Urban Subwatershed Restoration Manual Series

1

An Integrated Framework to Restore Small Urban Watersheds

Version 1.0

March 2004

CENTER FOR WATERSHED PROTECTION

Manual 1

Photo Acknowledgments

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Urban Subwatershed Restoration Manual No. 1

An Integrated Framework to Restore Small Urban Watersheds

Version 1.0

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Washington, D.C.

March 2004

Foreword

Urban watershed restoration has recently evolved into a growing and sophisticated practice. Two decades ago, the number of watershed restoration efforts could be counted on one hand; now they number in the hundreds, with many more starting each year. With each new effort, more experience is gained, and the practice of restoring urban watersheds becomes ever more sophisticated and effective. We have learned many lessons so far: that restoration is technically challenging, takes many years to complete, and requires broad partnerships to build the dozens or even hundreds of restoration practices needed for a small watershed. While urban watershed restoration is extremely challenging, it is also exceptionally rewarding to make a real difference in the quality of our home waters.

This manual series was written for a broad audience with an interest in the methods and techniques to restore small urban watersheds, including planners, engineers, agency staff, watershed groups, and environmental consultants. The manuals distill our experience acquired in many different watershed restoration settings over the past two decades into a single package. During this time, we have sought to continuously refine, test and expand both our restoration practices and our subwatershed assessment tools. We sincerely hope that these manuals will help guide your efforts to successfully restore urban watersheds in your community.

Many thanks are extended to three external reviewers who carefully looked over drafts of this manuscript. They include Derek Booth, University of Washington Center for Water and Watershed Research; Bill Stack, City of Baltimore Department of Public Works; and Thomas Davenport, national nonpoint source expert for the U.S. Environmental Protection Agency. Much of this material was first presented at our inaugural Watershed Restoration Institute in September 2003, and the common sense feedback from institute participants is also keenly appreciated.

Many Center staff contributed to the development of this manual, including Ted Brown, Anne Kitchell, Chris Swann, Karen Cappiella, Hye Yeong Kwon, Jennifer Zielinski, and Stephanie Sprinkle. The hard work, diligent research and practical insights of this outstanding team is reflected throughout the manual. In addition, Tiffany Wright and Heather Holland cannot be thanked enough for their able assistance in editing, proofing and producing this manual. Finally, we would like to acknowledge the patience, insights and flexibility of our EPA project officer, Robert Goo, during the two years it took to produce this manual series under a cooperative agreement with US EPA Office of Water CP-82981501.

Sincerely,

Tom Schueler
Director of Watershed Research and Practice
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About the Restoration Manual Series

This is the first of a series of 11 manuals on techniques to restore small urban watersheds. The entire series of manuals was written by the Center for Watershed Protection to organize the enormous amount of information needed to restore small urban watersheds into a format that can easily be accessed by watershed groups, municipal staff, environmental consultants and other users. The contents of the manuals are organized as follows.

Manual 1: An Integrated Framework to Restore Small Urban Watersheds

The first manual introduces the basic concepts and techniques of urban watershed restoration, and sets forth the overall framework we use to evaluate subwatershed restoration potential. The manual emphasizes how past subwatershed alterations must be understood in order to set realistic expectations for future restoration. Toward this end, the manual presents a simple subwatershed classification system to define expected stream impacts and restoration potential. Next, the manual defines seven broad groups of restoration practices, and describes where to look in the subwatershed to implement them. The manual concludes by presenting a condensed summary of a planning approach to craft effective subwatershed restoration plans.

Manual 2: Methods to Develop Restoration Plans for Small Urban Watersheds

The second manual contains detailed guidance on how to put together an effective plan to restore urban subwatersheds. The manual outlines a practical, step-by-step approach to develop, adopt and implement a subwatershed plan in your community. Within each step, the manual presents a variety of desktop analysis, field assessment, and stakeholder involvement methods used to make critical restoration management decisions.

The next seven manuals provide specific guidance on how to identify, design, and construct the seven major groups of watershed restoration practices. Each of these "practice" manuals describes the range of techniques used to implement each practice, and provides detailed guidance on subwatershed assessment methods to find, evaluate and rank candidate sites. In addition, each manual provides extensive references and links to other useful resources and websites to design better restoration practices. The seven manuals are organized as follows.

Manual 3: Storm Water Retrofit Practices

The third manual focuses on storm water retrofit practices that can capture and treat storm water runoff before it is delivered to the stream. The manual describes both off-site storage and on-site retrofit techniques that can be used to remove storm water pollutants, minimize channel erosion, and help restore stream hydrology. The manual then presents guidance on how to assess retrofit potential at the subwatershed level, including methods to conduct a retrofit inventory, assess candidate sites, screen for priority projects, and evaluate their expected cumulative benefit. The manual concludes by offering tips on retrofit design, permitting, construction, and maintenance considerations in a series of 17 retrofit profile sheets.

Manual 4: Stream Repair and Restoration Practices

The fourth manual concentrates on practices used to enhance the appearance, stability, structure, or function of urban streams. The manual offers guidance on three broad approaches to urban stream restoration: stream cleanups, stream repairs, and more sophisticated comprehensive restoration designs. The manual emphasizes the powerful and relentless forces at work in urban streams, which must always be carefully evaluated in restoration and design. Next, the manual presents guidance on how to set appropriate restoration goals for your stream, and how to choose the best combination of stream restoration techniques to meet them.

The manual also outlines methods to assess stream restoration potential at the subwatershed level, including basic stream reach analysis, more detailed project investigations, and priority restoration project screenings. The manual concludes by offering practical advice to help design, permit, construct and maintain stream restoration practices in a series of more than 30 profile sheets.

Manual 5: Riparian Management Practices

The fifth manual examines practices to restore the quality of forests and wetlands within the remaining stream corridor and/or flood plain. It begins by describing four site preparation techniques that may be needed to make a site more suitable for planting, and then profiles four planting techniques for the riparian zone, based on its intended management use. The manual presents several methods to assess riparian restoration potential at the subwatershed level, including basic stream corridor analysis, detailed site investigations, and screening factors to choose priority reforestation projects. The manual concludes by reviewing effective site preparation and planting techniques in a series of eight riparian reforestation profile sheets.

Manual 6: Discharge Prevention Practices

The sixth manual covers practices used to prevent the entry of sewage and other pollutant discharges into the stream from pipes and spills. The manual describes a variety of techniques to find, fix and prevent these discharges that can be caused by illicit sewage connections, illicit business connections, failing sewage lines, or industrial/transport spills. The manual also briefly presents desktop and field methods to assess the severity of illicit discharge problems in your subwatershed. Lastly, the manual profiles 12 different “forensic” methods to detect and fix illicit discharges.

Manual 7: Pervious Area Management Practices

The seventh manual reviews subwatershed practices that can improve the quality of upland pervious areas, which include techniques to reclaim land, revegetate upland areas, and restore natural area remnants. When broadly applied, these techniques can improve the capacity of these lands to absorb rainfall and sustain healthy plant growth and cover. This brief manual also outlines methods to assess the potential for these techniques at both the site and subwatershed scale.

Manual 8: Pollution Source Control Practices

Pollution source control practices reduce or prevent pollution from residential neighborhoods or storm water hotspots. Thus, the eighth manual focuses on a wide range of stewardship and pollution prevention practices that can be employed in subwatersheds. The manual presents several methods to assess subwatershed pollution sources in order to develop and target education and/or enforcement efforts that can prevent or reduce polluting behaviors and operations. The manual outlines more than 100 different “carrot” and “stick” options that can be used for this purpose. Lastly, the manual presents profile sheets that describe 22 specific stewardship practices for residential neighborhoods, and 15 pollution prevention techniques for control of storm water hotspots.

Manual 9: Municipal Practices and Programs

The ninth manual focuses on municipal programs and practices that can directly support subwatershed restoration efforts. The five broad areas include improved street and storm drain maintenance practices, development/redevelopment standards, stewardship of public land, delivery of municipal stewardship services, and watershed education and enforcement. This last "practice" manual presents guidance on how municipalities can use these five programs and practices to promote subwatershed restoration goals. The manual also contains a series of profile sheets that recommends specific techniques to implement effective municipal practices and programs.

The series concludes with two user's manuals that explain how to perform field assessments to discover subwatershed restoration potential in the stream corridor and upland areas.

Manual 10: The Unified Stream Assessment: A User's Manual

The Unified Stream Assessment (USA) is a rapid technique to locate and evaluate problems and restoration opportunities within the urban stream corridor. The tenth manual is a user's guide that describes how to perform USA, and interpret the data collected to determine the stream corridor restoration potential for your subwatershed.

