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Strategies for Managing the Effects of Urban Development on Streams

National Water-Quality Assessment Program

Circular 1378

U.S. Department of the Interior
U.S. Geological Survey

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Strategies for Managing the Effects of Urban Development on Streams

By Karen Cappiella, William P. Stack, Lisa Fraley-McNeal, and Cecilia Lane,
Center for Watershed Protection,

and

Gerard McMahon,
U.S. Geological Survey

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Contents

Acronyms and Abbreviations Used in This Report

BCG	Biological Condition Gradient
BMP	best management practice
CLEAR	University of Connecticut Center for Land Use Education and Research
CT DEP	Connecticut Department of Environmental Protection
EPT	Ephemeroptera, Plecoptera, and Trichoptera invertebrate species
ESD	environmental site design
ESL	Environmentally Sensitive Lands
EUSE	effects of urban development on stream ecosystems
IDDE	illicit discharge detection and elimination
LID	low-impact development
MMDS	Milwaukee Metropolitan Sewerage District
MS4	Municipal Separate Storm Sewer System
NAWQA	National Water-Quality Assessment Program
NEMO	Northland Nonpoint Education for Municipal Officials
NPDES	National Pollutant Discharge Elimination System
NURP	National Urban Runoff Project
NYCDEP	New York City Department of Environmental Protection
PAH	polycyclic aromatic hydrocarbons
PR	pollutant removal
RR	runoff reduction
RRM	runoff-reduction method
RSC	regenerative stormwater conveyance
SPA	Special Protection Area
TMDL	total maximum daily loads
UConn	University of Connecticut
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQPC	Water Quality Protection Charge

Chapter 1
Introduction

Early Americans recognized the need to manage routine activities within the urban environment to protect the water resources that are vital to the health of the community:

> *Ther shall no man or woman, Launderer or Launderesse, dare to wash any uncleane Linnen, drive bucks, or throw out the water or suds of fowle cloathes, in the open streete, within the Pallizadoes, or within forty foote of the same, nor rench, and make cleane, any kettle, pot, or pan, or such like vessell within twenty foote of the olde well, or new Pumpe: nor shall any one aforesaid, within lesse than a quarter of one mile from the Pallizadoes, dare to doe the necessities of nature, since by thse unmanly, slothfull, and loathsome immodesties, the whole Fort may bee choaked, and poisoned...*
>
> — Excerpt from the first sanitation law in Virginia, enacted in 1610 to control pollution in the 3-year-old colonial settlement at Jamestown (Virtual Jamestown, 2011).

Urban development remains an important agent of environmental change in the United States. The U.S. population grew by 17 percent from 1982 to 1997, while urbanized land area grew by 47 percent, suggesting that urban land consumption far outpaced population growth (Fulton and others, 2001; Sierra Club, 2003; American Farmland Trust, 2009). Eighty percent of Americans now live in metropolitan areas. Each American effectively occupies about 20 percent more developed land (for housing, schools, shopping, roads, and other related services) than 20 years ago (Markham and Steinzor, 2006). Passel and Cohn (2008) predict a dramatic 48 percent increase in the population of the United States from 2005 to 2050. The advantages and challenges of living in these developed areas—convenience, congestion, employment, pollution—are part of the day-to-day realities of most Americans.

Nowhere are the environmental changes associated with urban development more evident than in urban streams. The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program investigation of the effects of urban development on stream ecosystems (EUSE) during 1999–2004 provides the most spatially comprehensive analysis of stream impacts of urban development that has been completed in the United States. A nationally consistent study design was used in nine metropolitan areas of the United States—Portland, Oregon; Salt Lake City, Utah; Birmingham, Alabama; Atlanta, Georgia; Raleigh, North Carolina; Boston, Massachusetts; Denver, Colorado; Dallas, Texas; and Milwaukee, Wisconsin (fig. 1; see *Effects of Urbanization on Stream Ecosystems*). A summary report published as part of the EUSE study describes several of these impacts on urban streams (Coles and others, 2012):

- **Urban streams are affected by multiple stressors—** Analyses of how urban-related changes in stream hydrology, habitat, and chemistry relate to the species composition of biological communities indicate that no single environmental factor was universally important across all the study areas in explaining the effects of urban development on stream ecosystems. Even within a single study area, the three biological communities that were surveyed—algal, invertebrate, and fish—had different responses to urban development and changing environmental factors.

- **Response of stream biota to urban development varied across the country—** Stream ecosystems, as defined by factors such as climate, geology, topography, land cover, and dominant land-use patterns, are fundamentally different across the country. These regional factors create a template for the stream reach components of hydrology, habitat, and chemistry that influences the species composition of aquatic biological communities. Consequently, even as a watershed undergoes urban development in a particular region, biological communities of the stream will still retain certain characteristics of species composition that are relatively distinct for the region.

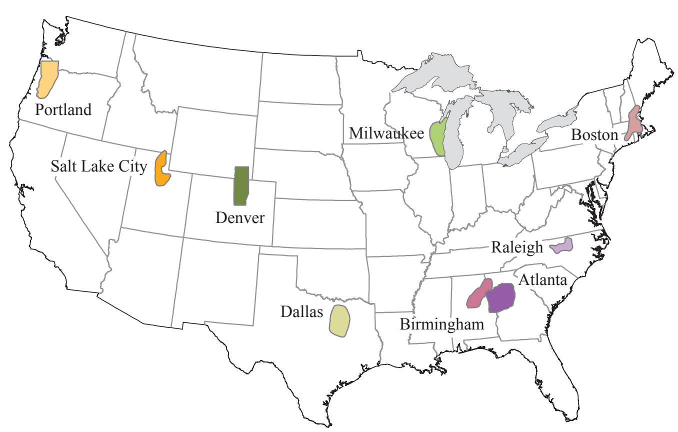


Figure 1. Streams from nine metropolitan areas across the continental United States were sampled to assess the effects of urban development on stream ecosystems.

- **Forested watersheds are likely to support the most sensitive biological communities—**In the Denver, Dallas, and Milwaukee study areas, the pre-urban land cover (grassland and agriculture) was an important factor in how the biological communities responded to urban development. In these three study areas, the decline in biological communities was consistently less than in the other study areas. The reason for this difference was not because biological communities in these regions are more resilient to stressors from urban development but because the biological communities had already lost sensitive species to stressors from pre-urban agricultural land-use activities (fig. 2).

- **Urban development significantly increases streamflow flashiness—**Urban development typically increases the amount of water entering a stream after a storm and decreases the time that it takes for the water to travel over altered land surfaces before entering the stream. Efforts to reduce flooding by draining water quickly from roads and parking lots can result in increased amounts of water reaching a stream within a short period of time, which can lead to stream flashiness and altered stream channels.

- **Urban development increases the number and concentration of contaminants in streams—**Concentrations of contaminants, including nitrogen, chloride, insecticides, and polycyclic aromatic hydrocarbons (PAHs), increased with urban development, although few measurements exceeded any human or aquatic-life benchmarks.

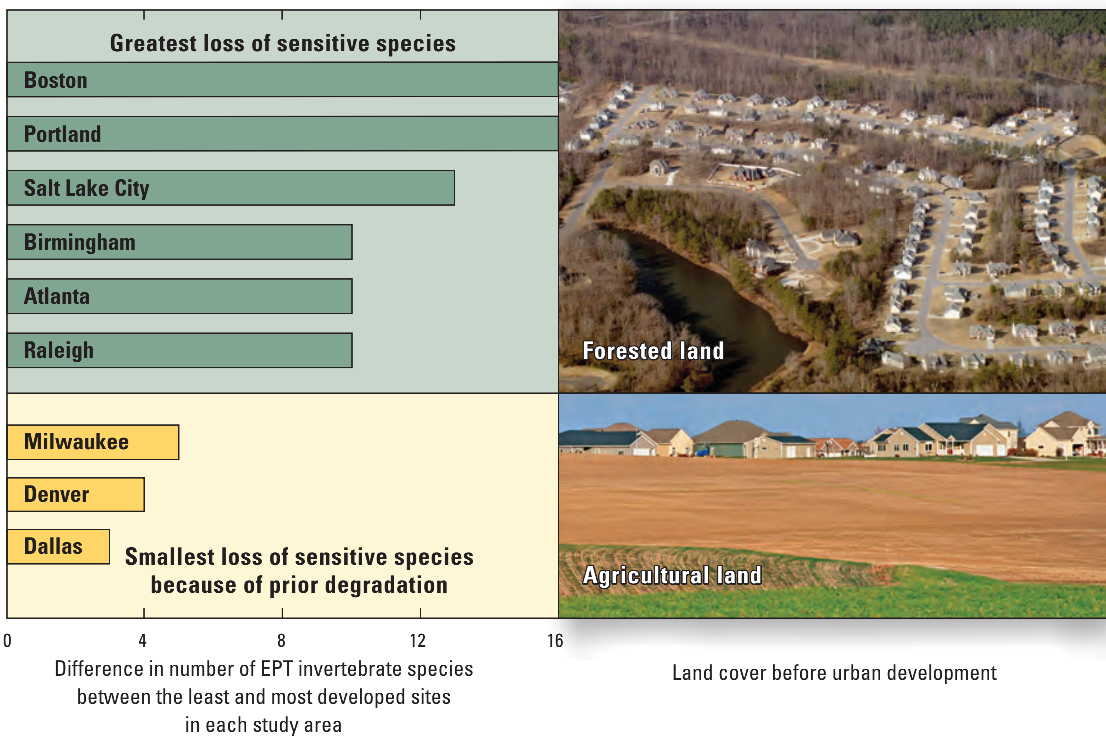


Figure 2. The loss of Ephemeroptera, Plecoptera, and Trichoptera (EPT) invertebrate species was greatest when urban development occurred on forested land (green bars). Fewer species were lost in streams of agricultural watersheds (yellow bars) because the biological communities already had endured some degree of degradation associated with agricultural land-use activities, and relatively sensitive EPT species were already absent in streams in these areas (from Coles and others, 2012).

Effects of Urbanization on Stream Ecosystems

The objectives of the effects of urban development on stream ecosystems (EUSE) study were to determine the magnitude and pattern of the physical, chemical, and biological response of streams to increasing urban development. The variations in these responses across the United States were addressed using data on streamflow conditions, stream habitat, and stream chemistry. Consistent sampling methods were used across the Nation to collect samples from streams in each watershed from three different communities of aquatic biota: algae, invertebrates, and fish in approximately 30 watersheds of similar size in each of the nine metropolitan study areas—Portland, Oregon; Salt Lake City, Utah; Birmingham, Alabama; Atlanta, Georgia; Raleigh, North Carolina; Boston, Massachusetts; Denver, Colorado; Dallas, Texas; and Milwaukee, Wisconsin. A great deal of research has been conducted by scientists working in government, academia, and other institutions (for example, Paul and Meyer, 2001; Walsh and others, 2005); however, the EUSE design for accomplishing these objectives was relatively unique. Investigations of the effects of urban development on stream ecosystems characteristically have focused on a particular environmental setting. The EUSE design enabled investigators to examine the stream ecosystem effects of urban development for a variety of distinct environmental settings across the continental United States. Rather than study how the physical, chemical, and biological characteristics of an individual stream evolve as the watershed urbanizes over time, this study employed a gradient approach, essentially trading space for time. Land cover in basins at the lower end of the gradient was assumed to represent the landscapes being converted to urban uses within each metropolitan study area. The physical, chemical, and biological characteristics of each of these watersheds represent the response to a given “level” of urban development; collectively, the responses across all watersheds in a metropolitan study area represent the pattern of stream ecosystem responses to increasing urban development.

Source for Additional Information

- National Water-Quality Assessment Program, Effects of Urbanization on Stream Ecosystems, accessed August 10, 2012, at *http://water.usgs.gov/nawqa/urban/*.

Purpose and Scope

This report serves as a companion report associated with the NAWQA effects of urban development on stream ecosystems Circular 1373, and illustrates management strategies used in the United States to reduce the impacts of urban development on stream systems described in Coles and others, 2012 (see *Effects of Urbanization on Stream Ecosystems*). Chapter 2 of this report presents a brief history of urban stream management in the United States, providing a context for the management strategies presented in later chapters. Chapter 3 introduces broad management goals linked to the USGS urban study findings about the relation between urban development and the physical, chemical, and biological condition of stream systems, and illustrates how these goals have been addressed using case study examples. Chapter 4 presents more detailed examples of management strategies that can be used to suppport the broad goals introduced in Chapter 3. The management strategies are drawn from the experiences of jurisdictions that are seeking to protect the condition of streams in urbanizing watersheds. These strategies are presented not as recommended courses of action but as examples of how municipalities have responded to the challenges of managing urban streams. Chapter 5 discusses three recurring challenges faced by those managing urbanizing streams as they develop and implement management strategies to improve the health of these stream systems.

Chapter 2

A Brief History of Urban Stream Management

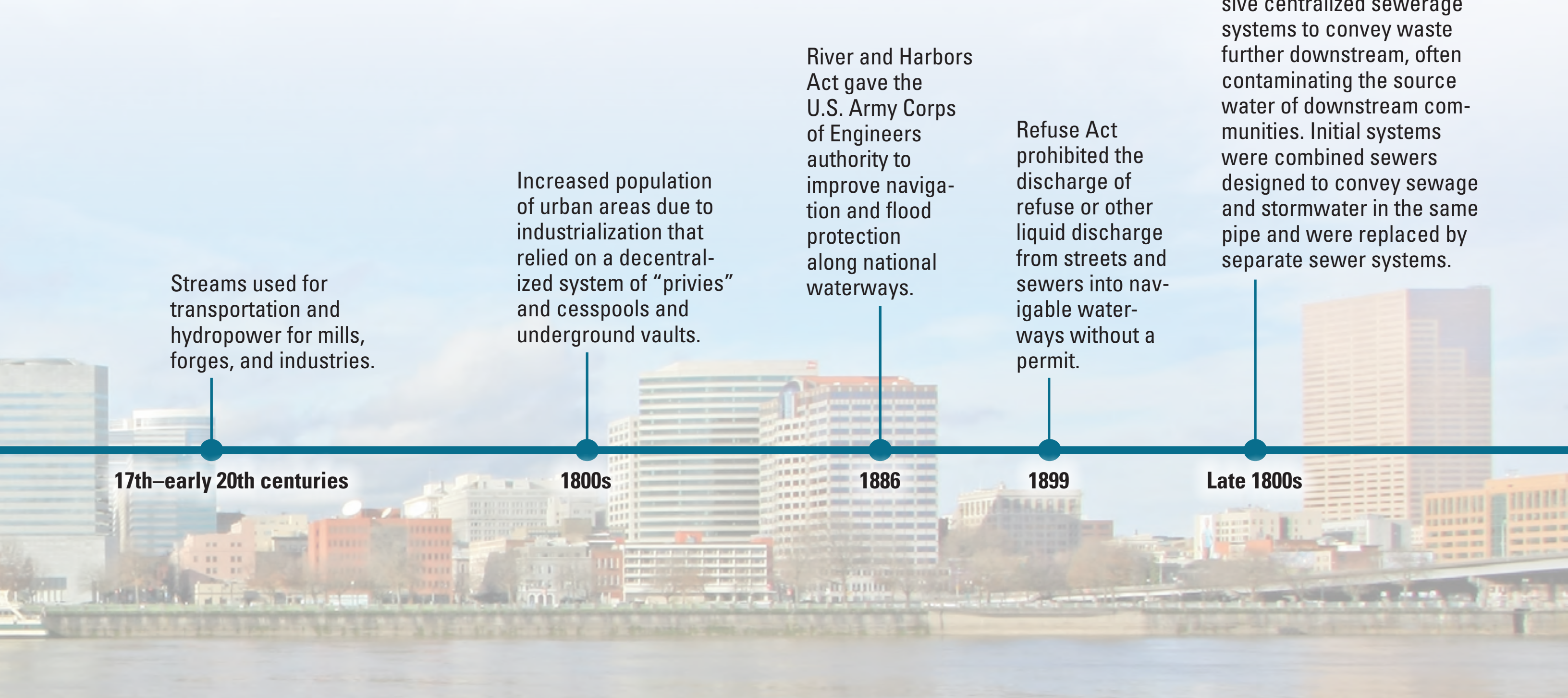
Urban stream management has evolved from the use of streams as conduits for waste to their gradual recovery by managing point and nonpoint pollution sources, rehabilitating the streams, and adopting stormwater management approaches that are more reflective of the natural hydrology of the land. The timeline below illustrates the major events, policies, and regulations that have influenced this evolution.

Streams as Conduits

The urban population of the United States increased from less than 5 percent in the late 1700s to 28 percent in 1880 (Kim, 2000). This expansion was accompanied by a continued reliance on a decentralized waste-disposal system comprised of "privies," cesspools, and underground vaults. These systems became strained as the population continued to grow, thus spilling untreated domestic waste, offal from stables, and wastes from slaughterhouses, kitchens, and industries into the Nation's waterways. Eventually, the amount of waste discharged far exceeded the capacity of these waters to process this material and resulted in noxious conditions and public health issues that included epidemics of cholera and typhoid outbreaks (Waring, 1883; Melosi, 2000; Levine, 2008).

Cities nationwide began to build large centralized sewerage systems in the late 1880s to convey these wastes further downstream, with the possibility for contaminating the source water for downstream communities. These pipe networks relied on gravity to convey flow; therefore, the logical placement of this infrastructure was in the stream valleys. This placement resulted in the straightening and engineering of the stream geometry to conform to the linear alignment of the pipe networks. Entire stream systems were piped and buried, not only alleviating flooding and disease, but creating useable land space for construction. Major metropolitan areas lost the majority of their small, headwater streams through this process. Philadelphia, for instance, lost approximately 73 percent (194 miles) of its stream network during the course of its development through piping (Philadelphia Water Department, 2008). While the River and Harbors Act of 1886 and later amendments authorized the U.S. Army Corps of Engineers to improve navigation and flood protection and prohibited dumping of refuse into navigable waterways without a permit, the disposal of municipal, agricultural, and industrial waste continued to be a legitimate and unabated use of urban waterways.

Major events in the history of urban stream impacts and management.



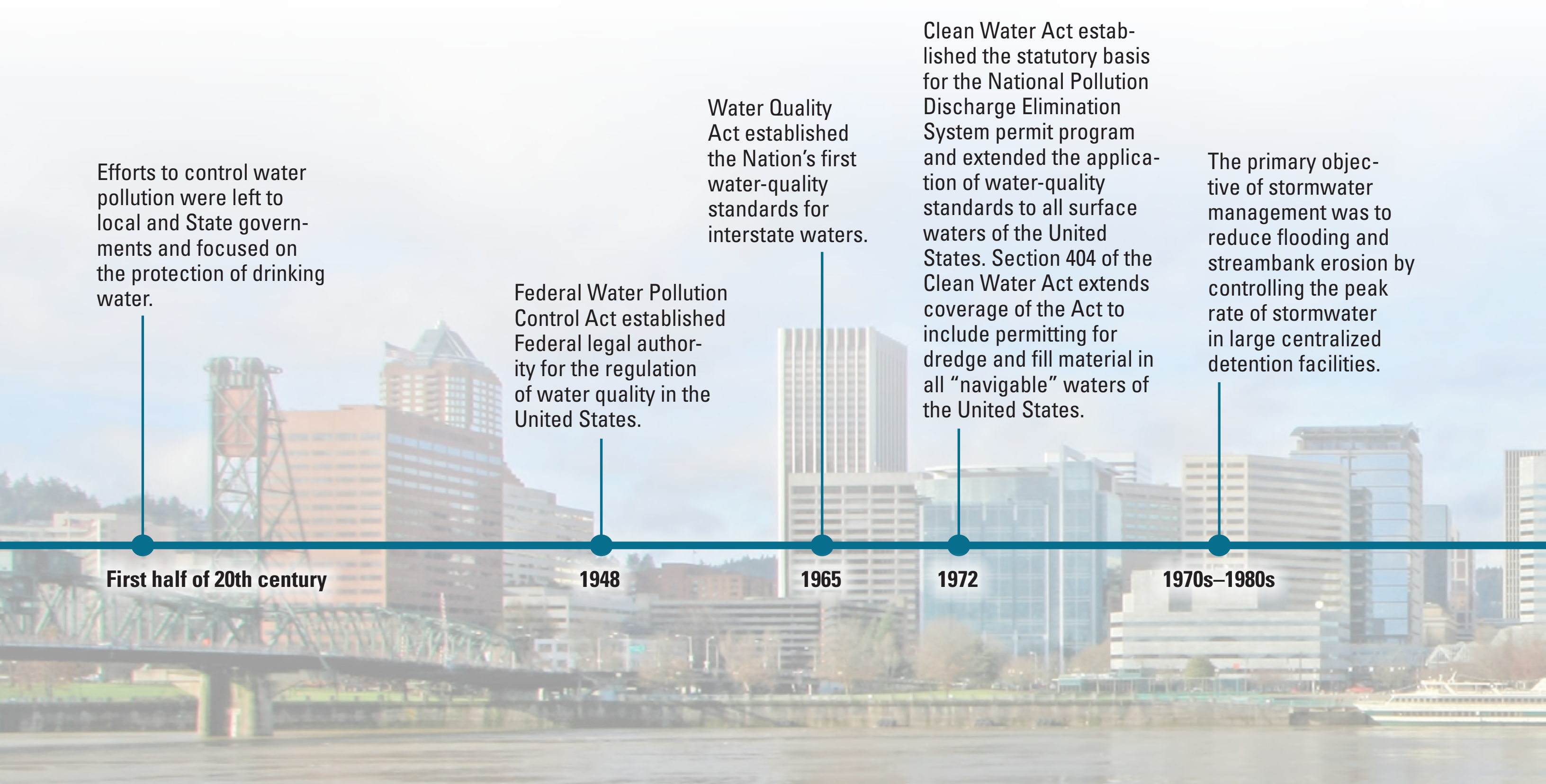
Early Efforts to Improve Water Quality by Regulating Point Sources

Efforts to control water pollution were the responsibility of local and State governments during the first half of the twentieth century, with the protection of drinking water being the primary focus (Ferrey, 2010). Continued growth of the Nation's population and industrial base meant that substantially more pollutants were discharged into area waterways, thus exceeding their capacity to assimilate these wastes. The conditions of the Nation's waterways became so degraded by the 1940s that Congress passed the Federal Water Pollution Control Act of 1948 (33 U.S.C. §§ 1251–1387; Ruckelshaus, 1972). This Act was the first comprehensive legislation to establish Federal legal authority for the regulation of water quality in the United States. The legislation adopted a cooperative approach to work with the States in developing plans to address water pollution and authorized the Surgeon General of the Public Health Service to prepare plans and programs to eliminate or reduce the pollution of interstate waters (fig. 3).

