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Learning from Nature: Reducing Urban Stormwater Impacts

by

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Learning from Nature:
Reducing Urban Stormwater Impacts

Jim Wulliman and *Paul Thomas*

The transformation of undeveloped land into our urban fabric of buildings and pavement typically increases surface water runoff, which can accelerate the erosion of drainageways and increase pollution loading to receiving waters. These stresses have ripple effects in the environment and in municipal budgets, which often are unprepared to deal with the costs of mitigating impacts to streams, lakes, and infrastructure.

Increased urban runoff and its associated impacts are caused by impervious surfaces that no longer infiltrate rainwater and by drainage facilities that capture runoff from these surfaces and accelerate it to the nearest drainageway. While many communities have adopted measures to reduce these negative effects, most programs don't come close to re-establishing the dynamics of a natural system that are necessary to have healthy streams and lakes (Figures 1 and 2).

Several stormwater management approaches recently explored in the Denver, Colorado area are attempting to "learn from nature" and incorporate beneficial features, functions, and processes that have been observed in nature. Using natural processes as a design guide can yield stormwater facilities that are functional, cost-effective, and attractive to people and wildlife.

Rainfall and Runoff in Natural Areas

Prior to any development, a natural area such as a prairie grassland has a capacity to absorb almost all rainfall events, producing surface runoff during

Figures 1 and 2. Urban pavement and roofs typically reduce the infiltration of rainfall into the ground, increasing surface runoff and contributing to stream degradation, habitat disruption, and increased pollutant loading to lakes and other receiving waters.

the most intense storms that on the average, less than once every year or two. When runoff does occur, flow patterns in natural areas are often shallow, wide, and relatively slow. Vegetation can provide significant resistance at shallow flow depths, holding back the water and keeping it from combining quickly with other flow streams and adding up to high runoff rates. It is generally only the largest storms that cause erosion and produce significant pollutant loads.

The capacity for infiltration, the resistance to flow, and the substantial flood storage found in nature are radically reduced in most urban environments. High rates and volumes of runoff also produce significant pollutant loadings, during almost all rainfall events, exceeding a tenth of an inch of rainfal. These small storms occure many times per year (Figure 3).

Integrating Natural Processes in an Urban Environment

Infiltration, resistance to flow, and flood storage can be integrated into urban projects to a greater degree than what has been typical of past practices. Natural processes can be emulated in the design of stormwater facilities to enhance their effectiveness and attractiveness.

Three stormwater management approaches being implemented in the Denver, Colorado area – each taking its design cue from processes observed in nature – serve to re-create more natural rainfall-runoff relationships and reduce urban stream erosion and pollutant loading. These three approaches include:

- creating healthy stream channels,
- designing effective stormwater detention, and
- increasing infiltration of site runoff.

Creating Healthy Stream Channels

Healthy stream channels – channels that are stable, well vegetated, and have natural floodplain overbanks – are able to relieve energy during high water events by allowing runoff to spread into the overbanks. Under the right conditions, this may slow the water down, reduce erosional forces, and, to some degree, increase the storage and infiltration of runoff. Water quality in smaller ruinoff events may be enhanced through vegetative filtering, infiltration, wetland processes, and arresting the erosion of bed and bank material that, in Colorado's Front Range, often contains significant amounts of adsorbed nutrients such as phosphorus. Nutrients are linked to high levels of algal productivity and eutrophication in Colorado lakes.

Figure 3. Emulation of natural processes -a design goal for this constructed wetlands detention basin in Greenwood Village, Colorado—allows stormwater management facilities to be functional, cost-effective, and attractive to people and wildlife.

However, increased urban runoff (i.e., peak flows and volumes) often degrades streams, creating deep, eroded channels that are inherently unstable and are subject to high flow velocities, eroision, and high sediment loads. Degraded urban channels typically require checks or drop structures to control the grade of the drainageway, rock riprap to stabilize banks, and revegetation to restore disturbed areas. The design of drainageway rehabilitation projects in the Denver area is evolving to the point where engineers are routinely working with landscape architects, plant ecologists, and wildlife biologists to incorporate the best characteristics of healthy, natural streams into urban drainageway improvement projects.