Manual 11: The Unified Subwatershed and Site Reconnaissance: A User's Manual

The last manual examines pollution sources and restoration potential within upland areas of urban subwatersheds. The manual provides detailed guidance on how to perform each of its four components — the Neighborhood Source Assessment (NSA), Hotspot Source Investigation (HSI), Pervious Area Assessment (PAA) and the analysis of Streets and Storm Drains (SSD). Together, these rapid surveys help identify upland restoration projects and source control to consider when devising subwatershed restoration plans.

Individual manuals in the series are scheduled for delivery throughout 2004, and each will be available for free downloading for a period of six months. After this window expires, they can be ordered online or as hard copies from the Center for a nominal charge. Be sure to check our website, www.cwp.org, to find out when each manual will be available and how it can be accessed.

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Introduction

This Manual presents the basic concepts used to restore urban streams, and outlines an integrated and practical framework for assessing restoration potential in small urban watersheds. The Manual is organized into six chapters:

Chapter 1: Organizing to Restore Urban Watersheds

This chapter introduces the basic concepts of organizing people to restore a local watershed. It begins by defining the language used to talk about watersheds and their restoration. Next, it explores national trends that are driving the rapid growth of urban watershed restoration efforts, as well as the diverse local issues that prompt restoration. Together, these national trends and local issues shape the unique restoration goals that guide local restoration efforts. These goals often prescribe a desired level of improvement in watershed health, as measured by a combination of physical, hydrologic, chemical, ecological or social indicators. Chapter 1 makes a strong case for defining these indicators in specific, measurable ways so that restoration progress can be tracked and monitored.

Chapter 1 also describes the four basic groups of stakeholders that must be engaged in local watershed restoration efforts: the public, agencies, watershed partners, and potential funders. As all of these stakeholders must interact to develop and implement an effective local restoration plan, the chapter concludes by describing how to build stakeholder involvement into the restoration planning process.

Chapter 2: Alteration of Urban Subwatersheds

Effective restoration requires a keen understanding of how a subwatershed has been altered in the past. This chapter reviews eight major subwatershed alterations that influence urban streams and their prospects for restoration. Alterations include the conversion of land to impervious cover; construction of sewer, water and storm drain infrastructure; management of pervious areas; fragmentation of natural area remnants; interruption of the stream corridor; expansion and encroachment of the floodplain; increased population density; and the creation of pollution hotspots.

Chapter 3: Impacts of Urbanization on Streams

Given a knowledge of the intensity of subwatershed development, recent urban stream research can help set realistic expectations for urban restoration. This chapter presents stream research within the context of the Impervious Cover Model (ICM). From a restoration standpoint, the ICM groups urban streams into three categories based on how much impervious cover exists in the subwatershed: *impacted streams*, *non-supporting streams* and *urban drainage*. The ICM is then used to develop specific quantitative or narrative predictions for stream indicators for each of the three stream categories. These predictions define the severity of current stream impacts and the prospects for their future restoration. Predictions are made for five major types of urban stream impacts: changes in stream hydrology, alteration of the stream corridor, stream habitat degradation, declining water quality and loss of aquatic diversity. Water quality impacts are further subdivided into predictions concerning eutrophication, exceedance of bacterial standards, aquatic life toxicity, sediment contamination, and trash and debris loading.

Chapter 4: Range of Available Subwatershed Restoration Practices

This chapter introduces the seven major groups of restoration practices used to restore urban subwatersheds. Four groups of practices are generally applied within the remaining stream corridor: storm water retrofits, stream restoration, riparian management, and discharge prevention practices. Three groups of practices can be applied in the upland areas of a subwatershed, including pervious area management, pollution source control, and improved municipal practice (although some on-site storm water retrofits can also be installed in upland areas). The chapter describes the many different restoration techniques and discusses how they contribute to subwatershed restoration goals. The chapter concludes with guidance on choosing the right combination of practices to meet specific restoration goals, in the context of the actual restoration potential of the subwatershed.

Chapter 5: Envisioning Restoration

Urban restoration is both an art and a science, and it takes some skill to imagine the possibilities for effective watershed restoration. This short chapter provides insight on how to envision the prospects for effective restoration at the subwatershed level, and outlines some key subwatershed characteristics that create these opportunities. This chapter describes 11 subwatershed features that offer opportunities for subwatershed restoration practices. The actual desktop and field assessment methods used to find these restoration opportunities are described in greater detail in Manuals 2, 10, and 11.

Chapter 6: A Framework to Guide Subwatershed Restoration

The last chapter introduces an eight-step process to develop and implement subwatershed restoration plans. Each step may include tasks involving desktop analysis, rapid field assessment, stakeholder involvement and management products. The eight-step framework can be used as a guide to develop, adopt, implement and track subwatershed restoration plans. Manual 2 provides more detail on the specific tasks and methods that can be used in subwatershed restoration planning framework.

The next seven manuals provide more detailed guidance on each of the seven types of watershed restoration practices:

Manual 3: Storm Water Retrofit Practices
Manual 4: Stream Repair Practices
Manual 5: Riparian Management Practices
Manual 6: Discharge Prevention Practices
Manual 7: Pervious Area Management Practices
Manual 8: Pollution Source Control Practices
Manual 9: Municipal Practices and Programs

Each of these manuals describes techniques to design and implement each restoration practice, and provides detailed guidance on site and subwatershed assessment methods. In addition, the manuals provide extensive references to other helpful resources for the design and construction of effective restoration practices.

The final two manuals outline field methods to assess subwatershed restoration potential:

Manual 10: The Unified Stream Assessment (USA)
Manual 11: The Unified Subwatershed and Site Reconnaissance (USSR)

Chapter 1: Organizing to Restore Urban Watersheds

Each watershed restoration partnership is unique, both in terms of the goals that guide it and the stakeholders that participate in it. The five parts of this chapter explore how to organize the partnerships needed to effectively restore urban watersheds.

The first part of Chapter 1 defines the basic terminology used to talk about watersheds and restoration. The second part examines the key trends driving the rapid growth in urban watershed restoration in communities across the country. The third part explores possible goals that can guide watershed restoration efforts and outlines how communities can develop the most appropriate and achievable goals. The fourth part describes the broad groups of stakeholders that must be involved in restoration plan development, while the fifth part outlines practical strategies for organizing stakeholders toward a common purpose.

1.1 Getting the Terminology Right

The words “urban,” “watershed” and “restoration” can mean many things to many people, and when they are combined, it can be a recipe for confusion. So, from the outset, we want to carefully define how each of these terms is used throughout this manual.

Urban is defined as any watershed or subwatershed with more than 10% total impervious cover.

Watersheds are land areas that drain surface and groundwater to a downstream water body, such as a river, lake or estuary. Watershed drainage areas are large, ranging from 20 to 100 square miles or more. Given their size, they may encompass many political jurisdictions, contain a mix of land uses (forest, agricultural, rural, suburban, urban), and have a broad range of pollution sources. Each watershed is composed of a number of smaller watersheds called “subwatersheds.”

Subwatersheds, as a general rule of thumb, have a drainage area of five to 10 square miles or less, and are the primary restoration unit in the context of this manual. The small size of subwatersheds makes them ideal restoration candidates for several reasons. First, subwatersheds can be rapidly mapped and assessed for restoration potential in a matter of months, with an initial restoration strategy following soon after. The small scale of a subwatershed also allows restoration practices to be designed, constructed and assessed within a few years. Also, most subwatersheds are contained within a single political jurisdiction, making it easier to coordinate local stakeholders. In our view, watershed restoration can only be effectively implemented at the subwatershed scale, although many subwatersheds may require restoration to achieve watershed goals.

Each urban subwatershed is drained by a network of perennial streams, each of which can be classified based on its relative order in the network. For example, a small stream with no tributaries or branches is defined as a *first order stream*. When two first order streams combine, they form a second order stream. Similarly, when two second order streams join, they create a third order stream, and so on. Given their relatively small drainage area, most urban subwatersheds only contain streams that range from first to third order. The health of these smaller headwater streams is the major focus of urban restoration efforts.

The stream corridor and upland areas are the two parts of a subwatershed. S*tream corridors* include the existing network of stream channels and the lands that surround them. *Upland areas* include the remaining subwatershed area that drains to the stream corridor. The relationship between the stream corridor and upland areas is depicted in Figure 1. As subwatersheds urbanize, both the length and width of the stream corridor decline, and upland areas begin to dominate the landscape.

