.
- Modify the "*selected plan*" as appropriate and proceed to develop the final master plan for the watershed.

Possible Alternatives to Examine
There is a wide array of alternatives that one can examine when conducting a master planning study. Each watershed is unique and there is no standard formula that can be used for each planning study. The following alternatives, however, are the ones that often will find their way into most planning studies for waterways:

Do Nothing. The "do nothing" alternative is always an option. It has the lowest initial capital cost, but does not address and, for all practical purposes, ignores the impacts an urbanizing watershed will have on its receiving streams. In a sense it is not a true option, but does serve to illustrate the long-term effects of doing nothing. Often this alternative will have the highest maintenance and rehabilitation costs when realistic life cycle cost analysis is done using the true cost (after accounting for inflation) of future work over a 25- to 50-year period. It is extremely hard to quantify the loss of ecological resources this option will yield over the planning period.

Full Conveyance. This alternative looks at channelizing the waterways to fully convey large flood events (e.g., 100-year flood). This is an alternative that can be cost effective and provide good benefits to the community in previously urbanized areas where frequent flooding is a problem. It does result in the loss or significant alteration of natural ecological resources. As a result, the aesthetic and environmental concerns of this alternative are seen as a disadvantage, as well as the downstream impacts that can occur when the flood-routing capacity of the urban floodplain is lost. However, when the flood damages to the local residents are understood and/or the potential for loss of life is present, this alternative does offer advantages to an area that is fully urbanized.

Detention for Flood Control. The reduced peak discharges that can result from detention storage need to be analyzed and quantified. Detention facilities can reduce the size and cost of downstream conveyance systems and can reduce flood damages along natural waterways, but can also require significant land resources and costs. Stormwater detention by itself, unless it prevents very frequent flooding, can rarely be justified on an economic basis. But, when the facility can be made to also provide other functions, such as urban open spaces, parks, athletic fields, golf courses, and/or wildlife habitat, flood-control detention becomes a valuable option to consider.

Two categories of flood control detention are often considered. On-site facilities are located and sized to capture runoff from individual land development projects. They are often owned by the development's homeowners association, or sometimes by the municipality. Because they are installed at the time the land is undergoing changes, they are relatively easy to implement, but their long-term maintenance and existence is uncertain unless strong municipal inspection and maintenance assurance programs are in place. Their overall effectiveness for controlling peak flows along the natural waterways for larger watersheds is difficult to quantify and their sizing and design has to be clearly spelled out to meet the specific watershed and its waterway capacities and needs. Letting individual on-site detention facilities to be designed using only the site's historic peak runoff characteristics, has been found to be ineffective in protecting the waterways or reducing downstream flooding (Urbonas and Glidden, 1981).

Regional detention facilities can be located and sized during the planning process to capture runoff from relatively large areas. Regional facilities are relatively few in number and their effect can be easily quantified. However, they are difficult to implement because their financing has to come before land development in the watershed begins.

Detention for Water Quality Protection. To address the shortcomings of detention for flood control, which does virtually nothing to mitigate the effects of hydrologic changes resulting from urbanization, detention for water quality protection has to be considered. This detention differs in that it is intended to capture the smaller runoff events, such as the 1-year event, the 80th percentile event, the 90th percentile event, etc. and then release the captured volume over and extended period of time. It can be combined with flood control detention. The emptying time can be set to best mitigate the increased runoff flow volumes, flow rates and durations resulting form urbanization and to provide treatment of stormwater. By so doing this extended detention of smaller runoff events can reduce the energy and work the receiving streams are subjected to after urbanization and slow their degradation.

Another type of this detention is to combine it with stormwater infiltration, thereby reducing the surface runoff volumes as well, further mitigating the effects of changes in hydrology. Often referred to as Low Impact Development (LID) facilities, such as rain gardens, porous landscape detention, porous pavement, and other types all depend on having a detention volume that buffers rapid runoff rates and allows the infiltrating surfaces to get the job done instead of being overwhelmed and bypassed. All types of water quality protection practices are discussed later. An example of a degrading waterway that is attributed to hydrologic modification is illustrated in the left photograph of Figure 3.