One example of this approach is the Cottonwood Creek Project in southeast Denver. The project was recently constructed by the Cherry Creek Basin Water Quality Authority to help reduce the amount of sediment and phosphorus entering Cherry Creek Reservoir from a tributary with typical urban stream issues. The project involved filling in a deep, actively eroding channel to create a shallow, stable base flow channel meandering through riffles and pools. The rock riffles, constructed to replicate similar natural grade control formations observed in a nearby creek, provide grade control, energy dissipation, and aquatic habitat. The raised base flow channel is less than 2' below the surrounding overbanks, keeping the water table close to the ground surface to encourage the growth of riparian and upland vegetation, and allowing flood flows to spill into the wide overbank areas. This natural floodplain approach keeps velocities low and flood storage high, while enhancing water quality through infiltration, wetland processes, and control of channel erosion (Figures 4, 5, and 6).

Designing Effective Stormwater Detention

The basic urban management technique for providing flood storage and attenuation is stormwater detention, which replaces some of the losses in natural storage that results from urbanization. Stormwater detention consists of constructing impoundments that capture runoff during a storm and release it at reduced rates. However, when runoff is released from a number of individual detention basins over extended periods of time, the flows add to each other as they travel downstream, resulting in increased peak flows along the receiving waters. This diminishes the effectiveness of detention basins as a watershed management strategy. Also, most detention basins do not provide much flow reduction in the small, frequent storms that exacerbate stream erosion and diminish water quality in urban environments.

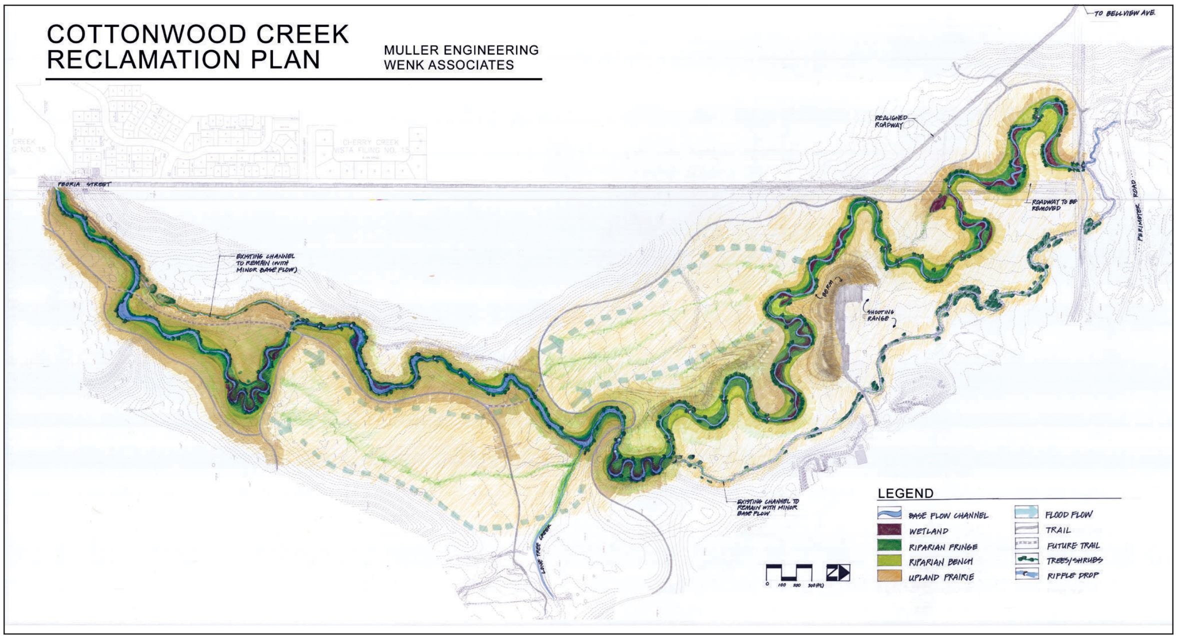


Figure 4. The Cottonwood Creek Project created a meandering base flow channel with rock riffles and pools and adjacent wide overbank areas where high flows can spread out to dissipate energy. The project, emulating a natural floodplain stream, was constructed by the Cherry Creek Basin Water Quality Authority to help protect Cherry Creek Reservoir.