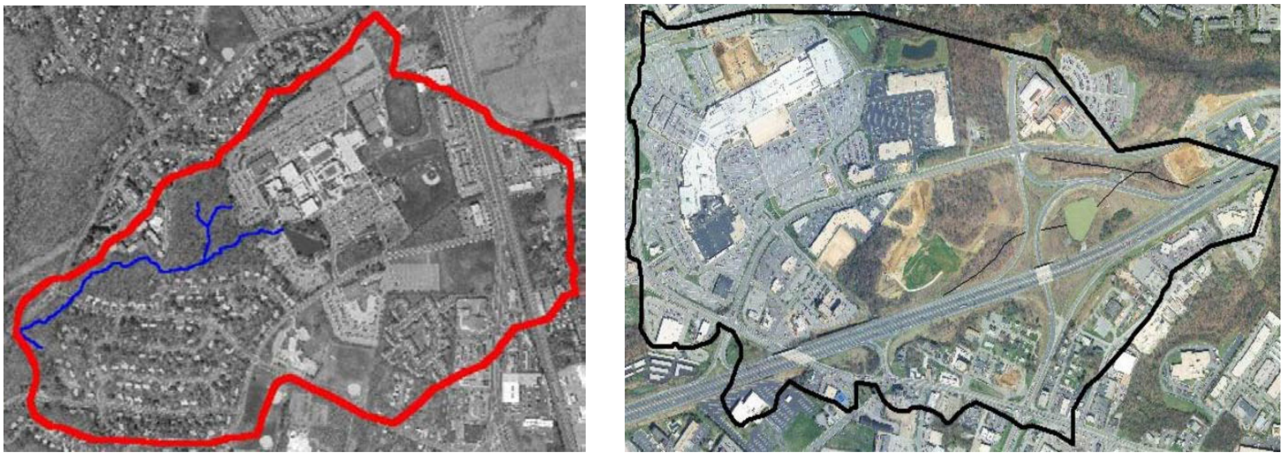


Figure 1: The Stream Corridor and Upland Areas in Urban Subwatersheds
The photo on the left illustrates a lightly developed subwatershed that has a relatively intact stream corridor and stream network, which can be compared to a highly urban subwatershed where both features have been virtually eliminated.

Restoration is used throughout this manual in its broadest sense, and is defined as the application of any combination of restoration practices that can improve stream health, as measured by improvements in physical, hydrological, chemical, ecological or social indicators of stream quality. Alternative terms such as "recovery," "repair," "rehabilitation," or "enhancement" were considered, but found inadequate. However, the use of the term "restoration" does not imply that full ecological restoration of an urban streams is always possible.

Restoration practice is used to describe the seven broad groups of practices used to restore urban subwatersheds. Four groups of restoration practices — storm water retrofits, stream restoration, riparian management and discharge prevention — are generally applied within the urban stream corridor. The remaining three groups of practices — pollution source control, pervious area management and municipal stewardship — are normally applied to upland areas of a subwatershed.

Stakeholders are defined as any agency, organization or individual involved in or affected by the decisions made in a subwatershed restoration plan. From a practical standpoint, it helps to think of four broad groups of stakeholders in each restoration effort: agencies, the public, watershed partners and potential funders. Each of these four stakeholder groups is further defined later in this chapter.

1.2 Trends Driving Growth in Urban Watershed Restoration

The remarkable growth in urban watershed restoration efforts has been fueled by several intersecting trends affecting thousands of communities across the nation: the need to control nonpoint source pollution, new regulatory mandates, increased municipal restoration capability, growth in urban watershed organizations, and greater public expectations for cleaner and greener neighborhoods.

Need to Control Nonpoint Pollution Sources

Most communities have clamped down on point sources of pollution to the furthest extent possible (e.g., sewage treatment plants and industrial discharges). Despite a multi-billion dollar investment over the last three decades, however, many urban streams and rivers still do not meet water quality standards and continue to experience severe habitat degradation. Consequently, communities are now shifting their control efforts to reduce nonpoint sources of pollution in order to meet clean water goals. In urban watersheds, nonpoint source control usually means better treatment of urban storm water runoff, which is best accomplished at the watershed or subwatershed scale.

Emerging Regulatory Drivers

A series of state and federal regulations are also prompting many communities to restore their urban watersheds. For example, when urban waters do not meet water quality standards prescribed under the Clean Water Act, agencies must develop pollutant reduction plans that show how these standards can be attained in the future. These plans, known as Total Maximum Daily Loads (or TMDLs), may require communities to implement restoration practices to reduce nonpoint source pollutant loads by specific amounts over a defined timetable.

In addition, many communities are now regulated under EPA's storm water NPDES permit program, which covers pollutants discharged from municipal storm drain systems. The municipal permit program applies to communities with populations of more than 50,000. Under these permits, communities must demonstrate that they have local programs to manage storm water, detect and eliminate illicit discharges, prevent pollution, and educate and involve the public. Larger communities are also responsible for monitoring the quality of their storm water runoff. A few states have even gone so far as to stipulate that a fixed percentage of each community must be restored during each permit cycle. As a result, many of the local programs required under municipal NPDES storm water permits support stronger local restoration programs (CWP, 2003).

Communities may also engage in watershed restoration to comprehensively address numerous other federal environmental mandates, control programs, and policies. Examples include the EPA minimum measures to control combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs), as well as source control measures that may be required under the Safe Drinking Water Act. Other federal agencies also encourage a watershed approach. A notable example is the National Flood Insurance Program (FEMA), which encourages watershed-based solutions to local flooding problems. In addition, watershed efforts to recover salmon populations in the Pacific Northwest have been prompted by the Endangered Species Act. Similar efforts have been triggered in the Texas hill country to protect the endangered Barton Springs salamander. Many federal agencies actively promote watershed restoration through new grant programs that support research and demonstration of wetland restoration, stream restoration, nonpoint source control and urban forestry practices.

Communities often find it a challenge to integrate the many state and federal regulatory drivers into a coherent whole, since they operate over many different watershed units and address multiple environmental endpoints. Urban watershed restoration planning offers a useful framework for this integration.

Increased Local Restoration Capability

In recent years, communities have greatly expanded the type and scope of their watershed restoration activities. For example, the Center recently surveyed more than 50 communities of all sizes to measure their current activity in urban watershed restoration. The average community had engaged in at least 10 of the 17 core restoration programs recommended as part of a local Smart Watersheds Program (CWP, 2004). Table 1 presents some of the interesting highlights from the survey. As can be seen, at least half of the communities reported some level of activity in many areas of urban watershed restoration. This finding suggests that more staff, programs, funding and mapping are available to support urban watershed restoration than ever before, and communities are rapidly acquiring more

Table 1: Selected Results of National Survey of Municipal Watershed Restoration Activity

Restoration Activity or Practice	Communities Reporting Activity (%)
Small Watershed Planning	55
Subwatershed GIS Mapping	80
Rapid Stream Assessment	49
Storm Water Retrofitting	53
Stream Restoration	51
Discharge Prevention	63
Urban Forestry	49
Watershed Education	65
Hotspot Pollution Prevention	35
Public Involvement	71

Note: 50 + communities surveyed, with populations ranging from 25,000 to 2,000,000. Restoration activity tended to be slightly higher in communities with larger populations and in those covered by Phase I storm water NPDES permits. For complete survey results, consult CWP (2004)

practical skills and experience to implement restoration practices. At the same time, the survey revealed that most local restoration efforts were still in an experimental or demonstration stage, and few communities had systematically integrated their restoration efforts at the subwatershed scale.

Growth in Urban Watershed Organizations

The recent growth of nonprofit watershed groups has also been impressive. More than 4,000 watershed groups are now established across the country, along with an equal number of land trusts, smart growth and "friends of" organizations. A majority of these groups are located in suburban or urban watersheds (CWP, 2002). The number, sophistication, and expectations of urban watershed groups have all increased sharply in recent years. These groups can exert considerable pressure to get communities to do a better job in restoring their urban watersheds. While urban watershed groups may often be impatient for results, they are becoming more effective advocates for local restoration.

Public Demand for Better Local Environment

Urban and suburban residents are concerned about the overall quality of life in their neighborhoods, and these concerns often extend beyond healthier streams. Residents are concerned about issues such as greenways, flooding, waterfront improvements, aesthetics, trash, and neighborhood revitalization. In addition, the public has a stronger awareness about local stream quality, and actively participates in both personal and watershed stewardship activities. The net effect is that the public is demanding better stream protection, and expects their community concerns to be fully integrated within the watershed restoration planning process.