Stabilizing Natural Waterways. Grade-control structures prevent downward incision of streams. When strategically positioned to reduce the longitudinal slope of natural channels, they accomplish the goal of stabilizing streams, gulches and ephemeral waterways, thus protecting existing riparian zones, private and public property and urban infrastructure (DeGroot and Urbonas, 2000). The protection and/or establishment of wetland and riparian vegetation, namely wildlife habitat, upstream of these structures is an added benefit. Grade controls also reduce silt deposits in downstream aquatic-habitat areas.

Two categories of grade-control structures are considered. Drop structures raise the degraded bottom of a stream to return its elevation close to what was there before degradation occurred. A check structure is installed as a hard-point across the stream before degradation occurs. Figure 3 has a pair of photographs showing a reach of Cherry Creek without adequate grade control and another reach with grade control. Planning for and eventually providing such facilities is an important element in any master-planning project for urbanizing watersheds.

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ADDRESSING WATER QUALITY

When planning for an urbanizing watershed, it is imperative that water quality, in addition to quantity, be addressed. There are large arrays of practices that can be considered, which in the Denver area and other parts of United States are generally referred to as best management practices (BMPs). In planning, the use and implementation of both structural and non-structural BMPs need to be addressed.

Nonstructural BMPs are directed at pollution prevention and source controls and include public education, adoption of local criteria and standards, establishing an institutional system to ensure the criteria and standards are followed and that the resultant facilities are property maintained, street and parking-lot maintenance to remove pollutants from paved surfaces, guidelines for domestic chemical use, and other "good housekeeping" practices that the municipalities, commerce, industry and the public can follow. Of particular importance is the adoption of building and land development standards that promote minimizing directly connected impervious areas, installation of porous paved surfaces and other facilities that promote stormwater infiltration and evapotranspiration (e.g., green roofs) and the use of stream buffers.

Figure 3. Cherry Creek without and with grouted-sloping-boulder grade control. Note the 2-meter down cutting and the bank erosion in the uncontrolled reach on the left.

Structural BMPs are facilities that help reduce surface runoff volumes and rates and remove pollutants of concern from the runoff. Those currently recommended for use in the Denver metropolitan area (UDFCD, 1999) include: (1) Grass buffers, (2) Grass swales, (3) Porous pavement, (4) Porous pavement detention, (5) Porous landscape detention, (6) Extended-detention basins, (7) Sand-filter basins, (8) Constructed wetland basins, (9) Retention ponds, and (10) Constructed wetland channels. Master planning for urban and urbanizing watersheds identifies the most appropriate control measures and optimum locations to best mitigate the effects of urbanization on the receiving waters. However, in watersheds where the local jurisdictions do not have sufficient institutional systems and/or fiscal means to implement the regional facilities in the master plan, the planning process has to recognize such realities and recommend appropriate on-site structural BMPs that are implemented on a land development-by-development project basis.

Assessing effectiveness of BMPs to mitigate the impact of urbanization on streams is an evolving science. Recent studies are beginning to shed some light on the interaction of BMP types, their use and the environmental response they impart on receiving headwater streams. These early field studies are showing that it may not be possible to maintain pristine conditions in the receiving streams, but they can be maintained at a fairly good biological integrity through the use of volume control and extended-detention types of BMPs (Horner, et. al., 2002).

IMPLEMENTATION

The success of any master plan depends upon whether or not it is implemented. The master plan provides a "roadmap" for the future and provides the basis for incorporating the facilities and practices it recommends as land-use changes occur or when funds become available to design and build new facilities. It also provides coherence of function so that each stormwater management facility, whether a channel, culvert, storm sewer, or detention basin provides the needed function to make the entire system work. For example, each time a parcel of land is proposed for urban development, the master plan guides the facilities that are to be provided by the new development and how they are integrated into the system as a whole. Site drainage cannot function in a vacuum; it is affected by what happens upstream and, in return, affects what happens downstream.

When implementing a master plan a certain amount of flexibility is warranted, however, the spirit of the plan and its major features must not be compromised if the community desires to have the system function as intended in the plan. Nevertheless, some modifications of the plan are expected over time. Any major omission of a critical plan element, such as a regional flood-detention basin, will render the plan ineffectual and create a potential for damage to public health, safety, and welfare.