Figure 5. Prior to the project, Cottonwood Creek was deeply incised and actively eroding, conveying phosphorus-laden sediment to Cherry Creek Reservoir.

A new detention concept is being explored in the Denver area that holds the potential for more effective peak flow reduction. The concept, called *full-spectrum detention,* has been shown through computer simulations to closely match pre-development runoff peaks both for large floods and smaller, frequent rainfall events, even for large watershed areas combining many individual detention facilities. The concept is described in detail in a paper posted for comment at the Web site of the Urban Drainage and Flood Control District (UDFCD) at http://udfed.org/technpapers.htm.

The concept works by trapping the additional volume of runoff that is generated by the urban impervious area ("excess urban runoff") and releasing it very slowly, while passing the balance of the runoff (approximating the pre-developed runoff volume) through a control outlet that reduces the peak flow to pre-development rates. The volume of "excess urban runoff" is surprisingly constant for a wide range of storms, based on Denver rainfall-runoff analyses. Once this excess volume is "swallowed up," controlling the residual runoff becomes easier; a single outlet sized to match pre-development 100-year release rates also effectively controls a full range of more frequent storms. The total 100-year detention volume required is slightly greater than current practice, but with what appears to be far more effective results.

Although *full-spectrum detention* will not totally eliminate the destabilizing effects of urbanization, it is expected that stream degradation will be reduced as runoff volume and peak rate are kept closer to pre-development

Figure 6. The project's grade-control structures were designed to emulate natural stream riffles using a mix of rock observed in a nearby creek.

Figure 8. Green roofs, like this garden area over a parking garage in Denver, Colorado, allows rainfall to infiltrate, reducing surface runoff and pollutant loading.

conditions. For these benefits to be realized, however, *full-spectrum detention* must be uniformly applied (i.e., no exceptions for public streets and other urbanization) and an ongoing maintenance program is necessary to assure the long-term performance of the basins.

Full-spectrum detention will help protect stormwater quality in other ways, too. A portion of sediment and other settle-able pollutants will drop out in the detention basin as the excess urban runoff volume is slowly released. If all or a portion of the excess urban runoff volume is encouraged to infiltrate into the ground following a storm, even greater pollutant removal may be possible, although groundwater protection and water rights issues need to be addressed in this case (Figure 7).

Increasing Infiltration of Site Runoff

The key to increasing the amount of rainfall that infiltrates into the ground on a development site is relatively simple—disrupting the direct flow of runoff from paved areas to storm drains and, instead, providing opportunities for runoff to travel over vegetated soil. Reducing or disconnecting impervious surfaces, using porous pavement, and conveying runoff over vegetated ground surfaces serves to filter, infiltrate, and attenuate runoff. This process, advanced in Prince George's County, Maryland, under the heading *Low Impact Development* (LID), has been encouraged for many years by th UDFCD as *minimizing*