1.3 Many Different Goals Guide Urban Watershed Restoration

No two urban watershed restoration efforts are ever alike. Each restoration effort has its own unique goals, which are shaped by the watershed scale, various restoration "drivers" and stakeholder input. This section reviews the impressive diversity of goals driving local watershed restoration efforts across the country. A sample of watershed restoration goals is depicted in Figure 2; most communities choose multiple goals to guide their watershed plan. In general, most restoration goals can be lumped into one of four broad categories: water quality, physical/ hydrological condition, biological diversity and community concerns.

Watershed restoration goals may be oriented toward the stream, the stream corridor, or upland areas, or some combination of all three. In addition, local restoration goals frequently differ in ambition. For example, some communities set goals with *prevention* in mind, e.g., simply to keep something bad from happening, like a pollution spill, flood damage, or sewage overflows. Other communities seek to systematically *repair* a problem (or set of problems) in the stream or its corridor, such as an eroding bank, a fish barrier or an inadequate forest buffer. The most ambitious communities set goals to *improve* conditions within the stream or its corridor. These communities seek a defined and measurable improvement for a desired indicator in stream health by comprehensively applying many restoration practices across a subwatershed.

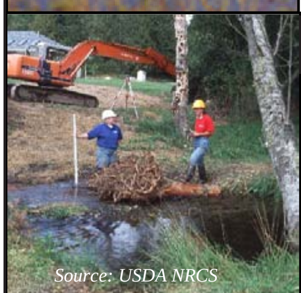
The choice of whether to set goals to prevent, repair or improve problems depends on the actual restoration opportunities within a subwatershed. These opportunities depend on at least three subwatershed factors: percent impervious cover, the length of intact stream corridor, and the fraction of the subwatershed that can be effectively treated by restoration practices. Consequently, communities often need to reconcile broad watershed restoration goals with the limited restoration potential of the many subwatersheds that comprise it. The balance between proposing ambitious goals at the watershed level and the ability to realistically achieve them in individual subwatersheds is a major theme of this manual.

Water Quality

- Reduce pollutants of concern (e.g. TSS, N, P, Zn, Cu, hydrocarbons, pesticides)
- Prevent illegal discharges/spills
- Meet water quality standards
- Reduce sediment contamination
- Allow water contact recreation
- Protect drinking water supply

Biological

- Restore aquatic diversity
- Restore wetlands/natural areas
- Expand forest cover
- Restore/reintroduce species (e.g. salmon)
- Improve fish passage
- Enhance wildlife habitat
- Remove invasive species
- Keep shellfish beds open
- Enhance riparian areas



Physical/Hydrological

- Increase groundwater recharge
- Reduce channel erosion
- Reclaim stream network
- Reduce flood damage
- Reconnect floodplain
- Restore physical habitat
- Protect municipal infrastructure

Community

- Eliminate trash/debris
- Create greenways/waterfront access/open space
- Revitalize neighborhoods
- Improve aesthetics/beautification
- Increase citizen awareness
- Improve recreation opportunities
- Increase fishing opportunities

Figure 2: General Classification of Watershed Restoration Goals
Many different goals can be selected to guide watershed restoration; most communities choose several different goals relating to water quality, biological, physical, and community indicators.

1.4 The Role of Stakeholders in Watershed Restoration

While restoration is driven by the goals of those that care for the watershed, aligning the efforts and resources of stakeholders towards common goals is critical to the adoption and implementation of any restoration plan. Ideally, the goals and vision for the watershed should be developed early in the restoration process, based on input from a broad group of stakeholders. Consequently, you need to know the key stakeholders in the watershed, and include them in virtually every step of the restoration process.

The term *stakeholder* is loosely defined as any agency, organization, or individual that is involved in or affected by the decisions made in a watershed plan. In theory, this definition includes just about everybody; in reality, it merely refers to those folks that actually show up to speak their mind.

Not all stakeholders are equal, however. In a literal sense, each has a different stake in the outcome of the plan, and is expected to perform a different role in the watershed restoration effort. Each comes to the table with varying degrees of watershed awareness, concern and/or expertise. Stakeholders also have different preferences as to how, when, and in what manner they want to be involved in the process. As a result, the outreach methods used to educate and inform stakeholders must be carefully calibrated to match their different levels of knowledge and understanding. For example, some stakeholders are daytime professionals expected to be at the table because of their job duties, whereas others are "night-timers" donating their time and expertise. Effective watershed managers recognize the wide diversity in stakeholders, and structure their planning process to provide multiple options and opportunities for involvement.

Stakeholders usually fall into one of four distinct groups that interact to produce restoration plans, as shown in Figure 3. The four groups include the public, agencies, watershed partners and potential funders.

Conceptually, stakeholder involvement can be viewed as a pyramid, with expanding levels of involvement. The base of the pyramid contains the greatest number of stakeholders, many of whom are initially unaware of watershed problems and their potential role in restoration. The awareness and involvement of stakeholders becomes progressively greater toward the top of the pyramid. Stakeholders found at the apex of the pyramid represent key decision-makers, and are generally considered the champions for restoration. The next section describes each of the four stakeholder groups in more detail.

Agency Stakeholders

Local government has primary responsibility for urban watershed restoration. In reality, these responsibilities are usually spread over a wide assortment of bureaus, departments, agencies and divisions that rarely coordinate much with each other. As a result, it is useful to think of all these individuals and units as occupying different levels of the stakeholder pyramid (Figure 4). The apex of the pyramid consists of the elected officials and the lead local restoration agency that are the champions of restoration, and who act to coordinate the actions of all other units of local government. Elected officials are critical stakeholders since they must vote to approve budgets for restoration plans.

The next tier consists of agencies that deal directly with local environmental issues or services, followed by agencies that own or control land where restoration practices may be constructed (e.g., schools, parks, etc.). The next rung is occupied by local agencies that may not initially perceive restoration as a core part of their mission. A good example is a local planning and zoning authority that can contribute to subwatershed restoration by adopting better development standards for infill and redevelopment.

The bottom of the pyramid consists of *state and federal* agencies that regulate water quality or protect natural resources. These agencies are critical, since they may need to approve permits for restoration practices or even