Amendments to the Act in 1972 changed the law so that water-quality standards applied not only to interstate waters but also to all surface waters of the United States (U.S. Environmental Protection Agency, 2010d). These amendments, known as the Clean Water Act, provide the statutory basis for the National Pollutant Discharge Elimination System (NPDES) permit program, which regulates industrial and municipal point sources (U.S. Environmental Protection Agency, 2011e). The objective of the Clean Water Act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (U.S. Environmental Protection Agency, 2010d).

Figure 3. Discharges of waste from industries into nearby waterways was once a common practice prior to regulated permitting under the Clean Water Act.

Major events in the history of urban stream impacts and management.

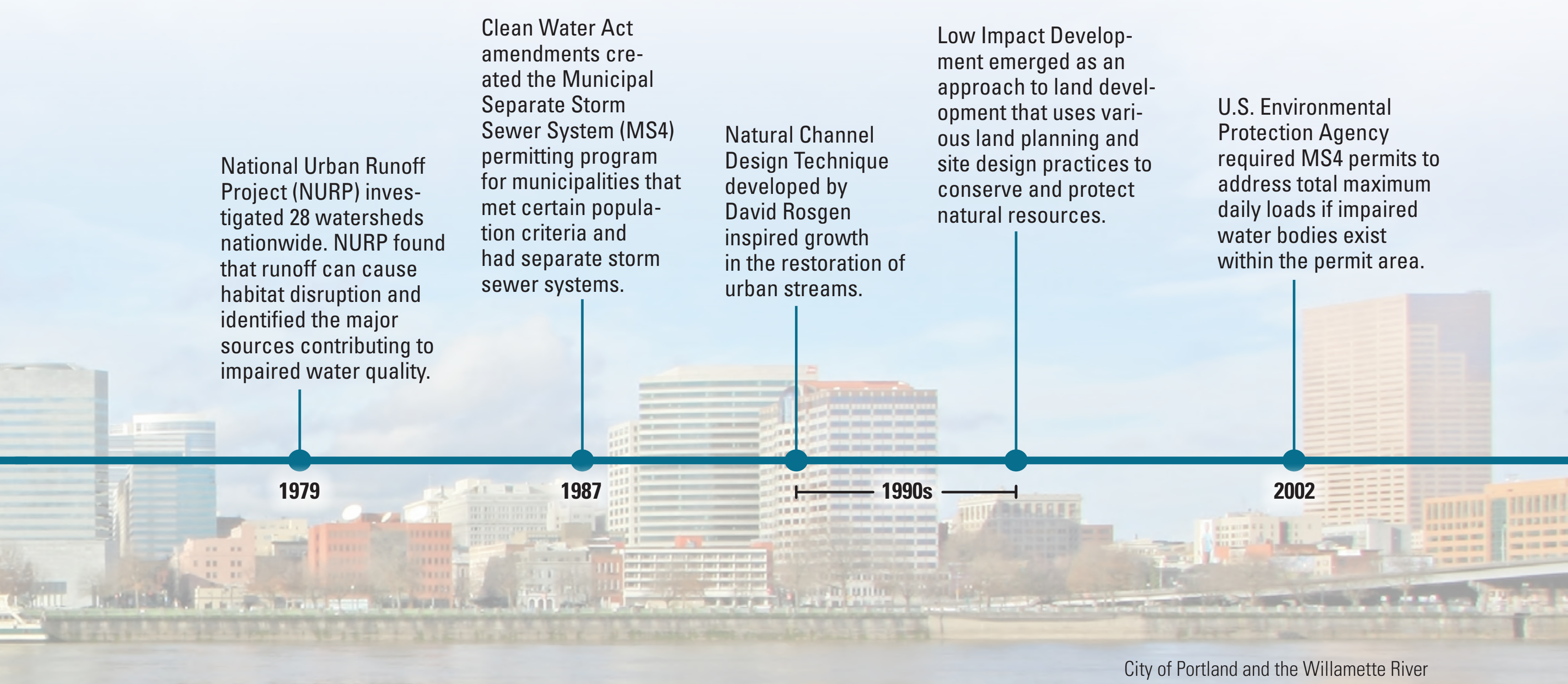


A Shift in Focus to Nonpoint-Source Pollution

Most of the effort and success of the Clean Water Act has been focused on the regulation of point sources, such as industrial and wastewater discharges. However, under Section 208 of the original Clean Water Act, States are required to designate area-wide wastewater treatment management planning agencies and to develop plans that include the control of agriculture, forest activities, construction activities, and the disposal of waste materials on land surfaces. This led to the implementation of local sediment and stormwater management programs and the pioneering of urban best management practices (BMPs), many of which were adapted from the agricultural sector.

Through the area-wide planning effort, the U.S. Environmental Protection Agency (USEPA) recognized that urban nonpoint-source pollution was one of the most prevalent and least understood issues contributing to the impairment of streams, groundwater, lakes, and estuaries. The USEPA initiated the National Urban Runoff Project in 1979 where 28 watersheds were selected nationwide to investigate the water-quality characteristics of urban runoff and the overall performance and effectiveness of BMPs at mitigating the effects on streams. The study results demonstrated the deleterious effect of urban runoff on stream ecosystems (U.S. Environmental Protection Agency, 1983). The study concluded that the physical impacts of runoff can be a major cause of habitat disruption in streams. Runoff from urban areas was shown to contain substantial quantities of the same general types of pollutants that are present in wastewaters and industrial discharges (for example, heavy metals, bacteria, synthetic organic compounds), often causing similar water-quality problems (fig. 4).

Figure 4. Water-quality sampling at stormwater outfalls, such as this one in Rock Creek, Oregon, has determined that runoff from urban areas contains an array of pollutants that are harmful to aquatic life.



City of Portland and the Willamette River

The knowledge gained from the National Urban Runoff Project influenced Congress to pass the Clean Water Act Amendments of 1987, which resulted in a comprehensive national program for addressing stormwater discharges. Municipalities in the early 1990s that met certain population criteria and that had separate storm sewer systems (referred to as "Municipal Separate Storm Sewer Systems" or "MS4s") were first issued 5-year permits that required the control of stormwater through programs such as stormwater retrofitting, elimination of illicit discharges, public education, stormwater runoff control from development sites, and sediment and erosion control.

The MS4 permits were initially programmatic in nature and not related directly to a specific water-quality outcome, although in 2002, the USEPA amended the guidance to state that MS4 permits must address total maximum daily loads (TMDLs) if impaired water bodies exist within the permit area. A TMDL is the amount of a pollutant that a water body can assimilate and still meet local water-quality standards. TMDLs are determined for impaired waterways, and pollutant load allocations are assigned to the major pollutant sources, such as wastewater-treatment plants and the municipal storm drain system. However, because of the variable nature of urban runoff, USEPA's guidance recommended that NPDES permit performance be measured by the degree of BMP implementation rather than by the quality of the stormwater discharging from pipes. This action allows, in theory, for an adaptive management approach, whereby permittees can use monitoring data to make adjustments to their BMP requirements as necessary to protect water quality. Unfortunately, developing and implementing an effective monitoring program to guide and fine-tune the selection of MS4 program activities have presented a substantial fiscal challenge to State and local jurisdictions.

Attempts to Restore Streams

Municipalities throughout the Nation soon recognized that programs that emphasize treating wastes before they enter streams (sometimes referred to as an "end of pipe" program), including the MS4 program, would be unlikely, by themselves, to restore streams to Clean Water Act standards. Physical repairs were needed in the stream channel to undo the degradation that had occurred over the past decades and centuries. Initially, improvements to stream channels were designed by hydraulic engineers and featured major structural interventions to reduce flooding and protect infrastructure (fig. 5). As a result of the Clean Water Act's broadening view of urban drainage to include concerns for ecosystem protection and urban sustainability (Burian and Edwards, 2002), a tremendous growth in the "restoration" of urban streams occurred in the 1990s (see *Urban Stream Restoration*).

Figure 5. This concrete channel in Villamann Creek, Wisconsin, is designed to quickly transport water downstream to reduce local flooding and protect infrastructure. Just upstream, the concrete channel was recently removed and a flood plain was created to provide more flood attenuation, habitat diversity, and beauty for stream and flood-plain organisms, including humans.

Urban Stream Restoration

The idea of urban stream "restoration" is a hotly debated topic among ecologists. The term itself is controversial, as some scientists believe that a stream cannot be considered "restored" unless its resulting physical, chemical, and biological characteristics are reflective of a natural or pre-disturbance condition, and that restoration to this degree is extremely difficult to achieve. A review of 24 different types of stream restoration practices (including over 450 individual practice installations) in Maryland and Illinois determined that, when sized, located, and installed correctly, these practices worked reasonably well in terms of some ecological outcomes, but the greatest deficiency identified was the inability of the practices to enhance habitat (Brown, 2000). Detractors also argue that restoration may be accompanied by large-scale construction that can devastate floral and faunal communities in the riparian corridor. Regardless of the impact in terms of ecological processes, restoration of degraded stream channels can ultimately result in an increase in tree canopy and shade, improved water quality, new recreational opportunities, and reduced erosion of property, outcomes that may provide important benefits to the people living or recreating near the restored urban stream.

Unfortunately, inadequate data are available to settle these debates. A nationwide study under the National River Science Synthesis (Palmer and Allan, 2006) concluded that of 37,099 stream "restoration" projects surveyed, only 10 percent had any form of assessment or monitoring. Despite this uncertainty, projects that mitigate some of the degradation that has occurred in urban streams may provide benefits that include cooler water temperatures, improved water quality, improved riparian habitat, stable streambanks, restoration of riffle-pool sequences enhancing fish and other aquatic habitats, and improved aesthetics (Kelly, 2001). Because of these benefits, watershed managers continue to value stream restoration to meet selected water-quality objectives. The management strategy, entitled Stream Repair, which is discussed later in this report, focuses on practices that provide ecological and (or) societal benefits.

Many urban stream restoration projects today are being integrated into a watershed planning framework that includes upland controls such as stormwater management (fig. 6). The scientific understanding of stream channel processes, especially in the urban setting, has evolved and continues to remain an active research area for the scientific community. Still, much of the focus of this work has been on understanding fluvial geomorphic processes. More applied research is needed to increase the understanding of stream ecosystem processes and to establish measureable outcomes, or endpoints for measuring the success of stream restoration, in terms that are meaningful both for natural floral and faunal communities and for people that live and recreate near urban streams.

Figure 6. Stream restoration project on an unnamed tributary to the Root River, Wisconsin. This formerly dry ditch in a major interstate interchange now provides diverse intermittent pool habitat for birds, insects, amphibians, and reptiles during dry spells. A 400-foot culvert under the road is designed to allow fish passage to headwater areas during runoff.

The Age of Low-Impact Development

Stormwater management has evolved considerably since the beginning of the MS4 program. Initially, the standard practice for treating stormwater runoff from development sites was to pipe runoff into a stormwater detention or retention pond. Controlling the peak rate of stormwater flow into the stream was intended to meet the primary objectives of reducing flooding and streambank erosion (fig. 7; National Academy of Sciences, 2008). However, when designed on a site-by-site basis without considering other hydrologic factors (for example, other stormwater facilities in the watershed), stormwater detention systems can actually worsen streambank erosion and contribute to downstream channel enlargement (Lee and Ham, 1988; MacRae, 1996). Although some stormwater detention BMPs provide reliable pollutant removal, primarily through settling of solids (American Society of Civil Engineers, 2007; Center for Watershed Protection, 2007), this approach generally does not reduce the volume of runoff from development sites, and provides only limited reduction of soluble pollutants (for example, nitrate). For example, seven research studies have concluded that stormwater ponds are incapable of preventing the degradation of aquatic life in downstream channels (Galli, 1990; Jones and others, 1996; Horner and May, 1999; Maxted, 1999; Maryland National Capital Park and Planning Commission, 2000; Horner and others, 2001; Stribling and others, 2001).

Despite these issues, centralized stormwater management facilities were the standard stormwater management practice (and still are in many regions) for addressing urban runoff issues. Not until the 1990s was a different philosophy embraced: low-impact development (LID). Low-impact development is an approach to land development that uses land planning and site design practices to conserve and protect natural resources, and has been adopted by many municipalities nationwide as the cornerstone of their MS4 stormwater management programs (fig. 8; Low Impact Development Center, 2000). Low-impact development moves beyond the implementation of stormwater practices to include strategic site design decisions throughout the development process aimed at minimizing adverse development impacts on the hydrologic cycle. The LID approach is gaining traction, especially given the recent promotion of these practices by the USEPA (Nancy Stoner and Cynthia Giles, U.S. Environmental Protection Agency, written commun., 2011). Future LID research and implementation efforts will involve continued integration of the LID concept with stormwater requirements for channel protection and flood control, so that stormwater criteria can be presented in a unified approach.

Progress in managing urban streams and their ecosystems during the past two centuries has been enhanced by the integration of science into the decision-making process. The following sections focus on how findings from the EUSE study and other research efforts can point toward more effective management strategies. This discussion highlights innovative management approaches being used today to protect and (or) rehabilitate urban streams.

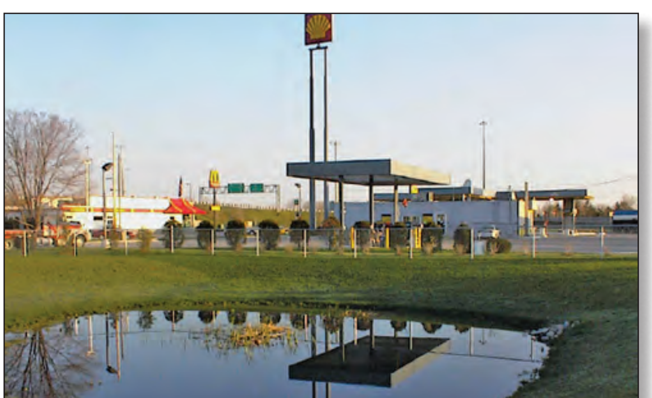


Figure 7. Traditional stormwater management focused on the use of large ponds to reduce the peak rate of stormwater flow and sediment concentrations. Photograph from Center for Watershed Protection.

Figure 8. Low-impact development (LID) is a more recent approach to stormwater management that uses site design to reduce runoff and conserve natural areas and incorporate smaller stormwater practices that are distributed throughout a site. This development in Charleston, South Carolina, includes several LID features, including open space preservation and the use of vegetated swales to convey and treat road runoff. Photograph from Center for Watershed Protection.

Source for Additional Information

- The Federal Water Pollution Control Act, as amended by the Clean Water Act, accessed August 10, 2012, at *http://epw.senate.gov/water.pdf*.

Chapter 3
Impacts of Urban Development on Streams and Implications for Watershed Management

If the chemical or biological conditions of a stream are meeting, or "attaining," water-quality standards, how can these conditions be maintained? If a stream is impaired, how can stream condition be improved? This chapter identifies a number of broad management goals that can be linked with U.S. Geologial Survey (USGS) urban study findings about the relation between urban development and the physical, chemical, and biological condition of stream systems (fig. 9). These goals are drawn from the experiences of communities across the Nation that are managing streams in urbanizing watersheds. Case studies are used to provide examples of how these goals have been addressed in jurisdictions throughout the United States.

Urban Streams Are Affected by Multiple Stressors

Determining which stressors are responsible for changes in the biological community in an urbanizing watershed presents substantial challenges for scientists. The characteristics of these stressors and their effect on algae, invertebrates, and fish may be difficult for non-scientists to understand (see *Understanding the Value of a Stream's Condition to Society*). Analyses of the responses of the three biological communities to changes in stream hydrology, habitat, and chemistry indicate that although urban development commonly leads to an immediate decline in the diversity of stream biota and the numbers of species sensitive to degraded streamflow, habitat, and stream chemistry conditions, no single factor is universally important in explaining responses to urban development across all study areas or biological communities (Brown and others, 2009; Coles and others, 2009; Cuffney and others, 2010). Because algae, fish, and invertebrates differ in their life cycles and requirements for food, shelter, and reproduction, these respective communities generally respond differently to stressors arising from changes in the physical and chemical processes that operate within the ecosystem. These differing responses can provide important clues about the types of stressors that are present in the ecosystem and may indicate potential avenues for management actions. These findings underscore the value of developing comprehensive watershed plans prior to urban development.

Because the degradation of aquatic biological communities begins at the onset of urban development, strategies that carefully manage development in undisturbed watersheds by using tools such as land-use planning and zoning may be needed to protect aquatic biological communities. In watersheds with impaired streams, opportunities to redevelop urban lands, including reducing, disconnecting, and (or) treating impervious cover, may provide a means to limit the adverse impacts to streams, because previous development of these lands often did not include measures to treat runoff from impervious surfaces. The responses of stream biota to urban development described in Coles and others (2012) indicate that stream-restoration efforts could have a positive effect on the biological condition and health of streams. Continuous declines in biological diversity and food-web complexity with increasing urban development may make streams more vulnerable to other changes, such as the introduction of non-native species. Management strategies that prevent rapid runoff from individual parcels of developed land to nearby streams also can help limit the transport of contaminants to the streams. These strategies can provide incremental improvements in the chemical condition of local waters and the reduction of pollutants delivered to downstream waters (Nisenson, 2005).

Figure 9. Urban sprawl in the west Atlanta Metropolitan Area, Douglas County, Georgia. Low-density large-lot residential development creates more impervious cover through more driveways, streets, and sidewalks than integrating small lots with public parks and natural areas.

The fish, invertebrate, and algae-specific response patterns to physical and chemical stressors underscore the advantage of evaluating more than one biological community when assessing the effects of disturbances to aquatic systems.

Response of Stream Biota to Urban Development Varies by Region Across the United States

Because of differences in climate, geology, topography, and historical land-use patterns, all of which define stream ecosystems, streams in different regions of the country respond differently to urban development (Kashuba and others, 2010). These environmental differences lead to variations in how hydrology, habitat, stream chemistry, and aquatic biota respond to urban development. These regional differences also were evident in the biological-community characteristics of streams with undeveloped watersheds and in the rate at which the biological communities changed as urban development occurred.

Management strategies that protect urban stream ecosystems recognize that the response of aquatic biota to urban development varies strongly from region to region across the country (fig. 10). Successful protection strategies account for the influence of regional characteristics, such as climate, geology, topography, and historical land-use patterns, and for the relations among multiple stressors and stream biota in a given region of the country. Achieving water-quality goals and preserving the integrity of aquatic biological communities is based on understanding how factors such as regionally specific setting, pattern of urban development, and physical and chemical stressors interact to influence the way a stream's health changes with urban development.

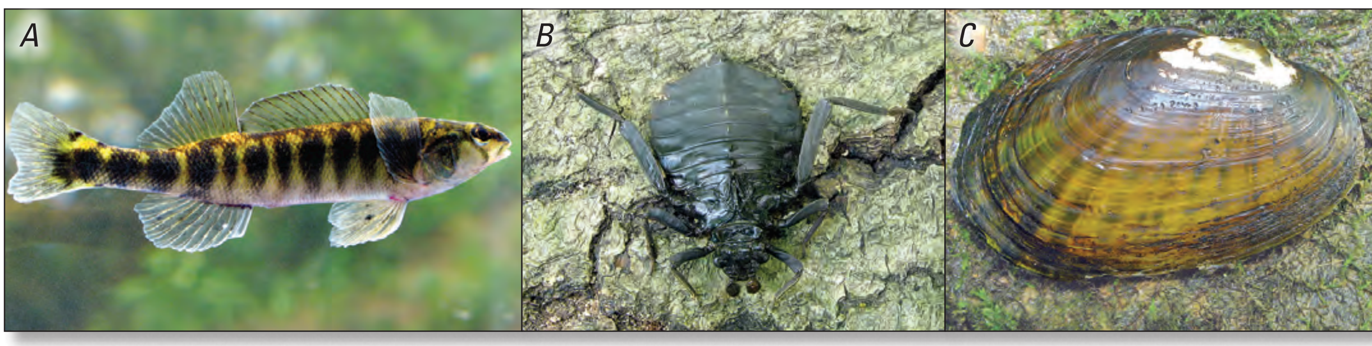


Figure 10. *(A)* The blackbanded darter, *(B)* nymph of the gomphid dragonfly *Hagenius*, and *(C)* southern rainbow mussel are all present in streams of the Cahaba Valley near Birmingham, Alabama. The presence and abundance of these organisms can be used to evaluate the conditions of streams in Alabama.