Any master plan is a living document. It cannot remain static for too long without outliving its usefulness. Thus as areas urbanize and facilities are installed, it becomes evident over time that the assumptions made when the plan was developed may have changed, or the community needs are not the same anymore. As a result, most master plans have to be updated over time. The District has developed over 120 master plans since 1970. About one-third of these are updates of older versions.

What has been learned over these years is that older plans require, for the most part, only minor technical modifications to provide flood-control systems that have similar service levels. On the other hand, community demands do change and the type of facilities being recommended can change. For example, a concrete-lined channel may have been acceptable 20 years ago, but now the community wants greenways and accessible open water. In some cases, a community did not follow the recommendations in the old master plan and the update has to deal with more restrictive conditions, especially lack of land availability. In addition, new requirements such as water-quality provisions must be addressed when formulating updated recommendations.

Figure 4 shows a grouted boulder drop structure that was installed in the Cherry Creek channel to arrest its continued degradation. A series of grade-control structures were recommended in a master plan for Cherry Creek that addressed, among other things, the fact that the channel bottom is eroding out and the concrete walls and adjacent infrastructure was being undermined. The master plan did not recommend the specific shape or materials to be used for this structure. These items were defined during final design and addressed community, aesthetic, public safety and other needs at this location. This is an example of how individual items in a master plan can be implemented over time as the need for its implementation is scheduled or emerges and funds become available.

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Figure 4. A grouted boulder grade control structure in combination with a trail crossing along Cherry Creek at a highly developed central city site.

SUMMARY AND CONCLUSIONS

Master planning procedures utilizing a systems approach, that began in the Denver area in early 1970s by addressing only municipal drainage and flood-control issues, have evolved over the years through the completion of over 120 master plans into holistic efforts that address a broad array of needs in urban and urbanizing watersheds. One of the principal goals today is to prevent significant degradation of the natural waterways, be they gulches, streams, rivers, lakes or reservoirs. As a result, master plans now address water quality, quantity, system stability and the aquatic habitat needs of the receiving waters. They also integrate flood control, fluvial geomorphology, water quality and surface runoff management concerns.

The authors illustrated some of the problems and issues more specific to the problems in semi-arid regions. These include a more dramatic shift in hydrology as the lands urbanize than seen in more water-rich areas of United States and elsewhere. The effect being much quicker and more dramatic increases in channel degradation and erosion and much greater percent increase in the pollutant loads reaching natural waterways. Nevertheless, these same impacts are seen and exist in wetter climates, but may take more time to manifest the symptoms to the point where they are noticeable.

Some of the master planning principles used over 20 to 30 years in the Denver metropolitan area have proven to be very successful. The approach currently used has evolved over the years to have much greater focus on the needs of the receiving streams and their natural resources. Thus, for stream protection reasons, it is recommended that the following four principles, among others, be looked at when conducting master planning studies in urban and urbanizing watersheds (UDFCD, 1999):

(1) Incorporate surface runoff volume reduction features and facilities as much as practicable when lands are projected to urbanize,

(2) Treat any residual runoff through the use of a clearly specified water quality capture volume (WQCV), sufficient in size (Guo and Urbonas, 1996) to capture the most frequent storm events and release these volumes slowly to minimize the energy of flow in the receiving streams,

(3) Stabilize natural waterways that receive urban runoff through the use of grade controls and other means as needed, and

(4) Provide additional measures to prevent contaminated industrial/commercial runoff and to capture contaminated spills before they reach receiving waters.

REFERENCES

APWA (1981). *Urban stormwater management*, Special Report No. 49. ISBN 0-917084-41-1. American Public Works Association, Kansas City, MO, USA.

ASCE and WEF (1992). *Design and construction of urban stormwater management systems.* ISBN 0-87262-855-8. Am. Soc. of Civil Eng., Reston, VA, USA.

Bledsoe, B. (2002). "Relationships of stream response to hydrologic changes," *Proceedings of a 2001 E.F. Conference: Linking Stormwater BMP Designs to Receiving Water Impact Mitigation*, p. 127-144. ISBN 0-7844-0602-2. Am. Soc. of Civil Eng., Reston, VA, USA.

Buie, E.C. (1970). "Planning water control for urbanizing watersheds." *Proceedings: ASCE National Water Resources Engineering Meeting*, Am. Soc. of Civil Eng., Reston, VA, USA.