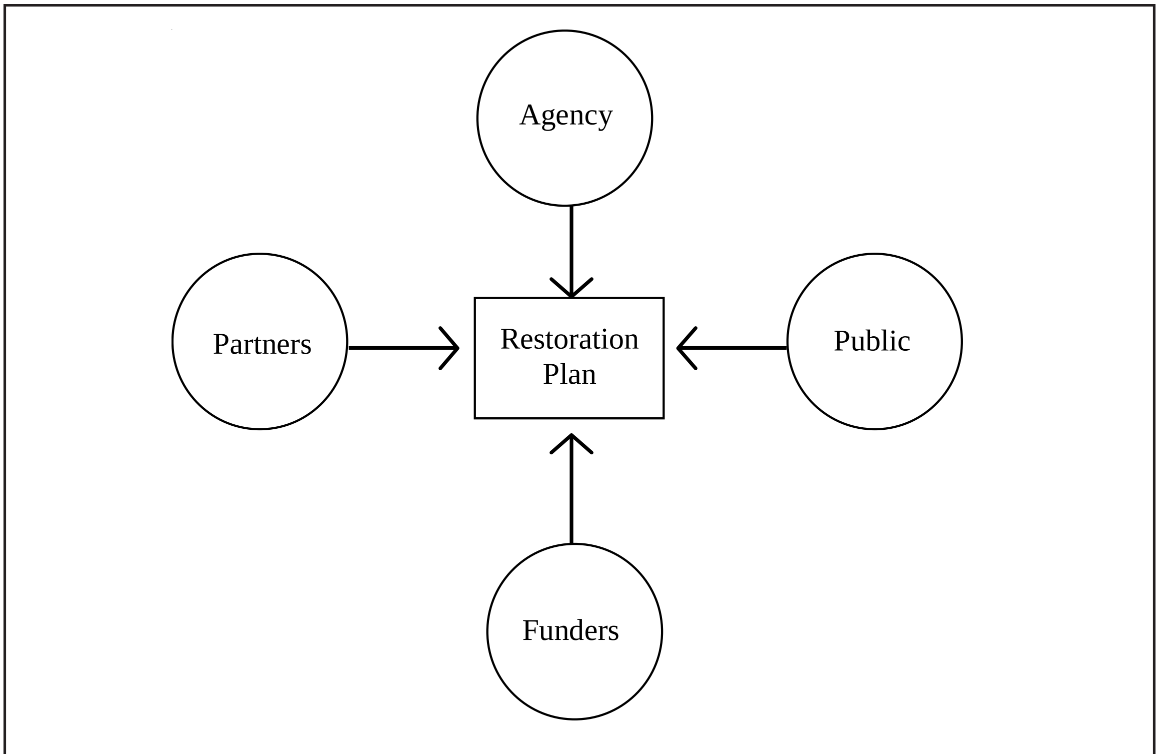


Figure 3: Four Types of Stakeholders Involved in Watershed Restoration Plans

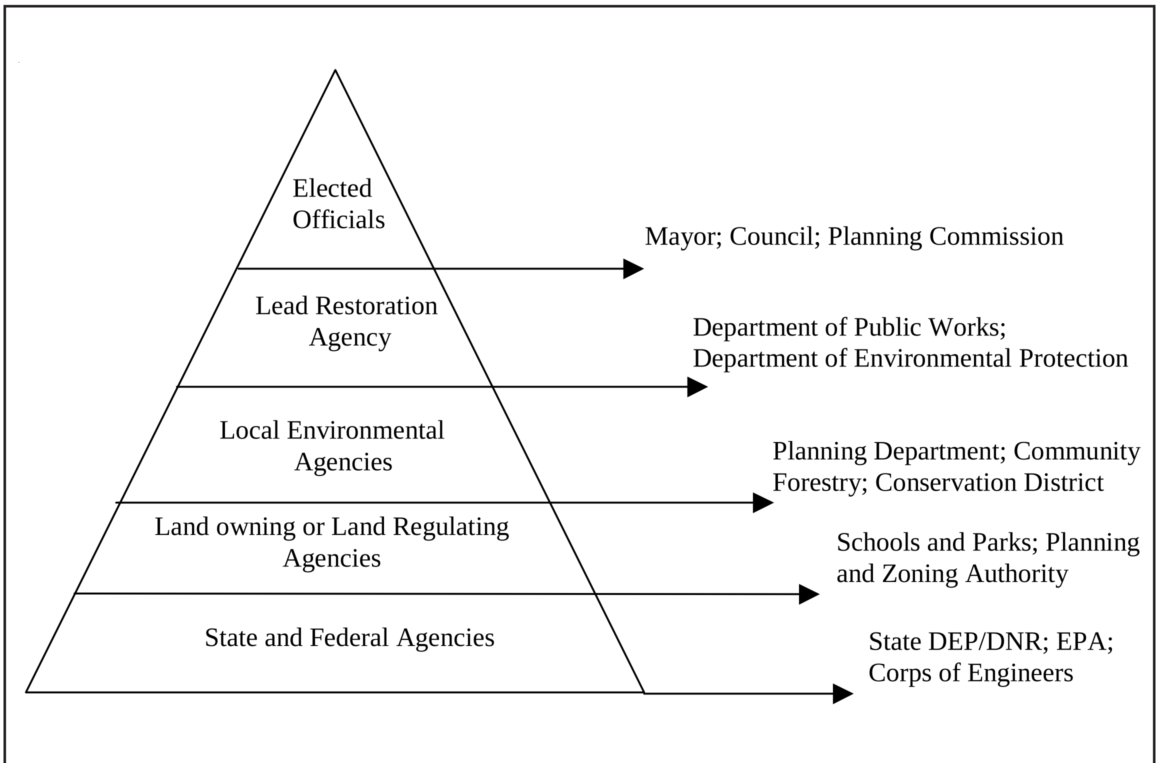


Figure 4: The Agency Stakeholder Pyramid

Dozens of local, state and even federal agency stakeholders need to be involved to coordinate effective local restoration planning.

approve the restoration plan itself (e.g., in the case of a TMDL). Some agencies can also lend staff expertise and provide monitoring and mapping data to support the restoration effort.

The Public

The public is a major stakeholder in every watershed restoration effort, although as individuals they may be unaware of this role. Indeed, watershed awareness and activism varies considerably among the public, and can be best understood in terms of a pyramid (Figure 5). The *general public* make up the bottom of the pyramid, and initially possess a low level of watershed awareness or involvement. Indeed, much of what they know about watersheds comes from the local paper or evening news. Increasing the awareness of the general public is important, given that the collective impact of their individual actions can improve or degrade watershed health.

The next level of the pyramid is occupied by the *receptive public*. As voters, they may support stronger local environmental initiatives, and might be willing to change daily behaviors to protect the watershed, such as installing rain barrels, planting trees or picking up after their pets. Education, outreach and direct municipal services may often be needed to improve personal stewardship among the receptive public.

The next subset is the *adjacent public*, which includes people that live near the stream corridor and will be positively or negatively affected by any restoration practices constructed within it. Since they have such a direct stake in the outcome of restoration, this group must be continuously informed as to how restoration practices will influence their neighborhood and property values.

The *activist public* occupies the next rung on the pyramid. This group consists of community leaders in neighborhood associations, civic groups, garden clubs, recreational enthusiasts, and the like. While watershed restoration may not be their main mission, the activist public often recognizes its potential benefits for the community. Enlisting the activist public in the restoration cause can be very important, given the strong influence they exert both in the community and on the local political process.

The apex of the pyramid is occupied by *watershed groups* that are organized to advocate for urban watersheds and help implement local restoration plans. Few subwatersheds possess such a group at the beginning of the restoration process, but they should always have one at the end.

Watershed Partners

The watershed partners stakeholder group consists of non-local government partners that are expected to perform many important roles in watershed restoration. Figure 6 depicts the diversity of watershed partners involved in local restoration.

Responsible parties include utilities whose activities or discharges are regulated by permit or ordinance. The goal is to align their pollution control efforts with the goals for watershed restoration.

Local media are also valuable watershed partners, since they have the best means to broadcast information about watershed restoration to the general public through local television, community newspaper and radio. Restoration requires a lot of expertise, and *local advisors* are the stakeholders that can bring it to the table. Examples of local advisors include engineers, environmental consultants, local scientists and educators. In addition, many non-profit organizations and regional planning agencies can contribute data and expertise to the watershed restoration effort.

Local businesses and landowners can be voluntary watershed partners, although they often start with a low level of awareness or may be suspicious of potential regulation. However, it is very important to enlist their cooperation to improve stewardship on the lands they own and the operations they control.

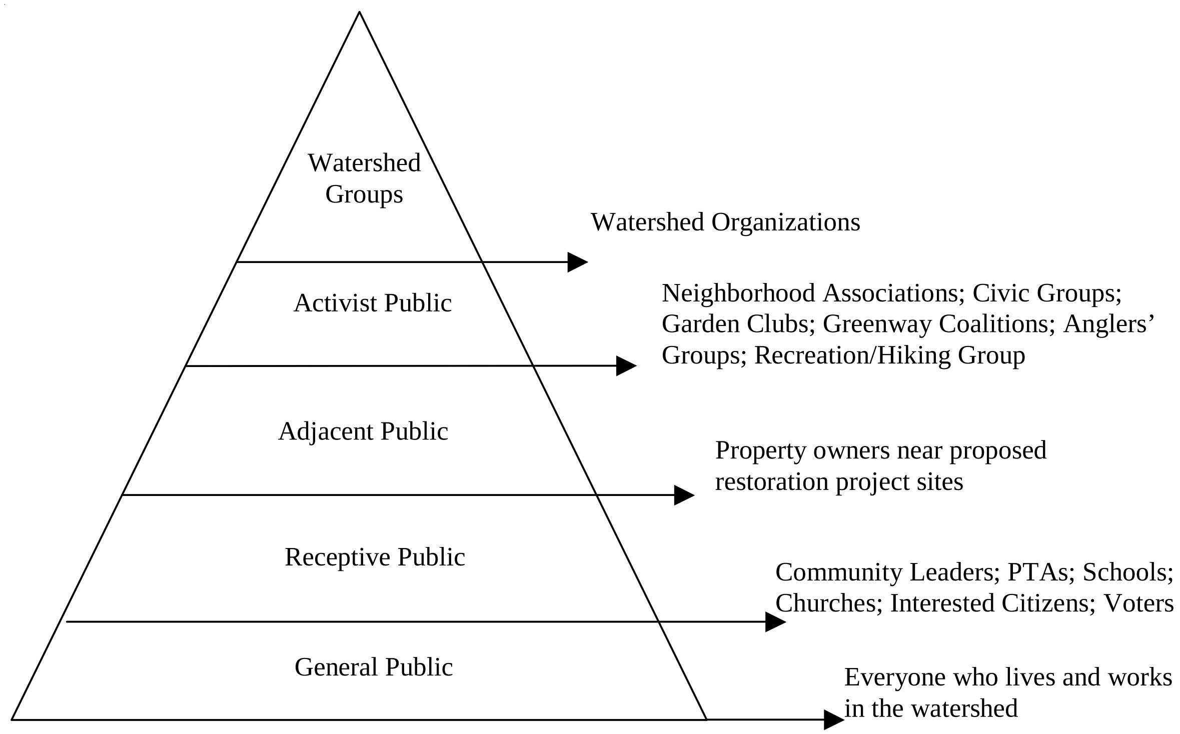


Figure 5: The Public Stakeholder Pyramid
Public stakeholders are not monolithic, but can be stratified on the basis of their awareness, stewardship activities, and interest in participating in the local watershed restoration process.