Understanding the Value of a Stream's Condition to Society

Natural and physical scientists have developed scientific measures to communicate information about the outcomes of physical, chemical, and biological processes associated with urban streams to a scientific audience. The public, however, may not think of these outcomes in the same terms, preferring to think about tangible benefits, such as revenue from tourism, or intangible benefits, such as the enjoyment of walking along a healthy stream. If stream condition is defined solely by using scientific metrics, such as chloride ion concentrations or the richness of Ephemeroptera, Plecoptera, Trichoptera (EPT) invertebrate species, which the public might not readily relate to or value, generating public support for the protection of urban streams may be hindered. As noted by Boyd and Banzhaf (2007), science-based information expressed only in terms that are meaningful to scientists cannot effectively influence public policy. Consequently, policymakers may not be able to make a direct connection between the condition of a stream described solely in scientific terms, however valid, and its impacts on people's well-being. For instance, even a complete and scientifically sound description of species diversity in a stream may not provide a meaningful connection to tangible benefits to people.

Environmental "endpoints" can be used for making a connection between scientifically oriented descriptions of stream conditions and the value that society places on these conditions. In order to provide a connection between the scientific and social domain, endpoints must make sense from both a scientific and a social-value perspective (Boyd and Banzhaf, 2007). From a scientific perspective, a useful environmental endpoint has several characteristics:

- Endpoints are biophysical results, such as EPT species richness or chloride ion concentration;
- Endpoints are tangible and can be measured in a consistent manner; and
- Endpoints make ecological sense; that is, they describe results of one or more ecological processes.

To be useful in determining the social value of an environmental outcome, ideally, an environmental endpoint should have these additional characteristics:

- Endpoints can be translated into terms that are commonly understood;
- Endpoints can be connected to some measure of human well-being that society cares about; and
- Endpoints are physically required for a societal benefit to be realized.

The Biological Condition Gradient (BCG) approach employed in the New England study described in Coles and others (2012) illustrates an approach to synthesize information about stream condition and societal benefits related to water quality in a way that meets the scientific and social criteria listed above. The BCG has six tiers for assessing the health of a stream by using biological samples. These tiers synthesize information about biological endpoints and the meaning of endpoints in terms of meeting or not meeting Clean Water Act standards. The assignment of a stream to any tier is based on a regionally appropriate assessment of a stream's aquatic biota, which is completed in a consistent, replicable, and scientifically accepted manner.

Because the BCG framework can be used to map changes in biological endpoints to levels of stream health, assignment of a stream to a BCG tier indicates if the stream is attaining water-quality standards of the Clean Water Act. The BCG tier to which a stream is assigned indicates to managers whether or not the stream meets a mandated standard for classification as a healthy stream. If not, enforcement actions, such as a required TMDL, can be taken, which could have important financial repercussions for an individual, corporation, or government jurisdiction.

Forested Watersheds Are Likely to Support the Most Sensitive Biological Communities

The EUSE findings indicate that degradation of stream biotic communities is generally more apparent in areas where urban development occurs on forested, rather than on agricultural land (fig. 11). This result is not because the biological communities in metropolitan areas developed on agricultural land were more resilient to stressors from urban development, but because the previous agricultural activities had already led to some degree of degradation in biological communities before urban development began. Watershed management strategies that conserve forests and reduce forest clearing during development and (or) increase tree canopy on urban land can limit the adverse impacts of urban development on stream aquatic biota.

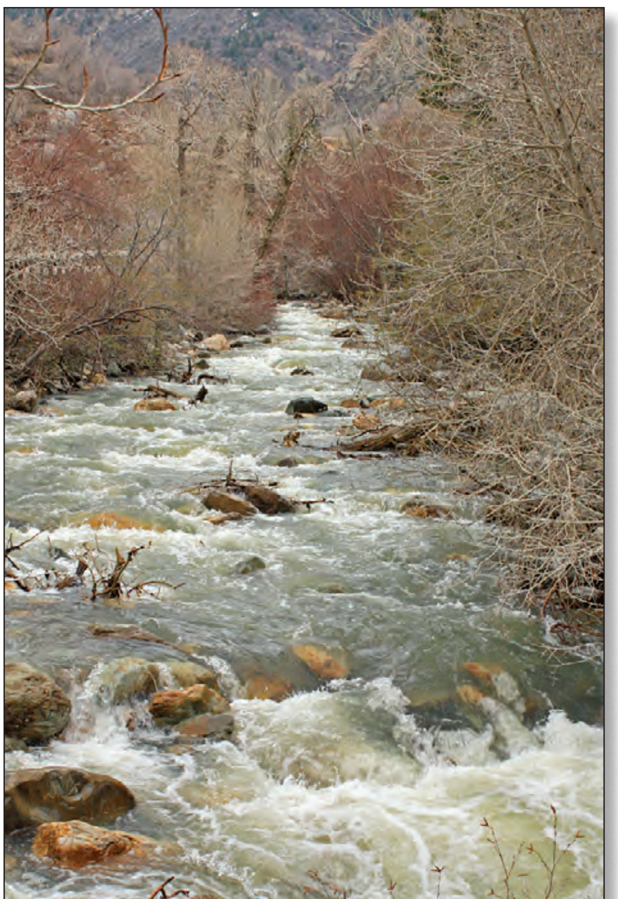


Figure 11. Streams draining forested watersheds are likely to support the most sensitive biological communities; therefore, forest conservation is particularly important to limit impacts as forested watersheds are urbanized.

Urban Development Substantially Increases Streamflow Flashiness

Landscape changes as a consequence of urban development, such as the addition of impervious cover and the compaction of soils, can substantially alter stream hydrology (Schueler and others, 2009; Steuer, 2010). Impervious cover can limit infiltration of precipitation to groundwater, so that stormwater flows quickly across impervious surfaces and is transmitted in storm drain pipes to streams, leading to a characteristic pattern of higher peak flows and "flashy" streamflow (fig. 12; Leopold, 1994; Guay, 1996; MacRae, 1996; Henshaw and Booth, 2000; Fongers and Fulcher, 2001). These changes also can result in down-stream channel incision, erosion, and widening, as well as loss of stream habitat and a decline in water quality (fig. 13; see *Urbanization and Stream Habitat*).

The encouragement of development patterns and storm-water management strategies that preserve the predevelopment hydrologic regime can minimize adverse effects of urban development. The implementation of stormwater BMPs in the 1970s and 1980s partially met this goal by controlling the peak rate of flow leaving a site. In some cases, however, this led to increased downstream flooding as a result of the cumulative increase in flow from individual development sites within a watershed because each site is approved, designed, and constructed on a site-by-site basis (Lee and Ham, 1988; MacRae, 1996). Based on this experience, the stormwater management paradigm is shifting to an approach that improves base flow by restoring infiltration to groundwater and reducing runoff volume, and reduces the frequency and duration of peak flows so as to prevent channel erosion and protect stream habitat (National Academy of Sciences, 2008). Some older urban areas developed with no or inadequate stormwater controls are being retrofitted to reduce runoff volume and peak flows from these areas. These objectives can be supported by efforts to limit impervious cover at the site or watershed scale as sites are developed and to reduce, disconnect, and (or) treat impervious cover on already developed lands.

Figure 12. Impervious cover includes surfaces that do not allow rainwater to infiltrate, such as this parking lot at the Hartsfield-Jackson Atlanta International Airport. As impervious cover increases in a watershed, the condition of streams declines as a result of increased runoff volume and velocity and the introduction of various pollutants to the stream.

Figure 13. As urban development in a watershed increases, flooding of small streams increases not only in frequency but in terms of the flood peak. Shown here is a flash flood on the South Fork Peachtree Creek near Atlanta, Georgia.

Urbanization and Stream Habitat

The increase in the volume and velocity of runoff from urban land surfaces can boost the energy or force of the water flowing in the stream. This increased energy may enlarge the stream's channel area through a process of erosion and channel incision, which can eventually disconnect a stream from its flood plain (Hammer, 1972; Morisawa and LaFlure, 1979; MacRae, 1996; Booth and Jackson, 1997). The changes in stream habitat in response to urban development can be inconsistent because habitat features are a reflection of a variety of factors, including riparian vegetation, stream slope and geologic setting, sediment sources and delivery, and previous channel engineering. Additionally, the habitat responses of the stream to the hydrologic and physical changes resulting from urban development typically unfold over several years or decades following development, making them more difficult to detect (Center for Watershed Protection, 2003; Leopold and others, 2005). The EUSE findings for habitat response were inconsistent across metropolitan areas due to these complexities.

Protection-oriented management goals can focus on preventing channel erosion by limiting construction within the stream channel and adjacent flood plain or implementing BMPs that reduce the frequency and duration of peak flows to mitigate the effects of upstream urban development on stream channels. In-stream management measures to stabilize the channels can be implemented in areas where stream channels have already been eroded substantially, although long-term rehabilitation success could depend on the stability of future land use in the uplands.

The Concentrations and Number of Contaminants in Streams Increase With Urban Development

The EUSE study found that in-stream contaminants, such as chloride, pesticides, and PAHs, increased when urban development occurred on forested land, whereas evidence of a stream chemistry response was present but weaker when development occurred on agricultural land. Many other studies support the general finding that urban development results in an increase in the number and concentrations of these and other pollutants (such as metals, bacteria, and sediment) in urban streams (fig. 14; U.S. Environmental Protection Agency, 1983; Pitt and others, 2004). Major sources of these pollutants include stormwater runoff, wastewater and industrial discharges, illegal dumping of toxic chemicals, and sewer overflows.

Management goals to address the implications of these findings may include adoption of strategies to limit pollutants leaving development sites and reduce pollutants from urban land. Additionally, strategies that reduce stormwater flows from urban sites can reduce or delay the transport of pollutants to streams.

Figure 14. Many studies have shown a relation between urban development and pollutants in urban streams. Although many contaminants are not readily apparent, a few, such as these trash deposits on Middle Branch near Baltimore, Maryland, are highly visible indicators of pollution.

Chapter 4

Watershed Management Strategies to Reduce the Impacts of Urban Development on Stream Systems

Many local governments and watershed organizations across the country are developing management plans that identify goals for the watershed, as well as a set of "management strategies" designed to achieve these goals. These local watershed planning efforts often are made in response to State or Federal requirements, such as ensuring that waters are meeting their designated uses under the Clean Water Act. Watershed management strategies may include a broad suite of regulations, voluntary actions, and local programs designed to minimize the impact of land-use alterations and pollution-generating behaviors. This chapter presents an overview of management strategies used by watershed managers to address the management goals identified in Chapter 3 (fig. 15; see *What is a Watershed Manager?*). Case studies are used to illustrate how each of these strategies have been implemented in communities across the United States.

Identifying and implementing appropriate management strategies can be difficult for watershed managers. Because urban streams include complex, interacting systems that function at multiple spatial and temporal scales that can cross jurisdictional boundaries, it is unlikely that any single watershed management strategy will eliminate all the adverse effects of urban development on stream ecosystems. A combination of approaches typically will be needed because the management strategies required to *prevent* impacts can differ from those used to *improve* conditions after streams have already been degraded. If management goals can be identified early in the development of a watershed plan, management strategies can be identified that will have a complementary effect on multiple goals. For example, strategies that address the goal to limit impervious cover will in turn reduce runoff volume and pollutant loads, and have downstream benefits such as preventing channel erosion and maintaining in-stream water quality.

A community can opt to apply the suite of management practices listed in figure 15 in a variety of ways, given the local political structure, regulatory mandates, available resources, stakeholder input, and other factors. However, obtaining support for a local ordinance can be a challenge and local governments in some States might have limited authority

Management Strategy	Watershed Management Goals for Developing Lands						Watershed Management Goals for Urban Land					
	Restrict development	Conserve forests and reduce forest cleaning	Limit impervious cover	Control runoff volume	Control peak flow rates	Limit pollutants	Encourage reuse of existing urban areas	Increase tree canopy	Reduce, disconnect, and (or) treat impervious cover	Reduce runoff volume and peak flows	Reduce pollutants	Stabilize stream channels
Land-use planning and zoning	●	●					●					
Source-water protection	●	●				●						
Natural resources conservation planning		●										
Stream corridor protection	●	●										
Better site design		●	●									
Impervious cover gaps			●						●			
Erosion and sediment control						●						
Runoff-reduction approach				●	●	●						
Wastewater management						●					●	
Stream repair												●
Redevelopment and infill policies and incentives							●		●	●	●	
Reforestation and urban forest management								●				
Stormwater retrofits									●	●	●	
Pollution source controls											●	
Illicit discharge detection and elimination											●	
Pollution caps						●					●	

Figure 15. Suite of management strategies that can be used to meet watershed management goals.

What is a Watershed Manager?

The term “watershed manager” is used in a broad sense in this chapter to refer to the wide range of people, such as State and municipal regulators, engineers, planners, environmental groups, elected officials, and public works staff, with some ability to directly or indirectly shape management actions that influence urban stream ecosystems. The range of management actions might include the development and application of land-use regulations and the implementation of technologies to mitigate the impact of urban development and chemical-use practices of individual homeowners.

to adopt new regulations (Lang, 1991). A non-regulatory approach to implementation is to provide financial incentives, paired with education programs that convince residents, business owners, industry, or developers of the benefits of implementing these practices. Financial incentives include tax breaks, cost sharing, and subsidies, as well as financial structures that discourage certain land-use practices by increasing the cost associated with them, such as fees based on the amount of impervious surface created.

Outreach and education programs, typically geared toward the general public, are designed to raise awareness of the connection between land-use activities and stream impacts and provide information on what they can do to help. Outreach and education programs are a relatively low-cost approach to improve the prospects for implementation of management strategies on private lands; this may be especially important in watersheds that have been fully developed. The long-term effectiveness of outreach and education programs to influence human behaviors and ultimately improve stream conditions has not been thoroughly evaluated.

Figure 16. Portland, Oregon, incorporates sustainability principles and practices into the city’s land-use planning. One of these practices is known as a Green Street, which is a vegetated facility that manages stormwater runoff at its source. In the photograph above, water from the street is diverted into a vegetated planter in the sidewalk. Photograph from Center for Watershed for Protection.

Land-Use Planning and Zoning

Watershed Management Goals Addressed:

- Restrict development in undisturbed watersheds
- Encourage reuse of existing urban areas
- Conserve forests and reduce forest clearing during development

Most local jurisdictions across the country have a comprehensive land-use plan (also called a master plan or general plan) and zoning map. The comprehensive land-use plan is considered a blueprint for how land in a given jurisdiction will be used and can be used to guide growth. Zoning provides the legal framework for development and regulates how land within a particular zone can be used. It is the primary tool used to implement the vision set forth in the comprehensive plan (fig. 16).

Specific planning and zoning techniques, such as overlay zoning, large-lot zoning, urban growth boundaries, and transfer of development rights, can be used to restrict urban development in undisturbed watersheds and direct development to already urbanized ones. Preserving open space, farmland, natural beauty, and critical environmental areas by investing time, attention, and resources in restoring center cities and older suburbs is a key tenet of a “Smart Growth” approach to land-use planning. Land-use planning and zoning techniques to protect urban streams allow communities to identify their most pristine and undisturbed streams and restrict development by conserving forests and other natural areas in their watersheds. Planning and zoning techniques can also be used to encourage reuse of existing urban areas to reduce pressure on the more sensitive watersheds. Urban reuse projects can be designed to reduce the impact of development if appropriate stormwater and development criteria are implemented to reduce, disconnect, and (or) treat impervious cover (U.S. Environmental Protection Agency, 2005; Jacob and Lopez, 2009).

The choice of where to allow development can be difficult for land planners in regions experiencing major population growth. Restricting development completely in a particular watershed or subwatershed may protect that

Case Study: Growth Management Strategies for Baltimore County, Maryland

Baltimore County, Maryland, began incorporating Smart Growth management policies into its regulations in the late 1960s as a way to limit development within the city's drinking-water supply watersheds, preserve the rural character of the countryside, and protect natural resources. These policies were adopted in response to the period of greatest population growth in the county's history and demonstrated consistent political will to coordinate growth with the provision of infrastructure, and to use innovative zoning techniques even in the face of opposition. The major components of the growth management approach were

- Adoption of an urban-rural growth boundary;
- Provision of infrastructure to communities inside the growth boundary first, and then to well-planned higher-density town centers;
- Protection of valuable natural resources in rural areas outside the growth boundary from intensive development through the use of protective Resource Conservation zoning and programs for permanent land preservation;
- Implementation of a watershed-based environmental management program to protect resources during land development and to restore degraded ecosystem functions in existing urban areas; and
- Redevelopment of older communities using new urbanism and "green" principles to enhance quality-of-life and environmental function (Outen, 2007).

Prior to enactment of Resource Conservation zoning, the prevailing development density over all of rural Baltimore County was one dwelling unit per acre. The Resource Conservation zones established four lower-density classifications outside the urban growth boundary that collectively covered more than 60 percent of the county. Almost 40 years after adopting an urban growth boundary, 87 percent of the 809,000 people in the county live inside the boundary on only one-third of its 607 square miles of land (Outen, 2007). Growth management has assured that agriculture, large forest blocks, and the watersheds of the metropolitan drinking-water system located in the northern two-thirds of Baltimore County will be protected for the future.

Source for Additional Information

- Baltimore County, Maryland, Smart Growth Policies, accessed August 17, 2012, at *http://www.baltimorecountymd.gov/Agencies/planning/masterplanning/smartgrowth.html*.

watershed but, if there is a demand for housing, the development has to go somewhere. This can give rise to a trade-off: zoning some areas for development at a higher density to allow for conservation of natural resources elsewhere. Recent research has shown a positive correlation between denser development and reduced pollutant loadings because the development of larger, suburban lots creates more impervious cover per house than denser, urban lots (U.S. Environmental Protection Agency, 2005; Jacob and Lopez, 2009). Additionally, larger lots are generally served by decentralized sewage treatment systems, which provide less effective treatment than centralized systems.

Another option to protect streams from urban impacts through zoning is to allow only very low density development (for example, requiring a minimum lot size of 10 acres) in sensitive watersheds or subwatersheds. This approach has both strengths and weaknesses. Low density development can prevent streams from being severely degraded, but could spread low to moderate impacts out over a wider geographic area.

While broad-scale zoning techniques to protect natural resources are relatively easy to implement, an important caveat is that these techniques are not a guarantee of permanent protection for any individual property. Individual properties are often rezoned on a piecemeal basis (usually from agricultural use to residential or commercial use) in many communities; therefore, the initial vision for the community reflected in a comprehensive plan is circumvented. A primary weakness of most land-use planning and zoning is that it is done at the jurisdiction scale and does not consider the larger scale watershed boundaries. Jurisdictional limitations can make it difficult for a given community to protect their water resources when the land draining to these resources is outside of their jurisdiction.

Sources for Additional Information

- Smart Growth Network's "This is Smart Growth," accessed August 17, 2012, at *http://www.epa.gov/smartgrowth/tisg.htm.*
- U.S. Environmental Protection Agency's Smart Growth Web page, accessed August 17, 2012, at *http://www.epa.gov/smartgrowth/.*
- Smart Growth Online Web page, accessed August 17, 2012, at *http://www.smartgrowth.org/.*
- Green Valley Institute's Web page, accessed August 17, 2012, at *http://www.greenvalleyinstitute.org/.*

Source-Water Protection

Watershed Management Goals Addressed:

- Restrict development in undisturbed watersheds
- Conserve forests and reduce forest clearing during development
- Limit pollutants from development sites

The Safe Drinking Water Act requires States to assess the potential risks of public water-supply contamination from land-use activities within their source-water areas (fig. 17). Some communities go a step further and use this information to develop a source-water protection plan that includes restricting urban development and other high-risk activities within source-water protection areas. Source-water protection is, by definition, a management strategy for protecting drinking-water quality. Although a source-water protection plan can include any number of recommended actions, restricting development and conserving forests and native grasslands provide the most stringent protection for streams because they prevent landscape alterations. This type of protection plan may reduce the impacts to streams and other waterbodies that are associated with urban development.

Figure 17. The Occoquan Reservoir, a public water supply located in northern Virginia. In 1971, the Virginia State Water Control Board adopted a new policy to provide advanced treatment of wastewater in the Occoquan watershed and provide an ongoing program of water-quality monitoring. This source-water protection strategy for an already urbanized basin addressed the primary source of pollution to the water supply: wastewater-treatment plant effluent (*http://www.owml.vt.edu/aboutowml.htm*, accessed August 24, 2012). Photograph by Roger Snyder.

When source-water protection plans are developed, the specific management measures used to protect drinking-water supplies are numerous and vary within each watershed. Most measures, however, fall into two broad categories:

1. Use of zoning to regulate how much and what type of development is allowed within the source-water area. Development can also be restricted by purchasing land and using conservation easements to restrict land-use activities.

2. Use of education and incentives to encourage voluntary implementation of best management practices on agricultural, forest, or urban lands.

A major potential benefit of source-water protection planning is the prevention of water-quality problems before they occur. Two weaknesses of this approach, however, are that development and implementation of source-water protection plans are entirely voluntary, and source-water protection is usually not coordinated with similar efforts such as watershed planning and TMDL development. Additionally, there is a disconnect between the source-water assessment process and local land-use planning in many States, and conveying to the public the connection between their actions and downstream water quality can be a challenge.