DeGroot, W.R., and Urbonas, B.R. (2000). "Added benefits of grade control structures." *J. Floodplain Mgt.,* Floodplain Management Association, **2**(1), 7-12.

Doerfer, J.T., and Urbonas, B.R. (1993). "Stormwater quality characterization in the Denver metropolitan area." *Flood Hazard News,* Urban Drainage and Flood Control Dist., Denver, CO.

Dunne, T., and Leopold, L.B. (1978). *Water in environmental planning*. ISBN 0-7167-0079-4. W.H. Freeman and Company, San Francisco, CA, USA.

Guo, J.C.Y. and Urbonas, B. (1996). "Maximized detention volume determined by runoff capture ratio." *J. Water Res. Plann. Manage.*, **33**(1), 102-113, Am. Soc. of Civil Eng., Reston, VA, USA.

Harvey, M.D., and Watson, C.W. (1986). "Fluvial processes and morphological thresholds in incised channel restoration." *Water Resources Bulletin*, AWRA, **22**(3), 359-368.

Horner, R., May, C., Livingston E., Blaha D., Scoggins, M., Tims, J., Maxted, J., (2002). "Structural and non-structural best management practices (BMPs) for protecting streams," *Proceedings of a 2001 E.F. Conference: Linking Stormwater BMP Designs to Receiving Water Impact Mitigation*, p. 60-77. ISBN 0-7844-0602-2. Am. Soc. of Civil Eng., Reston, VA, USA.

Leopold, L.B., and Miller, J.P. (1956). *Ephemeral streams—Hydraulic factors and their relation to the drainage net*, U.S. Geological Survey Professional Paper 282-A.

Leopold, L.B. (1968). *Hydrology for urban land planning—A guidebook on the hydrologic effects of urban land use*, U.S. Geological Survey Circular 554.

MacRae, C.R. (1996). "Experience from morphological research on Canadian streams: Is control of the two-year frequency event the best basis for stream channel protection?" *Proceedings of an E.F. Conference: Effects of Watershed Development and Management on Aquatic Life*, ISBN 0-7844-0602-2. Am. Soc. of Civil Eng., Reston, VA, USA.

Nardi, C., and Roesner, L.A. (2003). "Making the case for stormwater volume controls." *Proceedings: Experience with Best Management Practices in Colorado,* Urban Drainage and Flood Control District, Denver, CO, USA. pp. 61–73.

Schueler, T. (1994). "The importance of imperviousness." *Watershed Protection Techniques*, **1**(3), 100-111.

Sovern, D.T., and Washington, P.M. (1996). "Effects of urban growth on stream habitat." *Proceedings of an E.F. Conference: Effects of Watershed Development and Management on Aquatic Life*. ISBN 0-7844-0602-2. Am. Soc. of Civil Eng., Reston, VA, USA.

UDFCD (1999). *Urban storm drainage criteria manual: Volume 3 - Best management practices.* Urban Drainage and Flood Control District, Denver, CO, USA. (Revised Apr. 30, 2003). http://www.udfcd.org/usdcm/vol3.htm

UDFCD (1969). *Urban storm drainage criteria manual: Volumes 1 and 2*. Urban Drainage and Flood Control District, Denver, CO, USA. (Revised June 2001).

UDFCD (2001). *Urban storm drainage criteria manual: Volumes 1 and 2*. Urban Drainage and Flood Control District, Denver, CO, USA.

Urbonas, B., and Glidden, M.W. (1981). "Potential effectiveness of detention policies." *Flood Hazard News*, Urban Drainage and Flood Control District, Denver, Colorado, USA, http://udfcd.org/techpapers.htm

Urbonas, B.R. (2003). "Effectiveness of urban stormwater BMPs in semi-arid climates," *Proceedings: Experience with Best Management Practices in Colorado*, Urban Drainage and Flood Control District, Denver, CO, USA. April 2003, pp. 6–19, http://udfcd.org/techpapers.htm

U.S. EPA (1983). *Results of the Nationwide Urban Runoff Program: Volume 1-Final Report*, U.S. Environmental Protection Agency, Washington, DC, USA.

White, G.F. (1945). *Human adjustment to floods: A geographical approach to the flood problem in the United States*, Research Paper No. 29, University of Chicago, Department of Geography, Chicago, IL, USA.

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