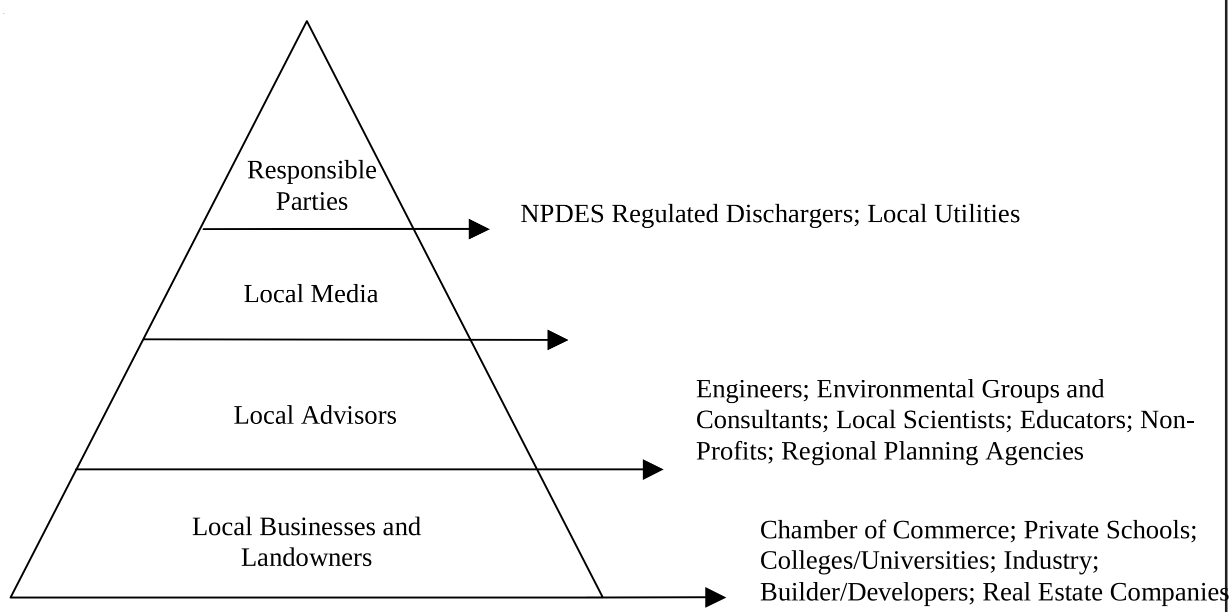


Figure 6: The Partner Stakeholder Pyramid
Many different partners comprise this diverse stakeholder group asked to perform many roles in watershed restoration, including implementing pollution controls, spreading the restoration message, providing expertise, and integrating restoration goals into their normal operations.

Funders

Funding partners are the stakeholders expected to finance watershed restoration at some point in the future. The diversity of funding stakeholders can also be viewed in terms of a pyramid (Figure 7). The top of the pyramid is occupied by *local government* who has the primary responsibility to finance restoration, especially during the early planning stages. The most common local revenue streams are operating budgets, capital budgets and storm water utilities. Most communities are already spending more money than they think on restoration activities, although these costs are frequently spread across many different agency budgets. Clearly, the agency heads, budget experts, and elected officials that control local purse strings are important individual stakeholders, and they need to be continuously educated on how restoration benefits the community and why the restoration investment is justified.

The next two levels on the funding pyramid are occupied by *state and federal funding sources*, which can provide grants, loans or direct technical services to supplement local restoration investments. State and federal funding stakeholders usually get many more funding requests than they can meet, so it is important to emphasize why the local watershed should be a top priority for funding and to demonstrate the width and breadth of the local restoration partnership. The last rung of the pyramid is occupied by *private funding sources*. This diverse group of funders includes foundations, corporations, and individuals that can provide supplemental funding for selected restoration tasks. Private funding sources like to give to people, and see on-the-ground results at the community scale. Consequently, they tend to support grassroots watershed organizations rather than local governments. All funding stakeholders should be viewed as investors, and should be continuously updated about the costs of restoration and the benefits it provides to the community.

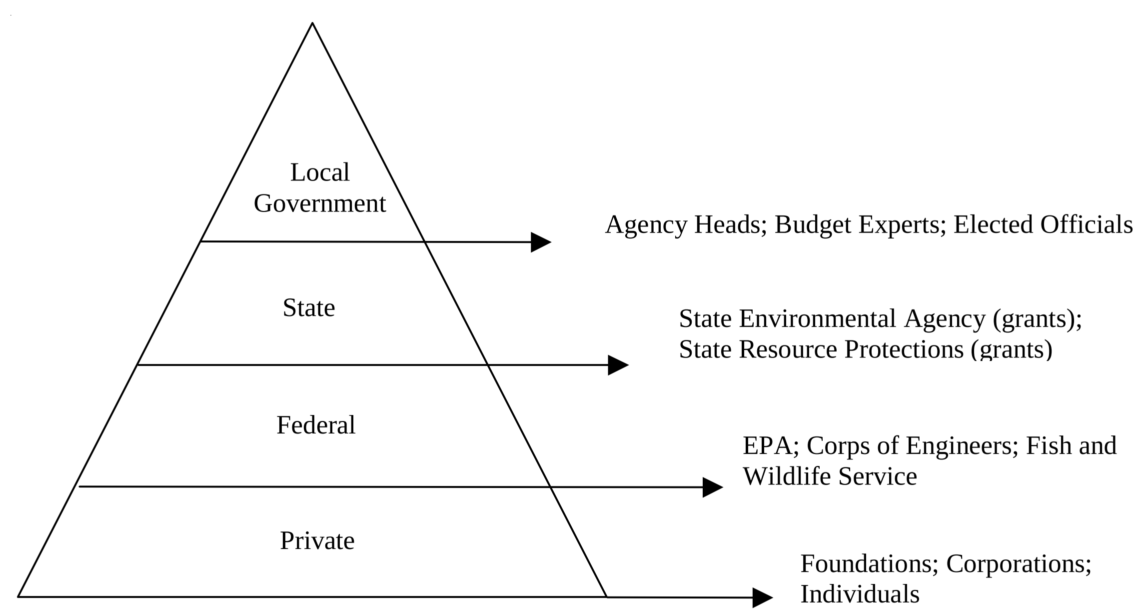


Figure 7: The Funder Stakeholder Pyramid

This group of stakeholders constitutes the major investors in local watershed restoration. Stakeholders near the top of the pyramid usually provide the greatest share of overall funding, but a targeted education strategy is always needed to cultivate each group of potential investors.

1.5 Organizing Stakeholders Into Action

There is no single path to successfully involve all four stakeholder groups in the watershed restoration process. However, it is a good p actice to involve them early and often, and particularly when setting the goals that drive the restoration effort. Manual 2 presents a series of methods for involving each of the four stakeholder groups during each step of the restoration process. Each method seeks to achieve a unique purpose, is targeted to a different combination of stakeholders, and employs customized outreach techniques. The ultimate goal is to organize stakeholders to create a strong partnership that can attract political support for the restoration plan.

Stakeholder involvement helps ensure that the restoration plan is realistic, scientifically sound, and reflects community values and desires. When the right mix of stakeholders agrees on clear and measurable goals, it can create a powerful impetus to guide restoration decisions.

Many consider watershed restoration to primarily be a technical endeavor, and it is certainly true that many technical skills are needed. In practice, however, successful restoration is mostly about organizing people and resources around common goals. Many non-technical skills must be learned to make restoration happen, such as coordination, communication, outreach and leadership.

Chapter 2: The Alteration of Urban Subwatersheds

The current state of an urban stream reflects past alterations to its subwatershed. These past subwatershed alterations must be fully understood before you can begin to make sense of an urban stream, set restoration goals or even think about prescribing the right restoration practices. This chapter reviews the ways in which hundreds of past human alterations collectively transform the character of urban subwatersheds into a complex mosaic of pervious and impervious areas, both of which are extensively modified by humans.