Sources for Additional Information

- U.S. Environmental Protection Agency, 2004, Primer for municipal wastewater treatment systems: U.S. Environmental Protection Agency, Office of Water and Office of Wastewater Management, EPA 832-R-04-001.
- U.S. Environmental Protection Agency Source Water Protection Web page, accessed August 10, 2012, at *http://water.epa.gov/infrastructure/drinkingwater/sourcewater/protection/index.cfm.*
- Source Water Collaborative, which provides customizable online tools for educating local policymakers about key actions to protect drinking water, accessed August 10, 2012, at *http://www.protectdrinkingwater.org/.*

Case Study: Source-Water Protection for New York City

The Catskill/Delaware reservoir system, which supplies part of the water supply for New York City, lies within a 1,600-square-mile watershed, 75 percent of which is forested. Utilizing the natural filtration abilities of the forests while restricting activities that can occur on the land has enabled New York City's Department of Environmental Protection (NYCDEP) to maintain filtration avoidance for this system.

In 1989, the USEPA's Surface Water Treatment Rule decreed that all surface waters used for public drinking supply must be subject to filtration. New York City did not use any filtration system prior to 1989. This decree would have cost the city an estimated $4 to $6 billion to develop a filtration system as well as a $300 million operating budget, which inevitably would have been passed onto the consumers. Instead, the city pursued alternative methods of protecting the quality of their water supply. New York City, in combination with the State, the USEPA, and local watershed municipalities and organizations, signed a Watershed Memorandum Agreement in 1997 that allowed for the city to work collaboratively with the partners to use a variety of source-water protection techniques to preserve water quality and, thus, exempt the city from the USEPA's filtration requirement (fig. 18). These techniques include land acquisition, a waterfowl management program, wastewater-treatment plant upgrades, stream management, wastewater infrastructure programs, watershed agricultural program, and watershed partnership programs.

Figure 18. The Roundout Reservoir is part of New York City's Delaware reservoir system for New York City's water supply network. New York City has successfully avoided having to construct a filtration plant for its Delaware system by implementing a long-term watershed management strategy that includes conservation of forest land. Photograph by Ed Ostapczuk.

Source for Additional Information

- New York City Watershed Protection, accessed August 10, 2012, at *http://www.nyc.gov/html/dep/html/watershed_protection/index.shtml*.

Case Study: Protecting Environmentally Sensitive Lands in Hernando County, Florida

The population of Hernando County, Florida, nearly tripled from 1980 to 2008, growing from 44,469 to 175,000 residents. The county established an Environmentally Sensitive Lands (ESL) program in 1988 that aimed to preserve the natural, cultural, and scenic resources. A bond referendum enabled the county to levy taxes to support the acquisition of lands that are ranked as environmentally valuable. An existing Conservation Element Chapter of the county’s Comprehensive Plan clearly states the county’s conservation goals and gives it the ability to protect and conserve the natural resources (fig. 19).

Potential land sites must first be nominated to Hernando County for consideration of acquisition by the ESL program, a process that includes conducting a field evaluation and site review. The project must demonstrate several of 15 total requisite criteria that include:

- Support of ecological communities,
- Support of exceptional biodiversity,
- Rarity or representation of vegetative communities,
- Compatibility with surrounding land use,
- Adjacent to existing conservation lands,
- Manageability,
- Consistency with the comprehensive plan,
- Hydrologic integrity of natural systems, and
- Recharge to the aquifer system.

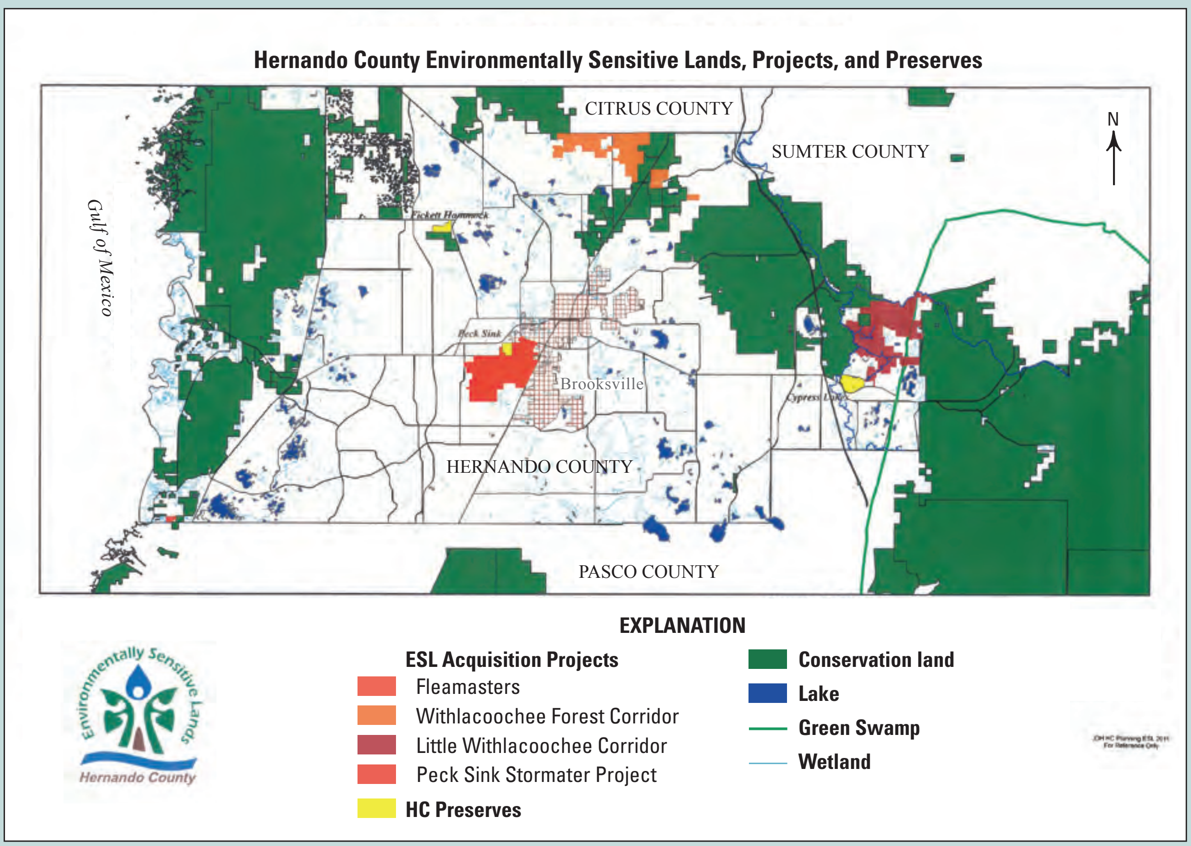


Figure 19. Hernando County, Florida, established the Environmentally Sensitive Lands program in 1988 to support the acquisition of environmentally valuable lands to preserve the natural, cultural, and scenic resources in the county (from Hernando County Planning Department, Brooksville, Florida).

An application is then submitted to an ESL Committee, and applications are reviewed and the projects are ranked according to specific project ranking criteria. A score of 30 or higher must be obtained for the land to be considered for acquisition. The ranking criteria consist of specific questions about the natural value and unique features of the land. Lands are assigned a range of point values in five different categories. The categories, along with the maximum obtainable points, are listed below:

- Ecological Criteria (maximum 20 points),
- Resource Management Criteria (maximum 10 points),
- Water Resources Criteria (maximum 10 points),
- Greenways/Wildlife Criteria (maximum 6 points), and
- Acquisition Considerations (maximum 11 points).

The top-ranked projects must obtain final approval by the county Board of Commissioners before the land is targeted for acquisition. The ESL program is voluntary and uses four methods for land acquisition:

- Fee Simple (acquired with property rights),
- Fee Less than Simple (some property rights still held by fee title holder),
- Donation, and
- Bargain sale.

The last two options generally provide the property seller a tax incentive. The project has been successful in acquiring thousands of acres of valuable natural resource lands.

Source for Additional Information

- Map of the ESL lands, along with the specific ranking criteria and requisite conditions, accessed August 17, 2012, at *http://www.hernandocounty.us/plan/ESL/*.

Natural Resources Conservation Planning

Watershed Management Goal Addressed:

- Conserve forests and reduce forest clearing during development

Natural resources conservation planning involves the inventory of existing natural resources and identification of the most ecologically important areas for conservation. Conservation strategies are implemented over time for the highest priority conservation sites to permanently protect them from being developed.

Natural resources conservation planning begins with an inventory of natural resources for the region of interest. Depending on the focus of the planning effort, this can include resources such as endangered species habitats, wildlife corridors, hydrologic reserve areas, and contiguous forests and wetlands. The inventory is based on mapping layers, but may also involve some field assessments of individual sites to evaluate their suitability for conservation. The entity doing the inventory, often a State agency or conservation group, ranks individual properties based on their conservation value and can work with local partners to refine the ranking to include factors such as vulnerability, feasibility, and community values or to place a greater weight on specific environmental functions of interest.

Numerous techniques are used to conserve land, such as land acquisition, conservation easements, and natural resource protection regulations. These techniques range from providing permanent and absolute protection to very limited protection. Conservation planning is not in and of itself a regulatory practice. Typically, a community will adopt a conservation plan and map by incorporating them into the comprehensive plan, open space plan, or watershed plan. This information will be used to target specific properties for conservation as funds become available, or to encourage voluntary conservation as part of incentive programs. Some communities will use the information to limit development in sensitive natural resource areas by using zoning to restrict development entirely on specific parcels or to require protection of a specific type of resource on all sites as land is developed.

The major strength of conservation planning is that it takes a proactive approach to water resource protection by identifying the most important natural areas in advance of site plan submittals. Proactive protection represents the most cost effective approach to prevent urban impacts. However, it is often difficult to get support for protection measures such as forest conservation until after these areas are converted to urban land and downstream waterbodies are degraded. Proposed restrictions on land-use activities can be met with strong opposition from landowners and the public.

Stream Corridor Protection

Watershed Management Goals Addressed:

- Restrict development within stream corridors
- Conserve forests and reduce forest clearing during development

The stream corridor and its associated flood plain provide important benefits, such as flood control and nutrient processing. These areas can be dramatically changed by upstream development. Adverse impacts to the stream can be prevented through stream corridor protection, which includes restricting development within the stream corridor and flood plain and providing a vegetated buffer. Forests located in the stream corridor have enormous potential to mitigate the effects of urbanization on streams by storing floodwaters, removing pollutants from soils and water, reducing temperatures, stabilizing soils, and promoting infiltration of rainwater (fig. 20). These forests also provide shade to the stream and are important sources of food and habitat (for example, leaf litter and woody debris) to the stream ecosystem. Numerous studies document the strong relation between riparian forest cover and watershed health (Goetz and others, 2003; Wang and others, 2003; Moore and Palmer, 2005). However, the beneficial impact of riparian forest cover appears to diminish as urban development increases because the degradation caused by upland stormwater runoff overwhelms the more localized benefits of riparian canopy cover (Goetz and others, 2003; Roy and others, 2005; Roy and others, 2006; Walsh and others, 2007).

Stream corridor protection strategies generally take the form of special protection ordinances or zoning regulations. Special protection ordinances, such as stream buffer ordinances or flood-plain ordinances, provide a local government with regulatory power to protect natural resources outside of zoning by directly regulating activities in and around them. Some States require local governments to adopt and implement special protection ordinances. Zoning-based resource protection regulations also can be used to protect sensitive stream corridors. Resource protection zones directly limit or prohibit incompatible development within these zones. Very low-intensity uses are usually authorized, while other types of uses are outright prohibited. Additional activities might be allowed under a conditional use permit, which could require mitigation for impacts. The use of zoning to protect natural resources generally includes mapping the areas to be protected, adopting the map as part of local zoning, and adopting written regulations that set forth permitted and prohibited uses for that zone (Kusler, 2006).

Many communities have adopted stream buffer requirements as one element of an overall urban watershed protection strategy. However, the ability of a particular buffer to actually create its many benefits may depend on factors such as how well the buffer is planned or designed, the use of performance standards that are scientifically based (for example, width, vegetative targets), and adequate enforcement mechanisms. Table 1 presents 10 practical performance criteria for urban stream buffers that are drawn from field research and local experience across the country (Schueler, 2000).

Flood-plain ordinances not only help to preserve the integrity of the stream corridor but also have an added benefit to people by preventing flood-related deaths and property damage that could occur were development allowed in the flood plain. A community's agreement to adopt and enforce flood-plain management ordinances, particularly with respect to new construction, is an important element in making flood insurance available to home and business owners. Currently (2012) more than 20,100 communities voluntarily adopt and enforce local flood-plain management ordinances that provide flood loss reduction building standards for new and existing development. Management practices that protect the stream corridor from impacts may be more cost effective than allowing development to proceed unimpeded and implementing stream repair practices later on to fix stream problems (Institute for Environmental Negotiation, 2002).

Figure 20. This stretch of Pigeon House Branch near Raleigh, North Carolina, has an intact forested riparian buffer, which provides stream shading, stabilizes the stream's banks, and provides habitat.

Case Study: Benefits of Protecting Stream Buffers in Kansas City, Missouri

Since 2004, Kansas City environmental managers have systematically evaluated stream quality throughout the city and quantified the relation between riparian buffers and stream quality. A comprehensive inventory of stream assets demonstrated that the health and stability of the city's streams are influenced by the quantity and quality of riparian buffers (Brown and others, 2009). The results support national research on the importance of stream buffers in watershed management. Consequently, Kansas City adopted a stream-setback ordinance in August 2008 that prohibits flood-plain development and focuses on preserving adjacent riparian buffers through development controls, low-impact development provisions, and incentives. This ordinance addresses stormwater management, natural-resource protection, and future development by protecting sufficient riparian buffers to maintain the city's streams and environmental quality while providing incentives and flexibility for developers who build near streams.

The stream-setback ordinance is designed to help avoid future liabilities by protecting new development and infrastructure from flood damage while preserving natural resources that provide multiple benefits. Limiting development near streambanks is expected to improve Kansas City's water quality, reduce erosion and sedimentation, and protect riparian-corridor habitat and greenways. A provision of "conservation development" options protects important riparian resources and, at the same time, allows development within the outer zone of the buffer. Little development under the guidance of this setback ordinance has occurred since its enactment because of economic conditions. A formal monitoring program to assess the effect of the program on stream conditions does not currently exist (Patty Noll, Kansas City Planning and Development Department, Kansas City, Missouri, oral commun., 2011).

Source for Additional Information

- Kansas City, Missouri, stream buffer program information, accessed August 17, 2012, at *http://ww4.kcmo.org/planning/devmgmt/zoningord/Stream%20setback%20fact%20sheet.pdf.*

Table 1. Considerations in developing and implementing an urban stream buffer.

Minimum total width of 100 feet, including flood plain
Zone-specific goals and restrictions for the outer, middle, and streamside zones
Adopt a vegetative target based on predevelopment plant community
Expand the width of the middle zone to pick up wetlands, slopes, and larger streams
Use clear and measurable criteria to delineate the origin and boundaries of the buffer
The number and conditions for stream and buffer crossings should be limited
The use of buffer for stormwater runoff treatment should be carefully prescribed
Buffer boundaries should be visible before, during, and after construction
Buffer education and enforcement are needed to protect buffer integrity
Buffer administration should be flexible and fair to landowners

From Schueler, 2000.

Sources for Additional Information

- Schueler, T., 2000, The Architecture of Urban Stream Buffers, *in* Schueler, T., and Holland, H., eds., Article 39 in The Practice of Watershed Protection: Center for Watershed Protection.
- Flood-plain management resources from FEMA, accessed August 17, 2012, at *http://www.fema.gov/national-flood-insurance-program-1.*

Better Site Design

Watershed Management Goals Addressed:

- Conserve forests and reduce forest clearing during development
- Limit impervious cover at the site scale

Better Site Design, also known as environmentally sensitive site design or low-impact development (LID), refers to a set of techniques for conserving natural areas, reducing impervious cover, and treating runoff at the scale of an individual development (fig. 21; Center for Watershed Protection, 1998a). Better Site Design can be implemented through local codes and ordinances governing site development. In many communities, review and revision of these regulations is necessary to identify and remove barriers to Better Site Design implementation (Center for Watershed Protection, 1998a). This protection strategy is applied on a development-specific basis as watersheds are urbanized. Numerous studies have demonstrated the pollutant reduction benefits associated with Better Site Design at the scale of the individual site (Center for Watershed Protection, 1998a, 1998b, 2002; Cheng and others, 2004; Dietz and Clausen, 2008).

The size, appearance, location, and design of individual development parcels or subdivisions are determined in large part by local subdivision codes and zoning ordinances. Better Site Design principles generally encompass one of three areas: (1) Residential Streets and Parking Lots, (2) Lot Development, and (3) Conservation of Natural Areas. Residential Streets and Parking Lots principles focus on those codes, ordinances, and standards that determine the size, shape, and construction of parking lots, roadways, and driveways in the suburban landscape. Lot Development principles focus on the regulations that determine lot size, lot shape, housing density, and the overall design and appearance of neighborhoods. Conservation of Natural Areas principles address codes and ordinances that promote (or impede) protection of existing natural areas and incorporation of open spaces into new development.

Financial incentives for developers to use Better Site Design techniques include the reduced cost associated with many of the techniques that reduce clearing and impervious cover. Plan review staff can educate developers about these benefits to encourage the use of Better Site Design. Alternatively, State and local stormwater regulations that use the runoff-reduction approach provide a more tangible credit to developers in terms of reduced stormwater management requirements.

Source for Additional Information

- Center for Watershed Protection's Better Site Design resources, accessed August 10, 2012, at *http://www.cwp.org/documents/cat_view/77-better-site-design-publications.html*.

Case Study: Jordan Cove Urban Watershed Project, Waterford, Connecticut

The Jordan Cove Urban Watershed Project was a 10-year paired watershed study, designed to determine the water-quality and water-quantity impacts of traditional development versus Better Site Design. The study was conducted in the Jordan Cove watershed, which empties into a tidal estuary that is connected to Long Island Sound (Clausen, 2007). The traditional catchment was developed using standard zoning and construction practices and a typical curb and gutter stormwater conveyance system. The Better Site Design catchment was developed with reduced street widths, minimization of cul-de-sacs, vegetated channels for stormwater treatment, open space development, alternative and shared driveways, direction of rooftop and lot runoff to pervious areas, cluster development, turf minimization, and low-mow and no-mow areas.

As total impervious area increased in the traditional development catchment, there was an exponential increase in runoff volume and runoff coefficients; whereas in the Better Site Design catchment, runoff volume did not change with an increase in impervious cover. The study demonstrated the rapid increase in runoff production with even the slightest amount of traditional development. Mass export of pollutants was less in the Better Site Design catchment than the traditional catchment. Pollutant export was determined to be a function of the increase in flow in the traditional catchment, whereas the pollutant export from the Better Site Design catchment was similar to pollutant export from forested watersheds (Dietz and Clausen, 2008).

Source for Additional Information

- Jordan Cove Urban Watershed Project information, accessed August 17, 2012, at *http://www.jordancove.uconn.edu/*.

This curb extension bioretention in Portland, Oregon, collects and removes pollutants from runoff and also serves as a traffic calming device.

Forested buffer preserved along a stream in Salisbury, Maryland.

This Richland County, South Carolina, street uses permeable pavers that allow rainwater to infiltrate instead of generating excessive runoff.

Another way to reduce impervious cover is by limiting pavement on driveways to only what is needed, as shown on this driveway in Arlington, Virginia.

The Oak Terrace Preserve community in North Charleston, South Carolina, limited clearing and grading during construction to preserve large, mature trees as part of the development.

Figure 21. Examples of Better Site Design practices. Photographs from Center for Watershed Protection.

Impervious Cover Caps

Watershed Management Goals Addressed:

- Limit impervious cover at the watershed or site scale
- Reduce, disconnect, and (or) treat impervious cover on urban land

Impervious cover caps impose a numeric limit on the amount of hard surfaces, such as roads, buildings, and parking lots, on an individual lot or across a given watershed. Impervious cover is a metric that predicts the combined effects of urban development on streams, and caps are typically established to protect drinking water or high-quality streams. Some caps limit the total amount of impervious cover, while others focus solely on "connected" impervious cover, meaning surfaces that drain directly to a storm drain or local waterbody. Because impervious cover affects peak flow rates, runoff volume, and associated pollutant load, impervious cover caps might support the broader goals of protecting downstream receiving waters from urban impacts and improving stream conditions by removing, disconnecting, or treating existing impervious cover.

There are several ways that an impervious cover cap can be implemented. Some jurisdictions enforce the caps through their comprehensive plan and zoning by imposing numerical impervious cover limits on individual lots to stay below a designated impervious cover threshold for the watershed. This action requires close scrutiny of individual development proposals to ensure the development footprint is below the cap, or is otherwise mitigated, disconnected, or treated. An indirect way to implement a watershed impervious cover cap is through watershed-based zoning, which involves re-zoning of land within a smaller subwatershed to keep impervious cover below a certain threshold. Communities can provide a financial incentive for impervious-cover reduction in new developments by requiring developers to pay a fee for development projects that exceed the cap. The basic pricing mechanism is the average cost per impervious acre to provide an equivalent amount of stormwater treatment elsewhere in the watershed.