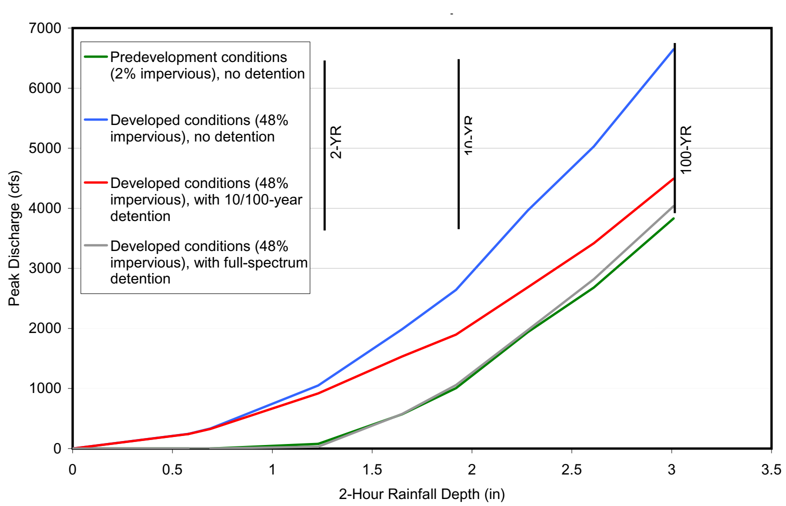
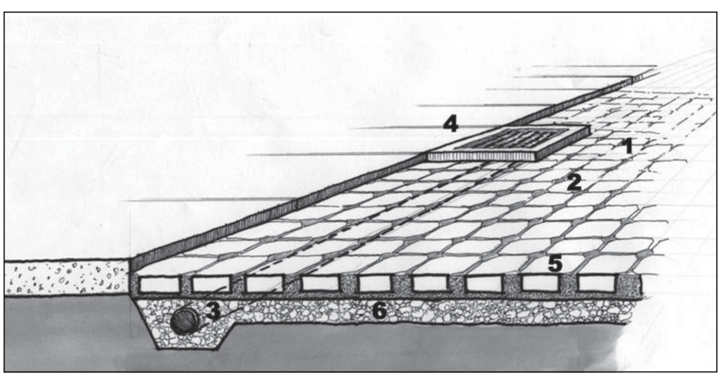


Figure 7. The full-spectrum *detention concept provides closer matching of natural, pre-development flow rates than conventional detention designs, especially for frequent, smaller storm events. It is expected that this detention concept could help reduce stream degradation and pollutant loading in urbanizing watersheds.*

Figure 9. Runoff drains through a spout from the roof of this office building in Denver to a splash block and rain garden below, creating an interesting landscape element while promoting infiltration.

Figures 10 and 11. Grass swales in residential and commercial areas are viable substitutes for inlets and storm sewers, slowing flows and enhancing infiltration and treatment of runoff.



Figures 12 and 13. Paving stones with an underlying rock base provide an attractive and functional porous pavement to infiltrate runoff at this Denver office building site.

directly connected impervious area (MDCIA). These practices reduce urban runoff to levels closer to natural, pre-development hydrologic conditions (see figures 8 through 15).

A number of specific techniques for reducing runoff are promoted in UDFCD's Urban Storm Drainage Criteria Manual, including:

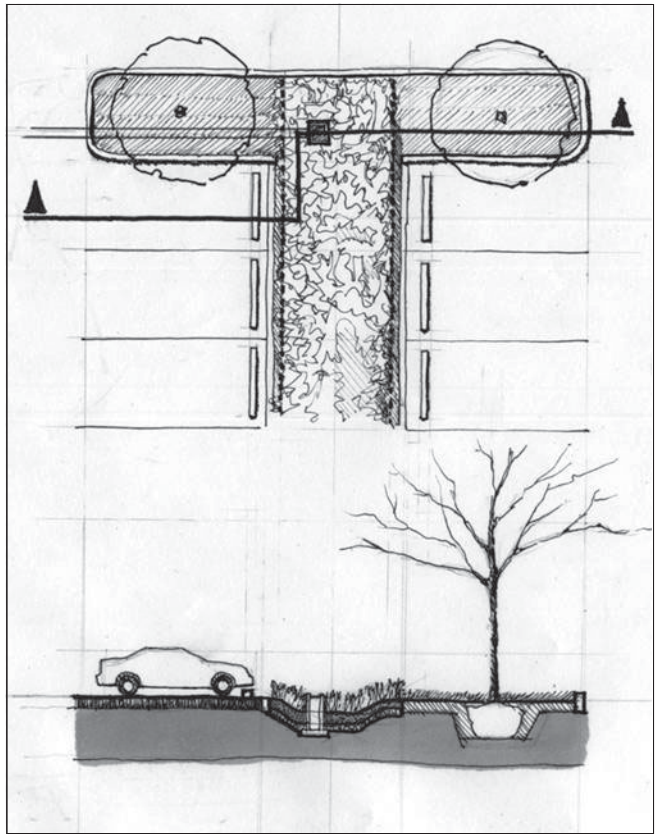
- allowing runoff to drain across grass buffers and through grass swales instead of conveying flows directly from roofs or pavement into a storm sewer;
- reducing pavement and using porous pavement; and
- incorporating porous landscape detention ("bio-retention" in LID terminology) in selected areas of the site.