Subwatersheds are progressively transformed and disturbed over the course of many decades or even centuries. Subwatersheds experience at least eight major alterations that are significant from the standpoint of restoration:

1. Conversion to Impervious Cover
2. Construction of Sewer, Water, and Storm Water Infrastructure
3. Intensive Management of Pervious Areas
4. Fragmentation of Natural Area Remnants
5. Interruption of the Stream Corridor
6. Encroachment and Expansion in the Flood Plain
7. Increased Population Density
8. Increased Density of Storm Water Hotspots

2.1 Conversion to Impervious Cover

The cycle begins with the clearing of forests, farms and wetlands, which are replaced by rooftops, roads, parking lots and other forms of impervious cover (IC). By our definition, urban subwatersheds can range from 10 to nearly 100% IC. The imprint of the built environment on subwatersheds of progressively greater impervious cover is clearly evident in Figure 8. Impervious cover fundamentally alters the hydrology of urban subwatersheds by generating increased storm water runoff and reducing the amount of rainfall that soaks into the ground. Impervious cover is also the best indicator to measure the intensity of subwatershed development and predict the severity of impacts to the remaining stream network (CWP, 2003).

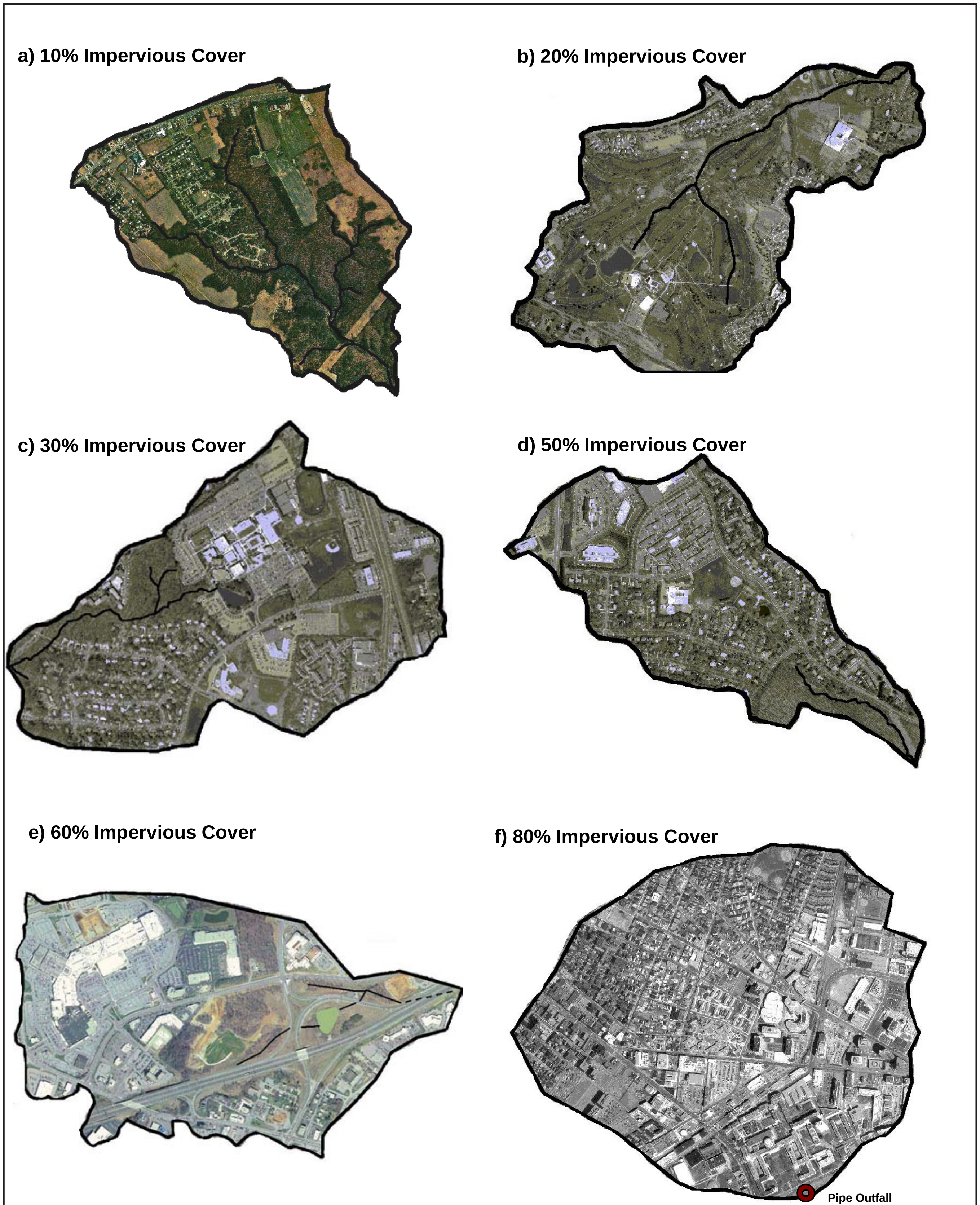


Figure 8: Six Urban Subwatersheds With Progressively Greater Impervious Cover
The imprint of IC is clearly evident in these six aerial photos of small urban subwatersheds with progressively greater IC. Note how both the stream network and corridor are diminished at higher levels of IC. Subwatershed IC is a key variable to assess the prospects for stream restoration.

2.2 Construction of Sewer, Water, and Storm Water Infrastructure

Urban subwatersheds are serviced by an enormous network of underground water, sewer, and storm drain pipes. Hundreds of miles of pipes can be found in a subwatershed as small as five square miles. Each kind of pipe has a pervasive influence on the subwatershed and can also severely constrain the location of restoration practices.

For example, sanitary sewer pipes often parallel the stream network and can become a source of sewage leaks and overflows. In other cases, sewer pipes can capture groundwater that would otherwise sustain stream flow. Since sewers often cross the stream network, they can also become barriers to fish migration. Even the network of pipes that supplies water to homes can influence the subwatershed. Depending on their age and condition, water distribution pipes can lose 10 or even 20% of their water volume to the stream.

Urban subwatersheds also possess an extensive network of storm drain pipes that deliver storm water flows rapidly and efficiently to the stream. This efficiency comes at an environmental cost, as storm drains increase downstream floods and deliver pollutants entrained in storm water runoff. Storm drains "short circuit" natural riparian areas, which reduces their effectiveness in removing pollutants. Storm drain pipes can also cause severe localized erosion at their outfalls, unless they are extensively armored.

2.3 Intensive Management of Pervious Areas

When subwatersheds are viewed from the air, areas of impervious cover are seen interspersed within a larger matrix of pervious areas. Most of the remaining pervious areas have been highly disturbed in the past and few retain the soil and vegetation qualities they once possessed. The most fundamental change is caused by the disturbance of native soils. Progressive cycles of development and redevelopment involve wholesale earthmoving; erosion or removal of topsoil; compaction of subsoils; and the filling of depressions, wetlands and natural rainfall storage areas. Consequently, the soils of urban pervious areas often lack the fertility, tilth, and recharge characteristics of their non-urban counterparts (Schueler, 2000). From a practical standpoint, the hydrology of many urban pervious areas is more similar to impervious areas than natural ones.

The vegetative cover of pervious areas ranges from bare earth to urban forest, but the majority is managed as turf grass or lawn. Most pervious areas are continuously mowed to arrest the natural pattern of vegetative succession. While there is some tree cover in most urban subwatersheds, most urban "forest" has less than 50% canopy coverage (American Forests, 2001). As a result, urban forests lack the structure and understory of their rural counterparts, and are often dominated by non-native trees, shrubs and vines.

2.4 Fragmentation of Natural Area Remnants

A few isolated fragments of forests and wetlands always seem to persist in urban subwatersheds. A typical pattern is depicted in Figure 9, which shows the distribution of forest and wetland remnants in the Watts Branch subwatershed located in suburban Maryland. Often, natural area remnants are located in areas that were extremely difficult to develop (e.g., steep slopes), were abandoned and have since regrown, or grew up over time within parks, cemeteries and public open space. In other situations, subwatershed alterations cause changes in local hydrology that unintentionally create new urban wetlands. Common examples include old ponds, backwaters behind road crossings, and abandoned earthworks. Although of relatively recent origin, these wetlands may receive some protection under state or federal wetland protection statutes.