Another regulatory approach to establish an impervious cover cap is an impervious-cover TMDL. TMDLs are the primary tool to document how pollutant loads will be reduced to meet water-quality standards. In an impervious cover-based TMDL, impervious cover is used as a surrogate for increased runoff and pollutant loads to simplify the urban TMDL implementation process. Impervious cover-based TMDLs have been issued for small subwatersheds that have biological stream impairments associated with stormwater runoff, but no specific pollutant is listed as causing the impairment. A specific watershed impervious cover threshold is set as a surrogate for meeting water-quality standards, which requires removal of impervious cover, greater stormwater treatment for new development, offsets through stormwater retrofits, or other means to meet the established threshold.

The strength of impervious cover caps is that they are relatively easy to implement in the context of existing zoning to limit impervious cover and the volume of runoff generated. The main drawback is the difficulty in measuring the aggregate change in watershed impervious cover over time as a result of many individual zoning and development decisions. Impervious cover caps also require frequent monitoring to ensure that individual owners do not add more impervious cover in the post-construction phase. Impervious cover caps must be carefully implemented so as not to contribute to regional sprawl (for example, site level caps might not be effective because the extensive road networks used to connect individual lots produce more impervious area per dwelling unit than any other zoning category) or inadvertently drive development to nearby municipalities that do not have stringent land-use controls in place (Chesapeake Stormwater Network, 2008).

Sources for Additional Information

- Nonpoint Education for Municipal Officials document Addressing Imperviousness in Plans, Site Design and Land-Use Regulations, accessed August 10, 2012, at *http://nemo.uconn.edu/publications/tech_papers/tech_paper_1.pdf.*
- Chesapeake Stormwater Network's report The Reformulated Impervious Cover Model: Implications for Stream Classification, Subwatershed Management and Permitting, accessed August 10, 2012, at *http://www.chesapeakestormwater.net/all-things-stormwater/the-reformulated-impervious-cover-model.html.*

Case Study: The Eagleville Brook Watershed near Mansfield, Connecticut—Impervious Cover Total Maximum Daily Load

In 2006, the Connecticut Department of Environmental Protection (CT DEP) issued a total maximum daily load (TMDL) for impervious cover in the Eagleville Brook watershed, which drains a large portion of the University of Connecticut (UConn) campus near Mansfield, Conn. A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet water-quality standards, and it usually is based on modeling, monitoring data, or a combination of both (U.S. Environmental Protection Agency, 2010a). The Eagleville Brook TMDL, approved by the USEPA in February 2007, represented the first of its kind in the Nation. While TMDLs typically apply to a specific contaminant, this one addresses the impacts of urban development directly by using impervious cover as the TMDL metric. This approach was chosen, in part, because Eagleville Brook's biological impairment could not be attributed to any one contaminant. The CT DEP recognized that while impervious cover may not be the direct cause of the impairment, the strong link between impervious cover and the multiple stressors that affect stream biota make impervious cover a strong surrogate for these multiple stressors.

Beginning in 2005, the CT DEP has been conducting its own study of the relation between impervious cover and stream health (fig. 22). The CT DEP has analyzed the relation between invertebrate communities and impervious cover for 125 streams, using impervious cover estimates from a model created by the UConn Center for Land-Use Education and Research (CLEAR). Based on this analysis, the CT DEP concluded that 12 percent impervious cover is an appropriate limit for protecting aquatic life in the State's streams and a defensible basis for a TMDL in areas with complex and unspecified water-quality problems.

The impervious cover TMDL for Eagleville Brook was set at 11 percent to include a margin of safety. Mapping and field surveys were conducted by the UConn CLEAR's Nonpoint Education for Municipal Officials Program, the Center for Watershed Protection, and the Horsley Witten Group to measure the current watershed impervious cover and to identify opportunities to remove or disconnect and treat impervious cover. The goal of the TMDL is to have the watershed ecosystem look and act as if land cover in the watershed were 11 percent impervious or less. Approximately 50 retrofit opportunities were identified, including rain gardens, bioretention, downspout disconnection, green roofs, swale enhancements, soil amendments, dry swales, porous pavement, cisterns, sand filters, constructed wetlands, flood-plain reconnection, impervious cover removal, tree plantings, pervious area restoration, and stormwater planters. Retrofit designs were produced for 10 sites, and UConn has committed to implementing these designs as improvement projects are made on the campus.

Although the reduction in the area of impervious cover is the "yardstick" used to measure progress in this TMDL, the ultimate success will be restoration of the biological communities in Eagleville Brook by improving the stream's habitat and water quality. Initial monitoring results indicate that additional sources of contaminants, not attributed to impervious cover alone, may be present and need to be identified; such unexpected results indicate the importance of ongoing monitoring to quantify the effects of a project or program (Christopher Bellucci, Connecticut Department of Environmental Protection, State of Connecticut, written commun., 2011). This project provides an interesting example of using impervious cover in a regulatory framework for implementing low-impact development practices at the watershed scale. A number of other impervious cover TMDLs have been developed, including several in the State of Maine.

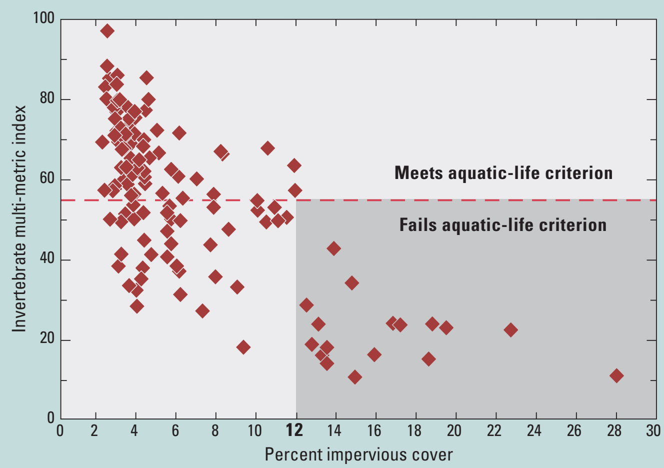


Figure 22. The Eagleville Brook impervious cover total maximum daily load (TMDL) is based on a Connecticut Department of Environmental Protection study that indicated that no streams in watersheds with impervious cover exceeding approximately 12 percent met the Connecticut aquatic-life criterion for healthy streams. Graph by Christopher Bellucci, Connecticut Department of Environmental Protection.

Source for Additional Information

- Eagleville Brook Watershed information, accessed August 10, 2012, at *http://www.epa.gov/owow_keep/tmdl/tmdlsatwork/eagleville_brook.html.*

Erosion and Sediment Control

Watershed Management Goal Addressed:

- Reduce pollutants from development sites

The construction phase of urban development has a high potential to affect streams, due to the high potential for erosion and delivery of sediment to the stream (fig. 23). Municipalities regulated under the NPDES program are required to develop a program to reduce pollutants in runoff from all construction sites disturbing an acre or more of land and discharging to a waterbody. Some communities regulate smaller construction sites as well. Another approach is to implement numeric standards for total suspended solids and (or) turbidity and require monitoring to determine if the standards are being met.

The NPDES requirements for erosion and sediment control include developing an ordinance that establishes the legal authority to enact and enforce an erosion and sediment control program. Municipalities are also required to provide municipal program oversight, enforce construction site planning and management procedures, and require implementation of BMPs to control erosion, runoff, and sediment, as well as BMPs to control other waste at the construction site. Some examples of erosion, runoff, and sediment control BMPs include sequencing of construction to limit the amount of soil exposed at any given time, use of mulch to prevent erosion of exposed slopes, and installation of silt fences to prevent sediment from entering adjacent waterways (fig. 24).

The strength of erosion and sediment control programs is that they directly regulate this pollution source. Nevertheless, controlling sediment from construction sites remains challenging; construction sites with erosion and sediment control practices can deliver six times the amount of sediment present in runoff from a stabilized urban landscape to the stream (Schueler and Lugbill, 1990). In addition, not all communities or sites are regulated, thus the cumulative effects of these construction sites can be substantial. Erosion and sediment control practices are only effective when properly installed and enforced, which is a challenge for many understaffed erosion and sediment control programs.

Figure 23. Sediment-laden runoff from a nearby construction site makes its way into a small stream in the Accotink Creek watershed, Virginia, due to poor erosion and sediment control. Photograph from Center for Watershed Protection.

Source for Additional Information

- U.S. Environmental Protection Agency menu of BMPs for construction sites, accessed August 10, 2012, at *http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=4*.

Silt fences are used to contain sediment on a development site.

Hay is applied to temporarily stabilize soils on exposed sites and prevent erosion.

Asphalt barriers are used to direct stormwater runoff away from an inlet and into a sediment basin.

Sediment basins collect construction site runoff and associated sediment, preventing it from entering nearby streams.

Figure 24. Examples of erosion and sediment control techniques. Photographs from Center for Watershed Protection.

Case Study: Model Ordinances for Effective Erosion and Sediment Control in Minnesota

Sediment has been identified as one of the most damaging water pollutants in Minnesota and is the major pollutant by volume in State surface waters. Land is highly susceptible to erosion and (or) sedimentation during construction activities, especially when BMPs for erosion and sediment control are not installed and maintained properly; improper installation and maintenance of BMPs are common occurences that are documented by numerous studies and surveys (Brown and Caraco, 2000). Erosion and sediment control ordinances define program elements such as the threshold or trigger for which sites are subject to the ordinance, specific erosion, and sediment control criteria (such as clearing limits, phased clearing, or performance standards for temporary stabilization recommended BMPs), inspection procedures (including linking inspection frequency to storm events or seasonal rainfall patterns), enforcement procedures, and much more.

Erosion and sediment control in Minnesota is implemented in several ways. Some communities rely primarily on the Minnesota Pollution Control Agency to administer and enforce NPDES regulations, while others defer erosion and sediment control authority to local government organizations such as watershed districts, watershed management organizations, or the county. The Northland Nonpoint Education for Municipal Officials (NEMO) Program developed a model erosion and sediment control ordinance to assist this large number of communities with developing an effective ordinance for their erosion and sediment control program. The ordinance is designed to assist communities with applying NEMO land-use and water-quality principles to each community's unique circumstances. Building upon the requirement of the NPDES rules, this model provides alternative language and recommendations explaining how erosion and sediment control regulation can be implemented and enforced in different local government settings.

The key NEMO land-use and water-quality points emphasized in the model ordinance are as follows:

- Maintaining soil stability through effective use of BMPs,
- Scheduling of land-disturbing activities in the development process to prevent erosion and sedimentation, and
- Acknowledging the importance of inspection and enforcement.

The city of Minneapolis provides a model approach for erosion and sediment control. The USEPA has made the city's ordinance available on their Web site, Model Ordinances to Protect Local Resources (accessed August 10, 2012, at *http://www.epa.gov/owow/NPS/ordinance/*). Additionally, a review of erosion and sediment control ordinances conducted by Coleman and McCarthy (2004) at Pace Law School highlights Minneapolis' ordinance as progressive because it "applies to all land disturbances and soil storage activities… refers permittees to a Manual of Standards that describes acceptable Best Management Practices for use in controlling sedimentation and erosion…sets a schedule for mandatory inspections by the issuing authority… requires active land to be monitored and inspected by the permittee at least once a day and to monitor revegetated slopes regularly until 'adequate turf' is established." The provision of model ordinances, such as the Northland NEMO and Minneapolis ones, not only assists communities that have limited resources for ordinance development, but also helps to promote more widespread adoption of effective ordinance language for erosion and sediment control programs.

Source for Additional Information

- Northland Nonpoint Education for Municipal Officials (NEMO) Program, accessed August 10, 2012, at *http://www.pca.state.mn.us/index.php/component/option,com_docman/task,doc_view/gid,7428.*

Runoff-Reduction Approach

Watershed Management Goals Addressed:

- Control runoff volume from development sites
- Control peak flows from development sites
- Limit pollutants from development sites

The goals of the runoff-reduction approach are to retain a prescribed volume of stormwater runoff from the urbanized landscape and reduce pollutant loads (fig. 25). These goals can be met by using Better Site Design techniques to minimize the amount of runoff generated and by implementing BMPs that reduce the volume of stormwater leaving the site through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, or evapotranspiration.

The runoff-reduction approach is implemented through State or local stormwater regulations and design guidance that require a retained prescribed volume of runoff from the development site to achieve full or partial compliance with the water-quality and stream channel erosion requirements. When runoff-reduction practices are used throughout the site to reduce runoff, in principle, the size (and cost) of conventional stormwater BMPs designed only to control the peak rate of runoff should not be as large. The challenge in creating an incentive to use runoff-reduction practices lies in how to accurately credit the annual volume reduction to the water-quantity requirements.

Typically, multiple practices are distributed throughout each site to incrementally reduce the total stormwater runoff volume delivered to the stream (or storm drainage system). The major challenge with this approach is how to size and arrange the individual practices to meet the appropriate stream protection objectives, as there are few hydrologic techniques available to determine whether the design objective is being met. Another challenge with implementation of stormwater BMPs is to ensure there are measures in place (for example, maintenance agreement, maintenance protocol) so that regular maintenance occurs to keep the BMPs functioning as intended. The shift to runoff-reduction is quite recent, so monitoring efforts to demonstrate its effect on improving stream water-quality goals at the watershed scale have yet to be completed. The strength of the runoff-reduction approach is in its ability to produce a hydrologic outcome that more closely mimics predevelopment hydrology compared to traditional stormwater treatment practices.

The focus on runoff volume as the common currency for BMP evaluation is gaining wider acceptance across the country (National Academy of Sciences, 2008; Brown, 2010; Hubbart and others, 2010). The concept of runoff-reduction will help define the next generation of stormwater design. The promise of runoff-reduction is that the benefits go beyond the improvement of water quality. If site and stormwater designs can successfully implement runoff-reduction strategies, then these designs may contribute to a more natural (or predevelopment) hydrologic response and address runoff volume, duration, velocity, frequency, and groundwater recharge challenges associated with urban development. Important future work will involve continued integration of the runoff-reduction concept with stormwater requirements for channel protection and flood control, so that stormwater-related criteria can be managed in a unified approach.

Sources for Additional Information

- The Coastal Stormwater Supplement to the Georgia Stormwater Management Manual, accessed August 10, 2012, at *http://documents.atlantaregional.com/gastormwater/Georgia-CSS-Final-Apr-09.pdf.*
- The Virginia Stormwater BMP Clearinghouse, accessed August 10, 2012, at *http://www.vwrrc.vt.edu/swc/* provides more information on specific runoff-reduction practices.
- The U.S. Environmental Protection Agency Menu of BMPs describes a complete list of BMPs for post-construction stormwater control, accessed August 10, 2012, at *http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5*.

Rain garden/bioretention in a parking lot.

Vegetated swale in the Noisette subdivision in Charleston, South Carolina, is designed to reduce runoff from the roadway.

Permeable pavements are used in low-traffic areas to promote runoff reduction by infiltrating rainwater.

This parking lot, located in Gwinett County, Georgia, uses permeable pavements and incorporates bioretention into a vegetated island.

Routing water from a green roof through a series of ponds can reduce runoff from the building's roof and also can provide a green space for enjoyment.

Routing water from downspouts into rain barrels can reduce the amount of runoff diverted to storm drains and provide a significant source of water for lawn and gardens during the summer.

Figure 25. Examples of runoff-reduction practices. Photographs from U.S. Geological Survey, Nonpoint Education for Municipal Officials, and Center for Watershed Protection.

Case Study: Runoff-Reduction Method in Virginia

In 2004, the Commonwealth of Virginia amended its stormwater law to promote the use of low-impact development (LID). Although one or two localities developed a strategy for implementing LID practices, such as bioretention and planting of grass swales to reduce runoff volume and peak flows, no statewide regulatory framework was in place to provide incentives to use LID and other site design strategies aimed at reducing the impacts of development. During the process of updating the Virginia Stormwater Management Permit program regulations in 2007, the Virginia Department of Conservation and Recreation proceeded to update the BMP performance standards and develop a framework for measuring compliance with water-quality and channel-protection requirements. One of the results is the runoff-reduction method (RRM; table 2; Hirschman and others, 2008).

The RRM is a spreadsheet-based, stormwater design system that incorporates built-in incentives for the use of site-design strategies that minimize impacts to the natural or existing site hydrology. By addressing runoff volume, duration, velocity, frequency, groundwater recharge, and protection of stream channels, the RRM is intended to facilitate approaches that move beyond managing solely for peak flow rate and water-quality treatment. When used in conjunction with site-based pollutant load limits, the RRM approach also can help municipalities meet pollutant-reduction goals (for example, nutrient strategies, TMDLs) of the larger watershed.

The Virginia RRM is focused on compliance with site-based phosphorus load limits. Under the RRM, site designers can use combinations of practices that receive variable runoff-reduction and pollutant-removal credits based on average annual values derived from research studies (Hirschman and others, 2008). Site designers are encouraged to use practices that reduce the overall volume of runoff for the post-development condition to achieve the required load limit. The Virginia stormwater BMP clearinghouse Web site includes a list of BMPs that can be used and provides design standards and specifications for each BMP.

Sources for Additional Information

- Virginia Stormwater BMP Clearinghouse, accessed August 10, 2012, at *http://vwrrc.vt.edu/swc/.*
- Virginia Department of Conservation and Recreation, accessed August 10, 2012, at *http://www.dcr.virginia.gov/lr2f.shtml.*

Table 2. Practices included in the runoff-reduction method. Reproduced from Hirschman and others (2008).

[Practices in highlighted cells achieve both Runoff-Reduction (RR) and Pollutant Removal (PR) functions and can be used for Steps 2 and 3]

<table>
<tr><th>Step 1: Environmental Site Design (ESD)</th><th>Step 2: Runoff-Reduction (RR) Practices</th><th>Step 3: Pollutant Removal (PR) Practices</th></tr>
<tr><td>Forest conservation</td><td>Sheetflow to conserved open space</td><td>Filtering practice</td></tr>
<tr><td rowspan="2">Site reforestation</td><td rowspan="3">Rooftop disconnection:
• Simple
• To soil amendments
• To rain garden or dry well
• To rain tank or cistern</td><td>Constructed wetland</td></tr>
<tr><td>Wet swale</td></tr>
<tr><td>Soil restoration (combined with or separate from rooftop disconnection)</td><td rowspan="2">Wet pond</td></tr>
<tr><td rowspan="7">Site design to minimize impervious cover and soil disturbance</td><td>Green roof</td></tr>
<tr><td colspan="2">Grass channels</td></tr>
<tr><td colspan="2">Permeable pavement</td></tr>
<tr><td colspan="2">Bioretention</td></tr>
<tr><td colspan="2">Dry swale (water-quality swale)</td></tr>
<tr><td colspan="2">Infiltration</td></tr>
<tr><td colspan="2">Extended detention (ED) pond</td></tr>
</table>

Wastewater Management

Watershed Management Goals Addressed:

- Limit pollutants from development sites
- Reduce pollutants from urban land

Wastewater management is the practice of collecting and treating wastewater to remove and reduce pollutants so that the resulting water (effluent) can be discharged back into a nearby waterbody. The most common form of wastewater treatment in the United States consists of a centralized system of sewers and wastewater-treatment plants. The sewers collect municipal wastewater from homes, businesses, and industries and deliver it to facilities for treatment before it is discharged to waterbodies or land, or reused. Decentralized systems, such as septic systems, treat wastewater onsite from homes that are not connected to a centralized treatment plant. Approximately 25 percent of households nationwide are served by septic systems, primarily in rural areas (U.S. Environmental Protection Agency, 2004).

While all new developments in the United States provide some form of wastewater treatment, there are several instances where improvements can be made to address pollution problems. Examples of these improvements include wastewater-treatment plant upgrades to provide enhanced pollutant removal, reduction of combined sewer overflows and sanitary sewer overflows, and reduction of pollution from failing or outdated septic system technologies.

Upgrading wastewater-treatment plants to provide advanced treatment provides further removal of nutrients using biological or chemical processes. In jurisdictions with impaired waters, point-source dischargers may be under increasing pressure to upgrade their plants to meet TMDL limits because it is viewed as a simpler way to achieve pollutant reductions than requiring numerous landowners to implement BMPs on their properties. These upgrades will be required in many Chesapeake Bay watersheds to meet new nutrient load requirements (Maryland Department of the Environment, 2010).

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe (fig. 26). Combined sewer systems usually transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a waterbody. However, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant during periods of heavy rainfall or snowmelt. Therefore, combined sewer systems are designed to overflow occasionally and discharge excess wastewater (including raw sewage) directly to nearby streams, rivers, or other waterbodies.

Figure 26. Overflows from combined sewer systems include a mix of stormwater runoff and untreated wastewater and are released into nearby waters when the flows exceed the capacity of the treatment plant. Warnings signs are posted near this combined sewer discharge point along the Flint River in Georgia due to the public health risks of contact with contaminated water.

Separate sanitary sewer systems can also contribute pollutants from untreated wastewater to the stream. Older systems can have numerous cracks that not only allow for seepage of sewage into the groundwater, but also create a scenario where groundwater can leak into the sewer system subjecting the system to higher volumes than it was designed to carry (fig. 27). This scenario can overwhelm the system and cause overflows that are considered pollution sources regulated by the USEPA.

Septic systems can contribute pollutants to surface water and groundwater due to improper siting and lack of maintenance (Duda and Cromartie, 1982; Lipp and others, 2001; Cahoon and others, 2006). Even properly functioning conventional septic systems can be pollution sources because they are ineffective in removing dissolved forms of nitrogen, such as nitrate. Replacement of failing systems by using either conventional or alternative technology can reduce pollutant loadings. Education programs for homeowners can improve septic system management and maintenance. Areas with widespread failures might require system replacement or conversion to sewer within an entire neighborhood.