These practices that promote infiltration can be adapted to fit into the character of the development area in which they are being employed. While emulating natural processes to improve water quality, they do not have to appear "wild" and can in fact be very urban, modern landscape elements. Creative designers are incorporating water quality treatment devices into site landscaping, plazas, and even roof gardens. Whatever form these facilities take, they function at their best when they add value to the site and are maintainable for the long term.

The City and County of Denver has recently produced a guidance manual to further illustrate how these techniques can be integrated into site plans (see design principles in related article on page 31). The manual is directed not just to design engineers, but to land owners and site planners, to encourage integration of these best management practices (BMPs) right from the start.

Stormwater Management Based on Natural Processes

By designing stormwater management facilities that approximate the infiltration, resistance to flow, and flood storage that can be found in nature, urban projects can come closer to replicating the rainfall-runoff conditions found in nature. Stormwater runoff, stream erosion, and pollutant loading can be reduced during the most frequent rainfall events, helping to protect the water quality of our streams and lakes.



Figures 14 and 15. Parking lot medians and islands provide opportunities to capture runoff from paved surfaces and allow it to infiltrate through planted sandy soil material, a BMP termed bio-retention or porous landscaping detention.

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Design Principles for Stormwater Best Management Practices (BMPs)

The following design principles, summarized from the City and County of Denver's *Water Quality Management Plan*, provide a foundation for developing stormwater BMPs for a site, especially BMPs that enhance infiltration and reduce runoff.

Principle 1: Consider stormwater needs early in the development process.
Left to the end of the site development process, stormwater facilities will often be "shoe-horned" into the site, resulting in forced, constrained approaches. Stormwater quality and flood control requirements are just as fundamental to good site design as other elements such as building layout, grading, parking, and streets. Dealing with stormwater quality after major site plan decisions have been made is too late.

Principle 2: Take advantage of the entire site when planning for stormwater management facilities.
Often, stormwater quality and flood detention is dealt with only at the low corner of the site, and ignored on the remainder of the project. Spreading runoff over a larger portion of the site reduces the need for big corner-of-site basins that are often walled, unattractive, and difficult to maintain.

Principle 3: Consider runoff reduction techniques a prerequisite for other site BMPs.
The benefits of implementing runoff reduction are often overlooked. The techniques can lessen degradation in downstream channels, reduce pollutant loads, allow smaller detention facilities that require less area, and can help create an attractive site.

Principle 4: Integrate stormwater quality management and flood control.
Both stormwater quality, dealing primarily with small, frequent storms, and flood control, addressing large infrequent events, need to be integrated in a site's stormwater management system. Detention basins can be combined to handle both types of storms, or separate systems can be designed for water quality and flood control.

Principle 5: Design facilities that can be effectively maintained.
A key to public acceptance of stormwater management facilities is to create features that will endure and that are designed with maintenance in mind. Equipment access for sediment removal is especially important.

Principle 6: Develop stormwater quality facilities that are attractive.
Stormwater quality areas can add interest and diversity to a site. Public spaces like gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions. The goal is to create attractive facilities that enhance a community and to avoid designing BMPs that become nuisances or eyesores that detract from a site.

Principle 7: Address geotechnical and foundation design issues.
The emphasis on infiltration of rainwater heightens the need for good foundation design that addresses a range of potential soil-moisture issues. In Colorado, expansive soil is an especially critical issue that needs to be mitigated through facility placement, linings, under-drainage, and the like. Consideration of groundwater quality is also important; designers need to consider water quality effects associated with unwanted leaching of constituents from soils.

Principle 8: Design and maintain facilities with public safety in mind.
One of the highest priorities of engineers and public officials is to protect public health, safety and welfare. The design of stormwater quality facilities needs to consider public access issues and mosquito/West Nile virus concerns.