Figure 27. Sanitary sewer overflows can be caused by clogs in the sanitary sewer system or by infiltration of groundwater into the system through cracks in deteriorating pipes. This sanitary sewer overflow in Ellicott City, Maryland, discharged untreated wastewater into a parking lot before maintenance crews were able to fix the problem. Photograph from Center for Watershed Protection.

Sources for Additional Information

- The U.S. Environmental Protection Agency Menu of BMPs describes a complete listing of technology for wastewater treatment, accessed August 10, 2012, at *http://water.epa.gov/scitech/wastetech/mtbfact.cfm*.
- The U.S. Environmental Protection Agency combined sewer overflow Control Policy, accessed August 10, 2012, at *http://cfpub.epa.gov/npdes/home.cfm?program_id=5* provides guidance on how communities with combined sewer systems can meet Clean Water Act goals in as flexible and cost-effective a manner as possible.
- The Federal Clean Water State Revolving Fund is a source of funding for the repair and upgrade of failing septic systems, accessed August 10, 2012, at *http://water.epa.gov/grants_funding/cwsrf/cwsrf_index.cfm*.

Case Study: Using Green Infrastructure to Reduce Adverse Stormwater Impacts in Milwaukee, Wisconsin

The Milwaukee, Menomonee, and Kinnickinnic Rivers drain densely populated areas of Milwaukee, and the mouths of these rivers form an important harbor system for industry and recreation on Lake Michigan. As in other highly developed urban coastal cities, many miles of streams in the Milwaukee area were dredged, straightened, dammed, buried, or lined with concrete and stone to control flooding as urban areas expanded. Stream habitat that provided food and shelter for aquatic biota was lost. Flood plains and wetlands in and along riparian corridors were filled in and developed. Dams, culverts, and cement-lined channels barred the migration of native fish from Lake Michigan into important historical spawning headwater areas. Remaining habitats were disconnected and fragmented. Massive flooding continued to cause problems during large runoff-producing storms in the 1990s and 2000s.

Several large projects by multiple agencies and volunteer organizations have worked toward improving flood control, reconnecting important habitats, and improving water quality. During 1999–2002, Milwaukee Metropolitan Sewerage District (MMSD) completed the Lincoln Creek Environmental Restoration and Flood Control Project, a $111 million effort to protect 1,600 homes and businesses located within the flood plain from 100-year storms. Since 2007, the Southeastern Wisconsin Watersheds Trust has focused efforts on watershed restoration plans, watershed action teams, rehabilitation projects, and land protection. In 2009, a $4.7 million grant from the National Oceanic and Atmospheric Administration was awarded to Ozaukee County to remove fish barriers and reconnect 158 miles of stream and 119,000 acres of biologically important riparian, near-shore, and river mouth areas of the Milwaukee River. In 2010, MMSD was awarded about $4 million in USEPA Great Lakes Restoration Initiative grants to restore habitat and fish passage in the Kinnickinnic River and redesign the last stretch of the Menomonee River, which acts as a fish passage barrier between Lake Michigan and the rest of the watershed (fig. 28). Residential properties are being purchased to widen flood plains for re-creating flood storage and rehabilitation. Other areas require cleanup of contaminated sediment. Construction of the Deep Tunnel by MMSD helped alleviate flooding and pollution problems associated with an aging combined stormwater and sanitary-sewer system, preventing more than 70 billion gallons of wastewater from entering Lake Michigan since the Deep Tunnel came online in 1994.

Sources for Additional Information

- Milwaukee Metropolitan Sewerage District's Overflow Reduction Program, accessed August 10, 2012, at *http://v3.mmsd.com/AssetsClient/Documents/sustainability/SustainBookletweb1209.pdf*.
- Milwaukee Metropolitan Sewerage District's Deep Tunnel system, accessed August 21, 2012, at *http://v3.mmsd.com/DeepTunnel.aspx*.

Figure 28. Habitat is being restored along the Kinnickinnic River in Milwaukee, Wisconsin, to improve fish passage and reconnect the stream to the flood plain.

Stream Repair

Watershed Management Goals Addressed:

- Stabilize streambanks
- Improve in-stream habitat

In watersheds that have already been urbanized, stream repair practices can be used to stabilize streambanks as a way to prevent erosion that leads to property loss and downstream sediment pollution, create new habitat for wildlife and in-stream biota, reconnect streams to their flood plains to allow for natural removal of nutrients, sediments, and other pollutants, increase recreational usage of the stream by improving the aesthetics and accessibility, and aid in protecting the integrity of wastewater and sanitary sewer infrastructure. These stream repair practices can prevent wastewater pollutants from entering the streams.

Stream repair includes stream cleanups and the installation of simple stream repair practices to enhance the appearance and usability, structure, or function of urban streams (fig. 29). Stabilization of the stream corridor can be done as part of an overall strategy to meet environmental mandates such as MS4 permits or TMDLs, but often is initiated in response to local resident concerns such as erosion of stream-front properties, severe flooding, and so forth. Stream repair projects can also be installed as part of a comprehensive effort to restore an urban stream reach to a more natural condition.

The strength of this approach is that it directly addresses erosion and other problems in the stream corridor. However, focusing on only the stream corridor without consideration of upstream or downstream conditions can result in stream repair projects that are not successful. The challenges and uncertainties of stream restoration are described further in *Urban Stream Restoration* in Chapter 2.

Source for Additional Information

- Schueler, T., and Brown, K., 2004, Urban stream repair practices—Manual 4 in the urban subwatershed restoration manual series: Ellicott City, Md., Center for Watershed Protection.

In this Howard County, Maryland, stream, coir fiber logs made of tightly bound coconut fiber provide short-term protection along the toe of the streambank until the newly planted live stakes take root and stabilize the streambank.

Wing deflectors in Stony Run in Baltimore, Maryland, are used to redirect flow in the stream to concentrate flow away from the banks and toward the center of the stream.

Step pools, such as this one installed along Stony Run in Baltimore, Maryland, consist of a series of low elevation pools and wiers and are designed to dissipate energy along stream reaches that are downcutting.

The boulder revetment provides a more structural and immediate method to stabilize the stream bank in this Howard County, Maryland, stream reach.

Figure 29. Examples of stream repair practices, including rock vortex weirs, rootwads, channel redesign, boulder revetments, and vegetation establishment. Photographs from Center for Watershed Protection.

Case Study: Integrated Stormwater and Stream Corridor Management in Anne Arundel County, Maryland

The traditional approach to stormwater management and drainage infrastructure has been to focus on collection and conveyance of runoff from impervious surfaces to a BMP and ultimate discharge of this volume of water to an offsite receiving stream using a pipe. The increased discharge to the stream frequently results in channel erosion and loss of stream habitat, contributing to biological impairments. Headwater streams, which provide many ecologic and water-quality benefits, often receive the brunt of this impact. Additionally, this approach can result in costly infrastructure failures.

The Maryland Department of Public Works surveyed their stormwater outfalls and concluded that the majority of pipe outfalls, rip-rap, and gabion level spreaders and energy dissipation devices used to convey stormwater have failed and resulted in more than $600 million in damage to streams, adjacent wetlands, and steep slopes in Anne Arundel County. County leaders determined that a more thoughtful, cost-effective, and restorative approach to handling urban stormwater flows was clearly needed, and they decided to pursue more holistic and sustainable design solutions. The new preferred approach is often referred to as regenerative stormwater conveyance (RSC).

The RSC systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation, and underlying carbon-rich sand channel to treat and safely detain and convey stormflow, and convert stormwater to groundwater through infiltration (fig. 30). The RSC systems combine features and treatment benefits of swales, infiltration, filtering, and wetland practices. Not only is RSC applicable in new development, retrofit, and restoration scenarios, it is fully consistent with and even expands upon the principles of low-impact development, environmental site design, and sustainable green infrastructure.

The benefits of RSC include water-quality improvements, reduced stream erosion, aquatic and wetland habitat restoration, increase in flora and fauna diversity, restoration of shallow groundwater, restoration of perennial streamflow, and aesthetic improvements. RSC systems have been utilized primarily in the Coastal Plain of Maryland, but can be implemented in almost any region with some minor adaptations. These systems are currently being monitored to document their performance so they can be considered as a BMP in the Maryland Stormwater Manual.

Source for Additional Information

- Design guidelines for regenerative step pool storm conveyance, Anne Arundel County, accessed August 10, 2012, at *http://www.aacounty.org/DPW/Watershed/SPSCdraftunderreview.pdf*.

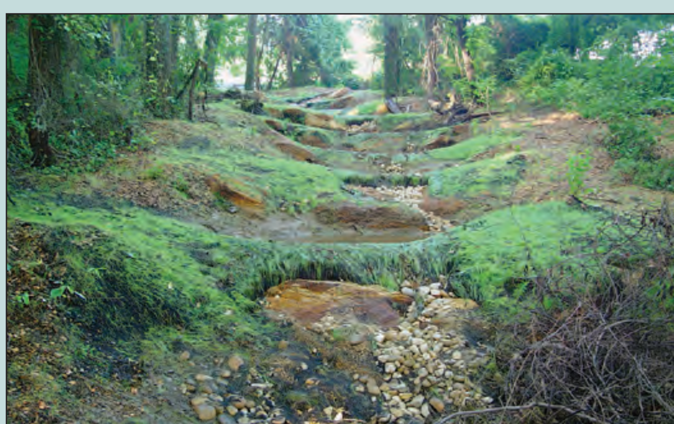


Figure 30. Regenerative Stormwater Conveyance System in Anne Arundel County, Maryland. Photograph by Keith Underwood, Underwood & Associates.

Redevelopment and Infill Policies and Incentives

Watershed Management Goals Addressed:

- Encourage reuse of existing urban areas
- Reduce, disconnect, and (or) treat impervious cover on urban land
- Reduce runoff volume and peak flows from urban land
- Reduce pollutants from urban land

Municipal growth and development policies can be designed to encourage the reuse of urban lands (fig. 31). These actions direct development away from undeveloped land and potentially limit urban sprawl. Reuse generally includes redevelopment, which is new construction on a site with an existing use (for example, conversion of commercial land to residential), and infill, which is development of a vacant parcel of land within an existing developed area. The use of planning tools such as transfer of development rights programs, land banks, and urban growth boundaries is one way to encourage redevelopment within an urban core instead of new development in the outlying suburbs (sometimes referred to as "greenfield" development). Policies that reduce the time and cost associated with redevelopment permitting and the site development process may help to redirect development away from the urban fringe. These include: density bonuses; expedited permitting; reduction in impact fees; reducing or eliminating parking requirements; providing tax incentives, grants, and loans; and reduced stormwater criteria for redevelopment.

Stormwater management policies that include specific requirements for redevelopment and (or) infill sites usually require a reduction in the amount of impervious surface, runoff volume or pollutant load, but are also less stringent than what would be required of new development. Since many of these highly urban sites are 100 percent impervious with no prior stormwater treatment, redeveloping them to these types of standards actually reduces runoff and pollutants from these sites and can increase community amenities such as green space (Chesapeake Stormwater Network, 2011). One policy option is to require sites to reduce the amount of impervious surface or runoff volume by some specified amount. A second option is to require some percentage of a redevelopment site to be treated in the same manner that new development would. Another possible application is to focus on increasing removal of a specific pollutant of concern (by requiring certain BMPs) for redevelopment and infill sites in impaired watersheds.

Redevelopment and infill site conditions may constrain implementation of certain types of stormwater treatment practices (for example, poorly drained soils may limit use of infiltration BMPs). The challenge is to find a balance between stormwater criteria that actually improve conditions at redevelopment sites without being so restrictive that they discourage redevelopment in the first place. It is also important to ensure there are adequate incentives for developers to implement the stormwater management practices to achieve the standards, as opposed to paying a fee in lieu of or looking outside the city for development opportunities.

Proponents of smart growth advocate for urban reuse projects that have a greater density or intensity than what previously existed on the site because, if intensity is lowered, this can actually add growth pressures to the urban fringe. Ideally, increasing urban intensity on redevelopment sites can be accomplished in a way that both attracts developers using incentives (for example, density bonuses) and improves water quality on site (for example, reducing the impervious cover footprint by building up instead of out). Coordination with neighboring jurisdictions is also essential to prevent redevelopment policies from simply driving new development to greenfield sites in these alternative locations.

Effective redevelopment and infill policies and incentives have the ability to reduce the impact of urban lands on downstream receiving waters by reducing runoff and pollutants from these sites as they are developed. This management strategy may be one of the most affordable ways to manage urban impacts in the long-term. In addition, it can protect natural areas from being developed and actually improve conditions in urban areas, resulting in a win-win situation.

Figure 31. Historic buildings near downtown Atlanta, Georgia, are being restored and reused as part of ongoing redevelopment efforts in the city.

Sources for Additional Information

- Water Environment Research Foundation's "Using Incentive Programs to Promote Stormwater BMPs," accessed August 10, 2012, at *http://www.werf.org/liveablecommunities/toolbox/incentives.htm.*
- PolicyLink's Land-use and Environment Tool Group, accessed August 10, 2012, at *http://www.policylink.org/site/c.lkIXLbMNJrE/b.5136715/k.53EF/Land_Use_and_Environment_Tool_Group.htm.*

Case Study: Infill and Redevelopment: A Second Chance for California's Ventura County Streams, Bays, and Estuaries

Ventura County, California, and the 10 cities contained within the county have adopted an approach to land development that promotes redevelopment, infill, and rehabilitation within municipal boundaries and preserves large areas of contiguous agricultural and open space between them. This approach has resulted in a substantially different character of development than the more ad-hoc development patterns that occur in most other California counties. A key land-use policy behind this approach is the Guidelines for Orderly Development, adopted in 1969, which is an agreement between the county and the 10 cities stating that urban development should occur within incorporated cities, which are better able to provide urban services. The county and the cities then adopted a series of seven greenbelts. Land within the greenbelts may not be annexed to the adjacent cities, which effectively prohibits development at urban densities within the greenbelts. The other major components of the county's unique growth management tradition are the Save Open-Space, Agricultural Resources, and City Urban Restriction Boundary initiatives. These measures require voter approval before development can occur in the affected areas.

Because infill and redevelopment projects are almost always more challenging to finance, design, and implement than greenfield projects, the county has developed additional programs and planning tools to facilitate these types of projects. For example, the Ventura Redevelopment Agency plays a central role in stimulating renovation and new development in downtown areas by developing housing and economic development plans as well as supplying services such as land cost buy-downs, construction of offsite improvements, and parcel assembly. Other services provided by the county to encourage infill and redevelopment include site inventories and assessments, market analysis, marketing programs, modeling and design assistance, financial and tax incentives, capital improvement plans, renewal/revitalization programs, and development of specific area plans.

Infill, redevelopment, and rehabilitation projects not only absorb new growth that would otherwise have taken place in greenfield areas, they also provide a second opportunity to protect water resources by installing stormwater BMPs where none previously existed. However, because of the challenges associated with redevelopment sites, stormwater management requirements that are overly restrictive can act as a deterrent to developers. This conundrum is acknowledged in the county's Water Resources and Land-Use Planning document, a unique watershed-based plan whose goal is to better align water and land-use planning through improved coordination between land-use and water planning efforts. In discussing stormwater criteria for redevelopment sites, the Local Government Commission suggests several potential innovations that may benefit developers and also protect stream ecosystems:

- Using incentives to attract redevelopment to those sites most beneficial for stormwater management (for example, large, highly impervious sites).
- The additional watershed benefits provided by redevelopment sites that accommodate greater density within a smaller site footprint (for example, high rises) are overlooked by stormwater requirements that are triggered by a threshold of land disturbance.

Source for Additional Information

- Local Government Commission, accessed August 10, 2012, at *http://water.lgc.org/ventura*.

Reforestation and Urban Forest Management

Watershed Management Goal Addressed:

- Increase tree canopy on urban land

Many cities and other jurisdictions have promoted reforestation in their urban areas because trees and forests provide multiple health, aesthetic, recreational, and environmental benefits (fig. 32; United States Conference of Mayors, no date; New York City Department of Environmental Protection, no date; Philadelphia Water Department, 2009; Milwaukee Metropolitan Sewerage District, 2009). These greening efforts focus on reforestation and tree planting to increase the urban tree canopy and maintenance and management of urban trees and forests to increase tree survivability and improve forest conditions. Urban tree canopy is defined as the layer of tree leaves, branches, and stems that cover the ground when viewed from above. Urban tree canopy provides an important stormwater management function by intercepting rainfall that would otherwise run off of paved surfaces and be transported into local waters though the storm drainage system, thus picking up various pollutants along the way. Urban tree canopy also reduces the urban heat island effect, reduces heating/cooling costs, lowers air temperatures, reduces air pollution, increases property values, provides wildlife habitat, and provides aesthetic and community benefits such as improved quality of life.

Methods to increase tree canopy include adoption of State or local forest conservation and riparian buffer regulations; local landscaping requirements; shading and canopy ordinances that require tree planting on redevelopment sites; ordinances that require a permit to remove a tree; community planting projects on public land; education and incentive programs to encourage tree planting on private lands; and simply allowing forests to naturally regenerate by ceasing mowing. Tree maintenance and long-term management is important to ensure that trees survive, thrive, and meet management objectives.

Another mechanism that is becoming increasingly popular to generate interest in tree planting is adoption of urban tree canopy goals. A growing number of cities and other municipalities across the country are setting numeric goals for urban tree canopy and implementing plans to achieve the goals. These initiatives usually have a high profile to spur public interest in tree planting and are accompanied by municipal efforts to identify potential planting areas on public lands and systematically reforest them. The ability to meet the urban tree canopy goal often requires the establishment of a municipal urban forestry program to head up reforestation efforts and manage and maintain the urban forest. These departments are typically responsible for managing street trees, specimen trees, and forest stands on public lands such as parks.

This management strategy is relatively inexpensive and provides many other community benefits above and beyond environmental ones. Additionally, unlike many other practices, the urban tree canopy approach can leverage the efforts of individual citizens as well as the efforts of the municipal government. Some challenges include a lack of available space for trees in highly urban areas; conflicts between trees and utilities; reliance on public participation to increase tree cover on private land; and the contribution of phosphorus to the environment from street trees, because in urban environments there is no forest floor or intact riparian ecosystem to process and recycle the nutrients resulting from degradation of leaves. Because of this latter challenge, street tree programs in watersheds where phosphorus is a problem will benefit from establishing or improving curbside leaf collection programs.

There are limited monitoring data to quantify the water-quality improvement and runoff-reduction effects of trees and forests; therefore, managers may be less likely to select reforestation as a BMP because they do not get the appropriate "credit" for its use. The data that do exist to support stormwater effects of trees are further complicated by the variable and often highly compacted nature of urban soils. However, new technologies and techniques such as "structural soils" offer great promise to prevent soil compaction by using stone lattice work or ridged cells to bear the load of the urban surface allowing for more root penetration and water absorption capacity and less infrastructure impacts.

Sources for Additional Information

- Center for Watershed Protection's Watershed Forestry Resource Guide, accessed August 10, 2012, at *http://www.forestsforwatersheds.org/.*
- Urban Watershed Forestry Manual Part 1: Methods for Increasing Forest Cover in a Watershed, accessed August 10, 2012, at *http://www.forestsforwatersheds.org/storage/completePart1ForestryManual.pdf.*
- Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites, accessed August 10, 2012, at *http://www.forestsforwatersheds.org/planting-and-maintaining-trees/.*
- Urban Watershed Forestry Manual Part 3: Urban Tree Planting Guide, accessed August 10, 2012, at *http://www.forestsforwatersheds.org/storage/Part3ForestryManual.pdf.*

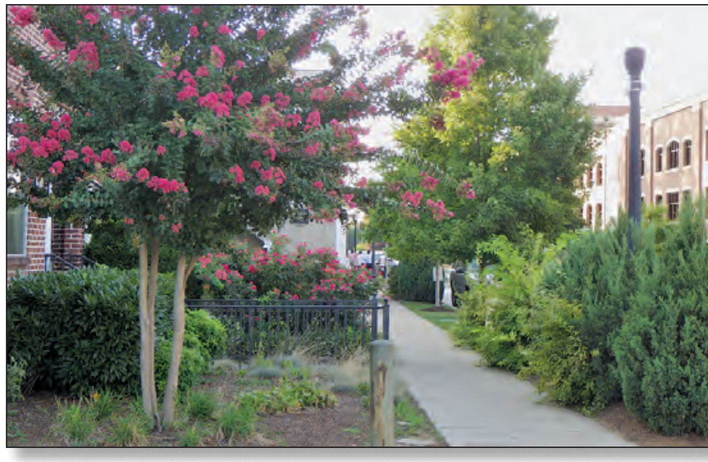


Figure 32. Incorporating street trees into urban areas is one method of increasing urban tree canopy, which reduces runoff by capturing rainwater and also provides shade, air-quality benefits, and more aesthetically pleasing neighborhoods. Photograph from U.S. Geological Survey.

Case Study: Million Trees LA Initiative, Los Angeles, California

The Million Trees LA Initiative aims to plant one million trees over several years and make Los Angeles the greenest city in the United States. The city intends to achieve several outcomes through this initiative as these trees will provide shade and save on energy costs, clean the air and help reduce greenhouse gases that cause global warming, capture polluted urban runoff, improve water quality, and add beauty to their neighborhoods.

The city of Los Angeles is collaborating with the U.S. Department of Agriculture, Forest Service Center for Urban Forest Research, which conducted a tree canopy analysis to determine (1) where existing trees are located within the city, (2) how much total area the tree canopy covers, and (3) where to plant future trees for maximum benefit (Million Trees LA, 2011). The current tree canopy cover is estimated to be 21 percent for Los Angeles, which is comparable to the existing tree canopy in Baltimore and New York City, and is slightly less than the national average of 27 percent. The tree canopy analysis involved quantifying areas of *potential* tree canopy, by identifying open vegetated areas not currently forested or impervious. Currently (2012), there is potential to add 2.5 million trees and increase the tree canopy by 12.4 percent in Los Angeles. Planting one million trees would allow Los Angeles to achieve 97 percent of their goal of 27 percent tree canopy.

Additional expected benefits from the initiative include:

- A savings of $10 million in annual energy costs each year citywide,
- Removal of 2,240,000 pounds of air pollutants annually,
- A savings of $23 million per year in air pollution cleanup costs,
- The capture of 1,925,000,000 gallons of stormwater per year, and
- A savings of $5 million in annual stormwater runoff costs.

The Million Trees LA Initiative uses a Web site to track progress toward their goal, providing a form to be completed by anyone planting a tree within the city limits. The Web site also contains a wealth of information on how to select the right tree for the right place, tree planting methods, and various events related to the tree canopy goal.

Source for Additional Information

- Million Trees LA Initiative, accessed August 10, 2012, at *http://www.milliontreesla.org/mtabout1.htm.*

Stormwater Retrofits

Watershed Management Goals Addressed:

- Reduce, disconnect, and (or) treat impervious cover on developed land
- Reduce runoff volume and peak flows from developed land
- Reduce pollutants from developed land

Stormwater retrofits help restore watersheds by providing stormwater treatment in locations where practices previously did not exist or were ineffective (fig. 33). They are typically installed within the stream corridor or upland areas to capture and treat stormwater runoff before it is delivered to receiving waters. Stormwater retrofits can be used to reduce runoff volume, peak flows, and pollutants from urban land, which can promote more natural hydrology and minimize stream channel erosion. Some retrofits can also reduce the amount of impervious cover present.

Figure 33. A green street in Portland, Oregon, a previously impervious street surface that was transformed into a landscaped green space that captures stormwater runoff and uses plants and soil to filter pollutants. Photograph from Center for Watershed Protection.

Storage and onsite retrofits represent two different approaches to attain treatment storage and involve different design and assessment methods. Storage retrofits include modifying existing ponds and providing new storage above roadway crossings or below outfalls for example, whereas onsite retrofits include new BMPs installed to treat runoff from individual parking lots, rooftops, or streets (fig. 34). Generally, storage retrofits are the most cost-effective approach to meet most watershed restoration objectives, although both retrofit approaches might be needed to get the desired level of watershed treatment.

Total maximum daily loads, especially impervious cover or volume-based TMDLs, are a primary regulatory driver for communities to implement stormwater retrofits. These policies can lead to the local government installing retrofits on public lands, but will usually include other strategies to encourage more widespread retrofits. Among these strategies are cost-share programs that provide rebates toward purchase of a rain barrel; education and outreach programs focused on getting homeowners and businesses to disconnect their downspouts or install rain barrels and rain gardens; and community demonstration projects that serve to educate developers and residents on how these practices can be both attractive and effective. Often, these demonstration projects are implemented by watershed organizations or the local government. Other communities are implementing retrofits on an incremental basis by requiring stormwater management every time a street is reconstructed. For example, the city of Madison, Wisconsin, is currently in the process of developing such an ordinance.

Stormwater retrofits can be expensive to install because they are being inserted into a built environment and must contend with site constraints such as utilities, adjacent roadways. and private property. However, retrofits can be an important strategy for jurisdictions to use to meet their water-quality goals. There is typically some limit on the amount of developed land that is suitable for retrofits so these generally need to be combined with other, more cost-effective, strategies to meet the broader watershed goals.

Many communities fund their stormwater retrofit programs through a stormwater utility. Stormwater utilities, similar to water and wastewater utilities, charge residents and businesses a monthly or quarterly fee to fund the operation of stormwater programs, maintenance of stormwater infrastructure, and compliance with stormwater permits. These utility fees provide a sustainable source of funding for stormwater programs and an incentive to reduce site impervious cover.

Utility fees typically range from $30 to $120 per year per residential unit and apply to new and existing development. An average unit impervious cover charge is applied to all homes and businesses in most cases. The utility fee can be an incentive to reduce site impervious cover on new development projects or for property owners to reduce "effective" impervious cover by offering credits for implementing disconnection strategies. Effective impervious cover is the percentage of impervious surfaces that is directly connected to the storm drain system or stream. Common strategies to "disconnect" impervious cover include downspout disconnection or redirecting downspouts to a rain garden or rain barrel.

Typically, a local ordinance is adopted to establish a stormwater utility. The revenue stream can also be used to issue bonds and leverage for grants and loans such as the State Revolving Loan Programs for water. A limitation is that some communities lack sufficient geographic information systems capacity to estimate impervious cover and charge for individual parcels, which could provide a much stronger incentive for homeowners to reduce impervious cover.

Before and after construction of a stormwater management channel leading from a strip mall area to outfall pipe in Lynchburg, Virginia. The previously grass channel was converted to a series of check dams and bioretention areas to reduce stormwater runoff and filter pollutants. Photographs from Center for Watershed Protection.

Greenstreet retrofit in New York. The photograph on the left shows the installation of geotextile fabric during construction. The completed retrofit is shown on the right, which includes a curb cut that carries stormwater into a bioretention area. Photographs by Nandan Shetty, New York City Parks and Recreation Department.

Figure 34. Before and after examples of stormwater retrofit practices.

Sources for Additional Information

- Schueler, T., Hirschman, D., Novotney, M., and Zielinski, J., 2007, Urban stormwater retrofit practices, version 1.0: Manual 3 in the urban subwatershed restoration manual series: Ellicott City, Md., Center for Watershed Protection.
- The Charles River Watershed Association provides an information packet to assist communities with developing a stormwater utility, accessed August 10, 2012, at *http://www.crwa.org/projects/stormwater/infopacket.html*.

Case Study: Mandatory Retrofitting in Maryland

Phase I MS4 communities in Maryland are required to "treat" a certain percentage of their untreated impervious cover each year as part of their NPDES permit. In February 2010, Montgomery County, Maryland, received an NPDES permit that requires the capture and control of stormwater runoff to the maximum extent practicable from 30 percent of the county's impervious, urban surfaces. The permit requires the restoration of 20 percent of the impervious surfaces that are not currently controlled to the maximum extent practicable (4,100 acres) along with the 10 percent requirement that exists from the previous permit cycle (Lindow and others, 2010). Therefore, the county has multiple programs designed to address this requirement, including a stormwater retrofit program, the majority of which is composed of stormwater pond retrofits, and a Rainscapes program aimed at disconnecting residential downspouts. The county implemented a stormwater utility in 2002 after years of study and recommendations by citizens serving on work groups and task forces, county council staff, and the Department of Environmental Protection. The utility fee appears as a line item on a property tax bill and is called the Water Quality Protection Charge (WQPC). The WQPC is based on the average amount of square feet of roof, sidewalk, and driveway for a single-family dwelling and is assessed on all residential properties and certain nonresidential properties. The WQPC is the sole source of funding for inspection and maintenance of stormwater management facilities, water-quality monitoring, and street sweeping and also partially pays for the implementation of stream restoration and stormwater retrofit projects.

Source for Additional Information

- Montgomery County NPDES, accessed August 10, 2012, at *http://www.montgomerycountymd.gov/dectmpl.asp?url=/content/dep/water/npdes.asp*.

Pollution Source Controls

Watershed Management Goals Addressed:

- Limit pollutants from development sites
- Reduce pollutants from urban land

Urban pollution source control programs generally have one of the following objectives: (1) to modify residential behaviors and practices used at municipal or commercial sites in order to prevent pollutants used onsite from entering stormwater runoff and local waterways, or (2) to modify industrial production processes and substitute less toxic products to reduce the pollutants. Many pollution source controls have additional benefits such as community greening, reduced waste and cost, reduced runoff volume, and fewer risks to human health due to reduced risk of pollutants entering the local water system (fig. 35).

Neighborhoods generate pollution from common residential behaviors that occur within distinct source areas. "Stormwater hotspots" generate pollution during common operations and activities that occur at certain commercial, industrial, institutional, or transport-related sites (Wright and others, 2005). Municipal operations have the ability to influence water quality within a community and can be improved to better support local watershed management goals and objectives. Pollution source control program goals are designed to encourage widespread behavior change in residential, commercial, and municipal activities (for example, reducing fertilizer use, installing a rain barrel, properly storing hazardous materials) to realize downstream water-quality improvements.

Pollution source controls can also be implemented as part of the industrial production or manufacturing process. The goal is to reduce or eliminate waste at the source by modifying production processes, promoting the use of nontoxic or less-toxic substances, implementing conservation techniques, and reusing materials rather than putting them into the waste stream (*http://www.epa.gov/p2/*, accessed August 22, 2012).

The NPDES stormwater program requires communities to develop practices and programs to control and reduce the amount of stormwater pollution that is discharged into their municipal storm drain systems. Communities regulated under the NPDES stormwater program have a legal responsibility to develop pollution source control programs to control and reduce stormwater pollution generated by their own operations. According to the regulations, the operator of a regulated MS4 community must develop a program to:

- Prevent or reduce the amount of stormwater pollution generated by municipal operations and conveyed into receiving waters,
- Train employees on how to incorporate pollution prevention/good housekeeping techniques into municipal operations, and
- Identify appropriate best management practices and measurable goals for preventing or reducing the amount of stormwater pollution generated by municipal operations.

Additionally, most communities now have a legal responsibility to conduct stormwater education to control neighborhood sources of pollutants. In particular, three minimum management measures require localities to provide some form of stormwater education to improve the following:

- Public education and outreach,
- Public involvement and participation, and
- Municipal pollution prevention/good housekeeping.

The major strength of this approach is that pollutants are prevented from entering waterways, effectively protecting their condition and integrity and eliminating the need for costly restoration. The major weakness is that although pollution source control programs might be required at the municipal level, the ultimate responsibility for changing pollutant-generating behaviors rests with the individual.

Installing pet waste pickup stations at parks and along walking trails can encourage pet owners to properly dispose of their pet waste, which can be a source of bacteria and nutrient pollution.

Business owners can prevent pollution by locating dumpsters away from storm drain inlets and making sure they are properly covered and maintained so they do not become a source of trash and other pollutants to local streams. Photograph from U.S. Geological Survey.

Figure 35. Examples of pollution source control opportunities.

Sources for Additional Information

- Detailed information on pollution source controls for neighborhoods, hotspots, and municipalities is in Schueler, T., Swann, C., Wright, T., and Sprinkle S., 2004, Pollution source control practices: Manual 8 in the urban subwatershed restoration manual series: Ellicott City, Md., Center for Watershed Protection.
- The National Pollution Prevention Roundtable provides a national forum for promoting the development, implementation, and evaluation of efforts to avoid, eliminate, or reduce pollution at the source, accessed August 10, 2012, at *http://www.p2.org/*.

Case Study: Citywide Ban on Coal Tar Sealants, Austin, Texas

The city of Austin, Texas, devotes more than $1 million annually to monitor local creeks to track trends in ecological integrity and water-quality impairment. The city maintains several monitoring stations in the Barton Springs segment of the Edwards aquifer, and collects samples for analysis of 18 stormwater pollutants in Austin's Town Lake. Findings from the monitoring program are quickly posted on their Web site. Particular concerns were raised when elevated polycyclic aromatic hydrocarbons (PAHs) were detected upstream from the popular Barton Springs swimming pool (Scoggins and others, 2007).

The PAHs are an environmental concern because (1) they are toxic to aquatic life, and (2) several of these compounds are suspected human carcinogens. Collaborative studies conducted by the U.S. Geological Survey and the city of Austin traced PAH sources to stormwater runoff generated from parking lots coated with coal-tar based sealant. Coal-tar based sealant, which has high concentrations of petrogenic PAHs, is a black liquid applied to parking lots and driveways in an effort to protect and beautify those surfaces (fig. 36). Once the source of the PAHs was identified, Austin implemented a citywide ban on the sale and use of coal-tar pavement sealants.

Figure 36. Application of coal-tar based sealcoat—the black, shiny emulsion painted or sprayed on asphalt pavement such as parking lots—can be a significant source of PAH contamination in stormwater runoff (from Van Metre and others, 2006).

Source for Additional Information

- City of Austin, accessed August 10, 2012, at *http://www.ci.austin.tx.us/watershed/surface_pahcoaltar.htm*.

Illicit Discharge Detection and Elimination

Watershed Management Goal Addressed:

- Reduce pollutants from urban land

Illicit discharges, or discharges other than stormwater to the storm drain, occur in most urban watersheds and can be an important source of pollutants (fig. 37; Brown and others, 2004). Under the NPDES program, regulated communities are required to establish programs to find and fix illicit discharges (Clean Water Act Section 402, National Pollutant Discharge Elimination System, 40 CFR § 402(p)(3)(B)). This involves dry-weather sampling of flowing stormwater outfalls to identify potential illicit discharges, determine the type of discharge (for example, sewage versus wash water), and track discharges to their sources. Once the sources of illicit discharges are discovered, they can be fixed, repaired, or eliminated through several different mechanisms (fig. 38).

Illicit discharge detection and elimination programs can reduce pollutant loads to receiving streams. Often, the fix is a simple one, but the associated pollutant load can be substantial. The elimination of illicit discharges could require a combination of incentives and regulations. For example, transitory discharges from generating sites can be minimized through pollution prevention practices and well-executed spill management and response plans.

Some illicit discharges are a result of illegal dumping of materials into the storm drain. While some instances of dumping may be intentional, others are likely the result of a lack of awareness of the purpose of the storm drain and its connection to the health of streams. Targeted education programs about stormwater infrastructure and illicit discharges can help prevent such discharges.

Figure 37. Algae growth on this stormwater outfall is an indicator of the presence of sewage. Flows of sewage to the storm sewer system enter local streams untreated and are considered an illicit discharge.

Figure 38. Team conducting dry weather outfall sampling for illicit discharges in the Jones Falls watershed in Baltimore, Maryland. Photograph from Center for Watershed Protection.

Sources for Additional Information

- U.S. Environmental Protection Agency, Illicit Discharge and Elimination, accessed August 10, 2012, at *http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=3.*
- Detailed guidance for an illicit discharge detection and elimination program is provided in Brown, E., Caraco, D., and Pitt, R., 2004, Illicit discharge detection and elimination: A guidance manual for program development and technical assessments: Washington, D.C., Center for Watershed Protection and University of Alabama, U.S. Environmental Protection Agency Office of Wastewater Management, EPA X-82907801-0.

Case Study: Illicit Discharge Detection and Elimination in Vermont Communities

The Vermont Legislature required the Vermont Department of Environmental Conservation to implement a statewide program to promote illicit discharge detection and elimination (IDDE) in 2000. The intent of the Legislature was to encourage widespread implementation of IDDE beyond just those communities required to develop IDDE programs under their NPDES permits. Stone Environmental and the Friends of the Winooski River have conducted IDDE surveys in 15 Vermont communities not subject to MS4 permit requirements. These communities include the municipalities of Montpelier, Berlin, Northfield, Barre City, Waterbury, Richmond, Waitsfield, Moretown, Brattleboro, and six towns in the Missisquoi River watershed (Stone Environmental, no date).

The primary tasks performed as part of the IDDE surveys were (1) to record observations and perform basic water-quality tests at flowing outfalls, other discharge points, and selected catch basins and junction manholes during dry-weather periods; and (2) where monitoring indicated contamination, to work with the community or business to investigate potential pollutant sources through the stormwater drainage system. The team assessed approximately 800 discharge points and tested flowing outfalls for ammonia (an indicator of wastewater), specific conductance, detergents, optical brighteners (which indicate wastewater or wash water) and fluoride (which indicates a drinking-water source). Samples exceeding thresholds for ammonia or optical brighteners were also tested for total phosphorus and the bacterium, *Escherichia coli* (*E. coli*).

Water-quality testing of the outfalls and other discharge points surveyed indicated sewage sources at 32 locations, petroleum discharges at 15 locations, and drinking-water leaks at 16 locations. Stone Environmental documented wastewater contamination of stormwater systems in the Missisquoi River watershed at North Troy, Richford, Enosburg Falls, and Swanton, and undertook efforts to locate specific contamination sources and implement repairs (Braun, 2011). Advanced investigation methods employed to track pollution sources included smoke testing, dye testing, and closed circuit television camera inspection. Stone Environmental estimates that these IDDE efforts have resulted in a decrease in phosphorus loading to Lake Champlain of 230 kilograms per year and also reduced risks of pathogen exposure. A variety of other problems identified through the IDDE surveys have also been addressed, such as water leaks, trash dumping, improper disposal of pet waste, and runoff from vehicle washing.

Despite these improvements, some potential water-quality problems remain unresolved. Given the intermittent nature of some illicit discharges and the many technical challenges inherent in finding sources of contamination in buried infrastructure, this is to be expected. The recommended approach is to implement a targeted program to resample and further investigate the unresolved cases. The State of Vermont is working to complete mapping and IDDE inventories of all towns with sewer systems in the Lake Champlain Basin and is in the process of engaging the Province of Quebec, Canada, and the State of New York to also begin this effort in communities located on Lake Champlain tributaries.

Source for Additional Information

- Vermont Department of Environmental Conservation, Clean and Clear Action Plan, stormwater mapping and illicit discharge detection and elimination program statewide, accessed August 10, 2012, at *http://www.anr.state.vt.us/cleanandclear/SW_IDDE_program.htm.*

Pollution Caps

Watershed Management Goals Addressed:

- Limit pollutants from development sites
- Reduce pollutants from urban land

Pollution caps limit the amount of a pollutant that can be discharged to surface waters at a given outfall, development site, or watershed. Pollution caps are primarily established and enforced through Federal regulatory programs such as the NPDES and TMDLs. At the watershed scale, these caps are particularly important to address the impacts of future growth and development once water-quality goals have been attained.

The NPDES permit program, as authorized by the Clean Water Act, controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are confined or discrete conveyances, such as pipe outfalls or man-made ditches, from which pollutants can be discharged (usually by industrial, municipal, and other facilities). The NPDES-permitted discharges are essentially a pollution cap that is assigned to a given point source.

Pollution caps can also be implemented at the watershed scale. The Clean Water Act requires States, territories, and authorized tribes to inventory their impaired waters. These are waters that are too polluted or otherwise degraded to meet the water-quality standards set by their respective States, territories, or authorized tribes. The Clean Water Act requires that jurisdictions establish priority rankings for waters on the lists and develop TMDLs for these waters. A TMDL is "a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water-quality standards" (*http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm*). To meet the established TMDL, pollutant reductions are required from both point-source and nonpoint-source polluters in the watershed through implementation of BMPs and other measures. The required load reductions for point-source discharges are enforced through the NPDES permits. The TMDL target is a cap, and future loadings must be offset to assure the cap is maintained.

An innovative mechanism that can be used to help meet the established cap at the watershed scale is water-quality trading. A water-quality trading program allows sources that reduce their pollutant loadings below target levels to sell their surplus reductions or "credits" to other sources that cannot meet their target levels (fig. 39). This approach allows pollution sources that can reduce pollutants at low cost (for example, agriculture) to sell credits to those facing higher-cost pollution reduction options (for example, wastewater-treatment plants) and improves the ability of communities to meet their TMDLs. Trading, in some cases, is the only feasible alternative to meet the TMDL. Most water-quality trading programs have focused on nutrients, although the potential exists to establish a program for other pollutants.

Federally mandated pollution caps, including the NPDES MS4 program and TMDLs, have been highly effective at reducing pollution from point sources. However, the ability of these programs to reduce nonpoint-source pollution is less

Figure 39. Some communities are participating in water-quality trading programs to meet pollution caps. An example of how such a trading program works is that a wastewater-treatment plant that is required to reduce nutrients by a certain amount may pay farmers to install best management practices, such as cover crops, to reduce the same amount of nutrients at a lower cost. The photograph shows that no-till planting of corn into a cover crop of barley reduces nutrients in runoff from this farm field at a lower cost (right) than it would to upgrade the small wastewater-treatment plant (left). Photographs by Jeff Vanuga, U.S. Department of Agriculture, Natural Resources Conservation Service.

clear (National Academy of Sciences, 2008). For example, TMDL requirements for regulated MS4 communities are expressed in terms of BMPs rather than as numeric limits (for example, load reductions) for individual pipe outfalls. Performance of the MS4 program is measured by the degree of BMP implementation and program implementation rather than by water-quality results. Therefore, there are limited data to determine whether these approaches are working to improve stream conditions without implementing a highly complex monitoring study within each individual permitted area.

The strength of the TMDL approach is that it provides a targeted numeric output that communities strive to reach rather than simply using the best available technology, an approach that might or might not enable communities to reach their water-quality goals. Most TMDLs are concentrated on a singular pollutant; that is, nutrients, sediment, and so forth. However, the development of the first impervious cover TMDL as a surrogate for increased runoff and pollutant loads could mean that the TMDL implementation process might be making strides toward a more comprehensive approach.

Sources for Additional Information

- U.S. Environmental Protection Agency Impaired Waters and Total Maximum Daily Loads, accessed August 10, 2012, at *http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm*.
- U.S. Environmental Protection Agency NPDES Permit Program Basics information, accessed August 10, 2012, at *http://cfpub.epa.gov/npdes/home.cfm?program_id=45*.

Case Study: Pollutant Trading in Oregon Focuses on Water Temperature

The Tualatin River drains a 712-square-mile basin on the west side of the Portland metropolitan area in northwestern Oregon. The urban area is served by four wastewater-treatment plants. The river was assigned a temperature TMDL by the Oregon Department of Environmental Quality in 2001, which showed that 40 percent of the thermal energy reaching the river was solar in nature and reached the river as a result of the loss of trees in rural and urban landscapes. The options to meet the TMDL were to reduce the temperature of the influent coming into the wastewater-treatment plants, reduce the temperature of the effluent being returned to the river through the use of costly refrigeration systems, remove all discharges to the river, or implement a temperature trading program. The most cost-effective and ecologically beneficial solution was to implement a temperature trading program that could result in the planned releases of cooler reservoir water during summer months and the shading of tributary riparian areas (shade credits). All of this was feasible as a result of a flexible watershed-based NPDES permit that allowed for temperature trading as a method of compliance.

Source for Additional Information

- Oregon Department of Environmental Quality water quality credit trading program information, accessed August 10, 2012, at *http://www.deq.state.or.us/wq/trading/docs/wqtradingcasestudy.pdf*.

A Water-Quality Monitoring Framework to Support Implementation of Management Strategies

Water-quality monitoring is not, in itself, a management strategy. Instead, monitoring activities develop information needed to understand the condition of water resources. Over time, a well-designed monitoring program can be used to understand the consequences of changing land-use patterns in a watershed or the consequences of implementing water-resource management strategies. Monitoring data can be used to address a variety of questions of interest to water-quality managers:

- What are the current stream conditions and source of impairment?
- What are the expected impacts of future development on these conditions?
- What is the impact of management strategies on conditions?
- How can management strategies be improved to meet watershed management goals?

Each year governmental and non-governmental organizations dedicate significant resources to describing the condition of watershed and associated water resources (National Water Quality Monitoring Council, 2004). Monitoring programs may be designed and run by water-quality professionals (see Coles and others, 2012; see also the case study *Watershed Monitoring in Montgomery County, Maryland*) or by coalitions of professional and interested citizen volunteers (see *Urban Watch Monitoring Program in Monterey, California, Helps to Target Pollution Sources*).

The National Water Quality Monitoring Council has developed a systematic process that, when followed, will help monitoring organizations produce and convey the information needed to understand, protect, and restore the Nation's waters (fig. 40). The framework illustrates the interconnectedness of monitoring objectives with the design and implementation of the monitoring effort. The "3 Cs" shown in the outer ring of the framework indicate the importance of communication, coordination, and collaboration within and among monitoring organizations at every step of the process.

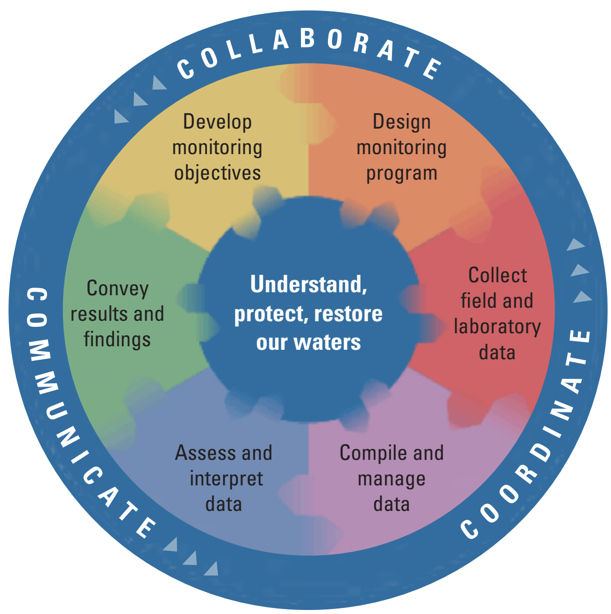


Figure 40. The National Water Quality Monitoring Council's Monitoring Framework illustrates a systematic process that will help monitoring entities produce and convey the information needed to understand, protect, and restore the quality of surface water and groundwater (from National Water Quality Monitoring Council, 2004).

Case Study: Watershed Monitoring in Montgomery County, Maryland

Montgomery County, Maryland, a suburb of Washington, D.C., has been experiencing degraded stream ecosystems during the past several decades. The county moved from chemical and physical stream monitoring to a biological monitoring approach in the 1980s and 1990s, because it was viewed as a more cost-effective tool to assess the cumulative impacts of land-use change on streams. The county monitored every watershed within its boundaries in 1997 to identify areas of healthy waters and areas of impairment. This monitoring involved comparing fish and macroinvertebrate conditions with ecoregion-based reference condition and assessing the condition of the surrounding riparian and in-stream habitat. The results were compared with information about current and future land use to develop appropriate watershed management strategies.

Montgomery County identified one watershed management category through this process as Special Protection Areas (SPAs), which are designated geographic areas that have “high quality or unusually sensitive water resources and environmental features that would be threatened by proposed land development if special water-quality protection measures were not applied.” The goal for managing SPAs is to maintain the water quality while allowing urban growth. The county council has designated four areas within Montgomery County as SPAs and passed SPA regulations that require the following special measures be applied to land development in SPAs:

- Reduce the overall impervious footprint of new development within SPA boundaries.
- Minimize large earth-disturbing activities that modify the natural topography.
- Protect natural features to the maximum extent possible.
- Use multiple erosion and sediment control and stormwater management structures in a linked series to clean stormwater runoff to the maximum extent possible.

Under the SPA regulations, the county conducts stream biomonitoring and water-quality monitoring before, during, and after development to document the health of the streams over time and to study the overall effects of development on the watershed. Additionally, developers are required to monitor selected parameters to evaluate the ability of the BMPs described above to minimize development impacts to the receiving streams. The monitoring data are used to evaluate the design and function of SPA BMPs, link BMP performance to changing stream conditions, and guide future planning decisions.

Montgomery County has partnered with the USEPA, USGS, and others to expand the monitoring at its Clarksburg SPA by comparing changes in stream conditions before and after construction as compared to a reference (undisturbed) watershed. The objective of the research is to quantify how stormwater BMPs can help to mitigate the effects of imperviousness on the health of the receiving streams. Preliminary results from the 2008 project report show that, although the BMPs are performing as expected, the efficiency of the BMPs has not been adequate to prevent degradation of biological conditions in the stream (Montgomery County Department of Environmental Protection, 2010). All but one of the stations in the Clarksburg SPA remained in fair to good condition in 2008. Conditions at two stations whose drainage areas had been stabilized improved from fair to good from 2007 to 2008. The 2008 report states that “the frequent, intense, and ongoing disturbances through the development period in the [SPA] may have impaired the ability of the benthic communities to fully recover to near pre-construction conditions. The level of recovery and the direct influence of [stormwater] BMPs (described to be “state-of-the-art” designs at the time) are unclear at this time” (Montgomery County Department of Environmental Protection, 2010).

Case Study: Urban Watch Monitoring Program in Monterey, California, Helps to Target Pollution Sources

The diversity of sea life and the quality of the marine environment make Monterey Bay one of the most popular diving destinations in the United States and home to the Monterey Bay National Marine Sanctuary. However, projected residential and light industrial growth rates have raised concern that increases in stormwater runoff will damage this delicate marine environment. The Urban Watch Water Quality Monitoring Program was established to protect this important resource.

The Urban Watch Water Quality Monitoring Program is a collaborative effort between the Cities of Monterey, Pacific Grove, and Capitola, the Coastal Watershed Council, and the Monterey Bay National Marine Sanctuary. Urban runoff is one of the leading sources of pollution into coastal waters. Urban Watch uses citizens to monitor and study streams and stormwater outfalls in the Monterey Bay watershed. Teams of volunteers trained in water-quality monitoring have conducted dry-weather sampling of stormwater outfalls draining to Monterey Bay since 1998. This continuing program has helped the Cities of Monterey, Pacific Grove, and Capitola and the Monterey Bay National Marine Sanctuary identify and implement targeted educational programs aimed at addressing urban pollutants entering the Monterey Bay National Marine Sanctuary.

Volunteers collect dry-weather water samples that are tested for several water-quality properties and constituents including detergents, phenols, ammonia, chlorine, turbidity, pH, water and air temperature, odor, and color. Additionally, volunteers note the presence of oily sheens, sewage, trash, or surface scum observed at the time of sampling. The premise of conducting dry-weather sampling of stormwater outfalls is that any discharge from an outfall is suspected to be an illicit discharge of pollutants (such as a cross connection from a sanitary sewer, or wash water from a nearby home or business) because these outfalls should only be flowing during wet weather. Program staff find monitoring data such as these very helpful in identifying current sources of pollution for removal as well as preventing future illicit discharges.

Monitoring in the first few years of sampling in the city of Monterey indicated the presence of detergents in 20 of 43 samples collected. Monitoring also revealed the presence of detergents in all samples collected at two sites. The high concentrations of detergents led volunteers to area restaurants. When restaurants wash floor mats and other kitchen apparatus outside, detergent and grease-laden water is discharged directly into the stormwater system. The partnership is using this information to design an efficient strategy for preventing these discharges in the future.

Sources for Additional Information

- Coastal Watershed Council Urban Watch information, accessed August 17, 2012, at *http://coastal-watershed.org/monitoring/urban-watch/*.
- Monterey Bay Sanctuary Citizen Watershed Monitoring Network information, accessed August 10, 2012, at *http://montereybay.noaa.gov/monitoringnetwork/about_us.html*.
- Natural Resources Defense Council summary of Urban Watch program, accessed August 10, 2012, at *http://www.nrdc.org/water/pollution/storm/chap9.asp#MBAY*.

Chapter 5

Key Challenges in Managing the Impacts of Urban Development on Streams

The biological, physical, chemical, and societal processes that shape urban stream ecosystems are complex. The EUSE study findings indicate that, regardless of the area of the country, urban development will have some adverse impacts on the physical, chemical, and biological systems that help define the conditions of urban stream ecosystems. Watershed managers face three recurring challenges as they develop and implement management strategies to improve the health of these systems: (1) scale and endpoint challenges, (2) uncertainty and knowledge gap challenges, and (3) implementation challenges.

Scale and Endpoint Challenges

Urban watershed management efforts are implemented against the backdrop of some important disconnects related to scale and endpoints. First, land use that results in adverse effects on urban streams is controlled at the local level, while most environmental regulations to protect water quality are enforced at the State or Federal level. Second, the scale at which urban stream impacts are most effectively measured and managed—the watershed scale—does not align with the jurisdictional boundaries within which most regulations and policies are applied. This difference in scale can make it difficult for a downstream municipality to protect their water resources when part of the watershed is outside their jurisdiction, such as when an upstream municipality has a disincentive to control development because of the loss of potential tax revenue. Therefore, municipal collaboration on watershed issues will enhance effective management of urban impacts (see the case study *Twin Cities Tax-Base Sharing Program Enhances Cross-Jurisdictional Land-Use Planning*). Although this approach has not been widely practiced or accepted, there are examples, such as the Ohio Lake Erie Balanced Growth Initiative (*http://www.glc.org/landuse/ohroundtable/ohiobgi.html,* accessed August 22, 2012). Third, the endpoints that are the focus of management strategies (for example, nitrogen loads) are not necessarily related to conditions that people care about. An endpoint can be chosen simply because it is easy to measure and (or) manipulate, or because it has always been used. The effectiveness of management activities can be difficult to assess, especially for non-scientists, if the outcomes of these activities are not measured in terms of water-quality or biological outcomes that have been identified as public concerns.

Uncertainty and Knowledge Gap Challenges

Interactions between regional, urban, and stream systems are dynamic and challenging to describe and explain. Some degree of uncertainty is unavoidable when assessing the influence of management practices on these systems. Some specific areas of uncertainty include:

- It is unknown whether particular urban stressors or management practices are more or less important at different levels of urban development. For example, is riparian forest cover more effective at mitigating the effects of urban development at low levels of development?
- The effectiveness of some individual management strategies, such as stream rehabilitation practices and reforestation, is not well understood, which limits the confidence in pollutant removal "credits" provided for implementation.
- The cumulative effectiveness of individual programmatic management strategies applied across a watershed is difficult to quantify due to the many variables at play. For example, what are the effects of stormwater management criteria for channel protection on downstream conditions?
- The extent to which the impacts of urban development can be mitigated at the river basin scale by implementing a full suite of management strategies in watersheds that make up the basin is not well understood.
- The effects of "legacy" pollutants can be difficult to distinguish from urban impacts. Legacy pollutants originate from historical land-use practices and are stored in the soil, streambed sediment, and groundwater. These could include pesticides applied in previously agricultural watersheds or now-banned chemicals such as chlordane that persist today in the urban environment.
- The feasibility of restoring specific functions of urban streams is not well understood, thus making it difficult to set realistic endpoints for restoration.
- The ability to define endpoints for assessing biological conditions that are measurable, ecologically meaningful, and applicable to the public is a challenge.
- Regional or local data, such as pollutant concentrations or data on biological communities, are often needed to select and design the most effective management strategies, but these data often are not readily available.

- Climate change adds another layer of uncertainty in terms of if and how management strategies should be adapted to accommodate future climate conditions.

Implementation Challenges

The best watershed management plan cannot protect or improve water quality if its recommendations are not implemented. Some common barriers to implementation, in addition to the uncertainties described above, include:

- Local codes and ordinances restrict the use of specific onsite practices and must be updated (Chesapeake Bay Program and Virginia Tech, 2002; Lassiter, 2008; National Academy of Sciences, 2008).
- Only a small proportion of communities around the country are adopting the most effective, science-based regulations to protect urban streams, while others lag behind and use out-of-date or ineffective policies (for example, stormwater regulations that are based on reducing the peak and allow use of dry ponds). Almost one-third of the States in the Nation do not currently have a water-quality or channel protection requirement as part of their State stormwater regulations (Gregory Hoffmann, Center for Watershed Protection, written commun., 2011). Recent updates to NPDES permits are the main drivers of communities adopting the more advanced regulations, and certain regions appear to be more "progressive" than others (Gregory Hoffmann, Center for Watershed Protection, written commun., 2011).
- Reduction of certain pollutants may require changes in behaviors (for example, reduced fertilizer application to residential lawns; fig. 41) and mindsets, which are challenging to induce and may occur only after a long period of time.
- The public might not realize the link between the actions they take on their land and the eventual impacts on a stream because the science of watershed management is often presented in unfamiliar language (see *Educating the Public on Recognizing Good Stream-Management Practices* in Chapter 6). Additionally, a variety of studies have reported that increasing public awareness and fostering supporting attitudes have little or no effect on changing behavior, due to barriers to behavioral change such as concerns over convenience, time, and skill required to make the change (Costanzo and others, 1986; McKenzie-Mohr, 2000) The result of this dynamic could be reluctance from the public to adopt new behaviors or comply with regulations.

Figure 41. Resident behaviors, such as applying lawn fertilizer, can have a cumulatively large impact on water quality. It is not yet well understood, however, what types of outreach programs are most effective in encouraging widespread behavioral change.

Case Study: Twin Cities Tax-Base Sharing Program Enhances Cross-Jurisdictional Land-Use Planning

While inter-jurisdictional collaboration could enhance effective management of urban development or other activities affecting water quality at the watershed scale, this collaboration has not been widely practiced or accepted. Obtaining inter-jurisdictional consensus for implementing a watershed-protection-oriented land-use plan that benefits one jurisdiction more than another is difficult at best, especially if one jurisdiction gains water-quality protection without having to limit development.

The Minnesota Fiscal Disparities Program is one approach for dealing with potential inequalities by granting all jurisdictions within a metropolitan area a partial share of the commercial-industrial property-tax base. Created by the Minnesota Fiscal Disparities Act of 1971, the Twin Cities tax-base sharing program was in response to inter-jurisdictional concerns about tax-base and tax-rate disparities and competition for development.

As described by Orfield and Wallace (2007), the Twin Cities program requires each taxing jurisdiction in a seven-county area to contribute 40 percent of the growth in value of its commercial-industrial tax capacity to a regional pool of funds. Municipalities are assigned a portion of the pool based on population and the ratio of total market value of property per capita in the jurisdiction to average market value of property per capita in the region. The formula assigns a greater share of the funds in the pool to municipalities with lower-than-average market value per capita than would be justified based on population alone, while high market-value localities receive a lower portion than their population share.

The Twin Cities metropolitan area has benefited from tax-base sharing by reducing incentives for individual jurisdictions to engage in fiscal zoning and tax-base competition practices that could jeopardize land conservation, which benefits the region as a whole. By reducing the need for local governments to compete with each other for revenue-generating land uses, such policies enhance the possibility for engaging in regional land-use planning.

Source for Additional Information

- Minnesota Fiscal Disparities Program, accessed August 10, 2012, at *http://www.metrocouncil.org/newsletter/planning2010/FiscalDisparitiesOct4.htm.*

Chapter 6

Conclusions

The continuing growth of urban areas throughout the Nation appears to be an inescapable fact. Degradation of the condition of stream biota can lead to the non-attainment of water-quality standards, resulting in the need for costly remediation efforts. Degraded stream biota communities may also become less resilient in the face of ongoing local increases in urban development as well as the continuation of broader-scale trends in human settlement patterns (larger and more numerous urban areas) and changes in global land use and climate. Finding a balance between people's desire to live in cities and suburbs and the health and resilience of biological communities in urban stream systems presents watershed managers and policymakers with formidable management challenges.

Use of innovative, adaptive management solutions will be the key to successfully engaging these challenges. Fortunately, a wide array of policies, technologies, incentives and educational strategies are available to watershed managers that, collectively, can prevent or mitigate the impacts of urban development on stream ecosystems, so that these important resources can be enjoyed by the many who live, work, and recreate near them.

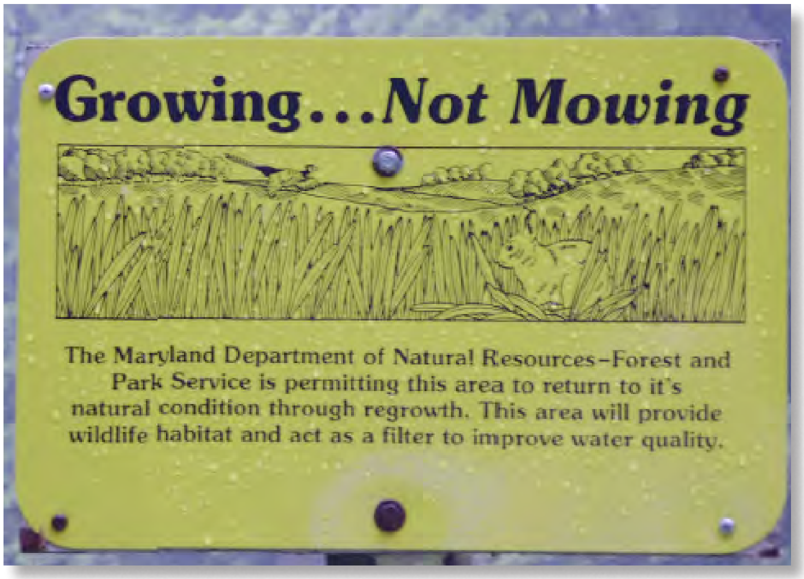


Figure 42. "Growing…Not Mowing" signs along the streams in King Farm in Rockville, Maryland, emphasize the importance of natural areas in providing wildlife habitat and water-quality protection. Photograph from Center for Watershed Protection.

Educating the Public on Recognizing Good Stream-Management Practices

Educating the general public about how the actions they take at home affect stream health is critical for environmental protection. Protecting streams may require making different choices, such as reducing fertilizer applications to residential lawns and gardens, which require re-evaluating familiar practices based on new awareness. A variety of studies, however, have determined that increasing awareness alone may not result in changing behavior (Costanzo and others, 1986; McKenzie-Mohr, 2000). Concerns over convenience and perceptions of the cost in time and resources can result in reluctance to adopt new practices, even if they are seen as beneficial.

Signage and other public educational tools that explain the purpose of best management practices are important to help the public understand the connection between things they see every day and the quality of the environment. For example, the King Farm urban-development plan in Rockville, Maryland, has an open-space framework intended to reflect the environmentally sensitive areas analysis completed by Montgomery County (U.S. Environmental Protection Agency, 2010b). Initially, the public did not understand the purpose of "no-disturbance" areas along the valleys of the Watts Branch tributaries. This was particularly true for those valleys where homes were built only on the side of the street opposite the valley. The public believed that the undeveloped side of the street should be mowed and landscaped; however, these actions would have limited the ability of the stream valleys to help remove contaminants from stormwater runoff. As a result, the city of Rockville instituted an educational signage program called "Growing…Not Mowing" and placed signs along all the stream valleys in King Farm (fig. 42). The signs explained that the natural, undeveloped space along the stream valleys helped protect the water quality and mitigate stormwater runoff to the streams. This educational effort not only led to the public's understanding and support of the diverse reasons for open space but also the value of communicating the intended purpose of management decisions.

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Chapter 7

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For additional information concerning the research in this report contact:

Chief, National Water-Quality Assessment Program
U.S. Geological Survey
413 National Center
12201 Sunrise Valley Drive
Reston, VA 20192

or visit our Web site at:
http://water.usgs.gov/nawqa/urban/

For information about the Center for Watershed Protection contact:

Center for Watershed Protection
8390 Main Street
Ellicott City, MD 21043
http://www.cwp.org/

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