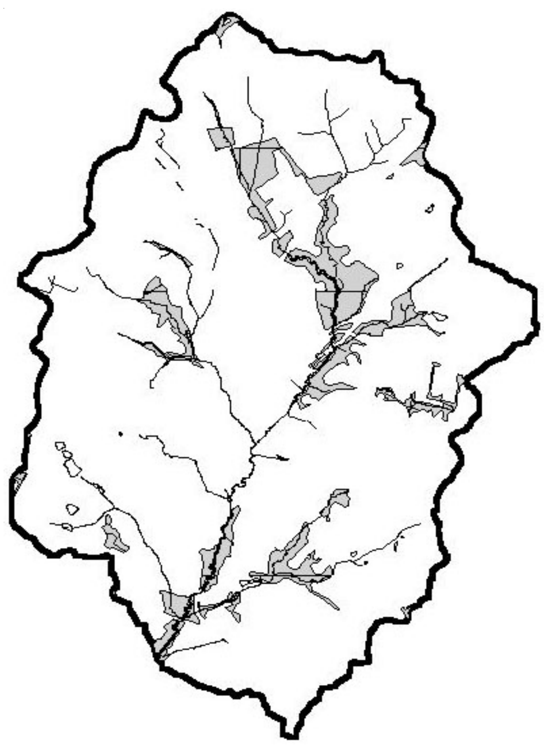


Figure 9: Distribution of Natural Area Remnants in a Non-Supporting Subwatershed
Although Watts Branch (Rockville, MD) has nearly 30% IC, it still contains significant forest and wetland fragments in its subwatershed, many of which are found in close proximity to the stream corridor.

Forest and wetland remnants are often isolated and have little or no connection with other natural habitats or the stream corridor. Typically, natural area remnants have a greater proportion of edge habitats compared to core habitats. Natural area remnants are particularly susceptible to invasions of non-native species of both plants and animals, and it is not uncommon for invasive species to become numerically dominant. Natural area remnants are also stressed by storm water runoff and urban heat island effects. As disturbed and isolated as they are, natural area remnants have intrinsic value as examples of nature in the city, and may present excellent opportunities for restoration in their own right.

2.5 Interruption of the Stream Corridor

Some kind of stream corridor remains in all but the most extremely developed subwatersheds, if for no other reason than it is usually too expensive to totally enclose all streams in pipes. The stream corridor that remains, however, is highly interrupted (i.e., it is frequently crossed, culverted, channelized, ditched, enclosed, armored or otherwise “improved”). Each of these types of interruptions can be found in the Maiden’s

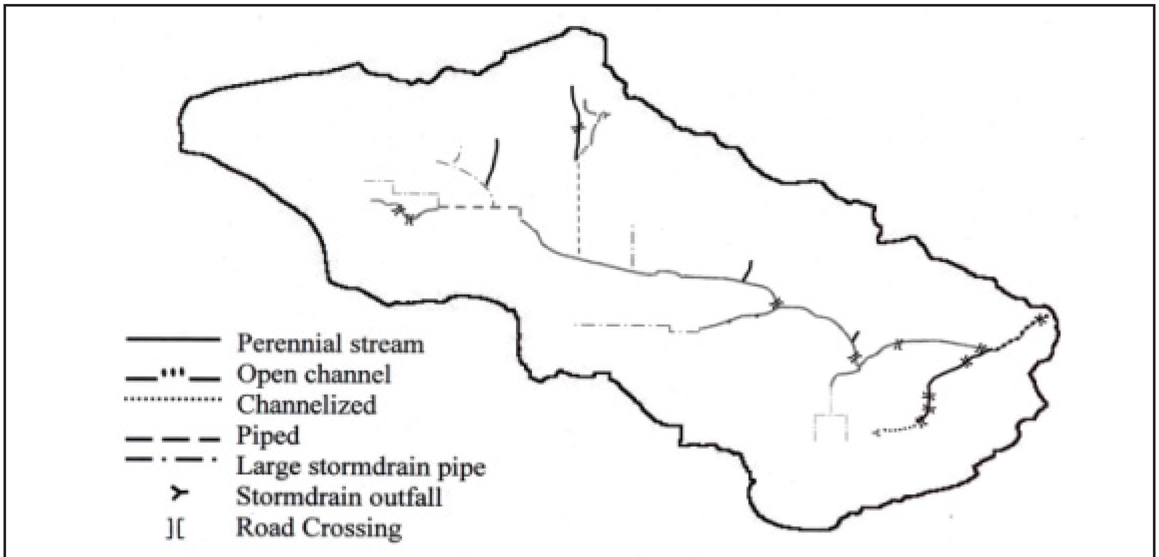


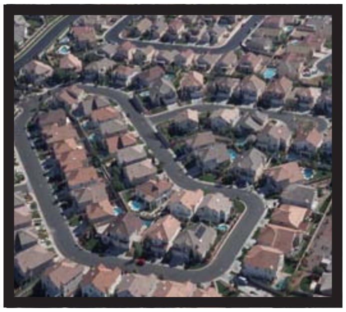
Figure 10: Stream Interruption in a Non-Supporting Subwatershed
This stream network of this Baltimore (MD) subwatershed has been extensively interrupted by road crossings, extended culverts, channelization and other engineering "improvements" over many decades. Most first order streams are not shown on the map because they have been enclosed by storm drains. Stream interruption is an important factor in determining fish passage, channel erosion, and aquatic habitat suitability.

Choice subwatershed located in Baltimore, MD (Figure 10). The subwatershed has about 40% impervious cover and experiences extensive channel alteration and interruption throughout its headwaters and main stem. In many ways, it resembles a broken pipe more than a stream network.

2.6 Encroachment and Expansion in the Flood Plain

The natural flood plain has always been an attractive but dangerous area in which to build, and communities have historically proceeded with development in these areas. In order to protect buildings from flood damage, landowners have incrementally modified the flood plain to allow development. The most common modification has been to fill the flood plain with earth to provide a higher platform for buildings. While the fill may provide local relief to landowners, it also sharply reduces the capacity of the flood plain and exacerbates downstream flooding problems. Other flood control remedies such as channelization, levees, and armoring produce similar effects. In addition, the frequent stream crossings found in urban subwatersheds can encroach on the flood plain. Undersized bridges or culverts that cross the flood plain may also reduce the capacity of the flood plain to handle flood waters.

Even if encroachment never occurred, urban flood plains will always expand in response to upstream development. Urban subwatersheds produce higher peak flooding rates; consequently, urban flood plains must expand to accommodate these higher flows. Both the height and width of the urban flood plain increase, so that when floods occur, more property is subject to inundation. Indeed, many urban subwatersheds are experiencing flood plain expansion, while at the same time they are losing flood plain capacity due to encroachment. Flood damages are the inevitable result.



2.7 Increased Population Density

Urban subwatersheds are home to many humans, pets and wildlife. Each of these populations can directly generate pollutants, such as bacteria or nutrients that can move from the subwatershed to the stream. Humans, presumably the most intelligent of the three groups, make daily decisions that can either improve or degrade conditions in a subwatershed. Negative choices such as dumping, littering, over-fertilizing or not picking up after a dog can directly diminish stream quality when these actions are multiplied many times over. On the other hand, positive choices such as installing rain barrels, adopting streams or planting trees can improve stream quality, particularly when they occur on a widespread basis. Thus, the collective attitudes, awareness and behaviors of subwatershed residents determine whether pollution will be generated or prevented.

2.8 Increased Density of Storm Water Hotspots

The density of storm water pollution hotspots increases as subwatersheds become more intensively developed. Hotspots are defined as commercial, industrial, institutional, municipal, and transport-related operations that tend to produce higher levels of storm water pollution, or present a higher potential risk for spills, leaks and illegal discharges. The nature and distribution of storm water hotspots is different in each urban subwatershed, but there are always quite a few of them, many of which are quite small. Considerable detective work is needed to find storm water hotspots and to prevent potential pollution discharges that can impair downstream water quality.

Together, these eight subwatershed alterations diminish the quality of streams and downstream waters. The next chapter reviews how these alterations impact streams, and how they can be predicted on the basis of subwatershed impervious cover.

Chapter 3: Impacts of Urbanization on Streams

This chapter summarizes recent research on the impact of urbanization on stream quality for subwatersheds with more than 10% impervious cover (IC). In general, changes in stream quality can be tracked according to five broad indicators:

1. Changes to stream hydrology
2. Physical alteration of the stream corridor
3. Stream habitat degradation
4. Declining water quality
5. Loss of aquatic diversity

Figure 11 outlines different stream impacts that can occur within each indicator category (CWP, 2003). This chapter describes how urban stream quality is related to subwatershed IC, and how stream restoration can be assessed within the context of the Impervious Cover Model (ICM).

Impervious cover is often used as a general index of the intensity of subwatershed development and the presumed severity of the seven other subwatershed alterations discussed in the last chapter. The relationship between subwatershed IC and stream quality indicators can be predicted by the ICM, which is based on hundreds of research studies on first to fourth order urban streams (CWP, 2003). It is important to keep in mind that the ICM is a guide and not a guarantee: ICM stream indicator predictions are general, and will not apply to every stream within the ICM classification. Urban streams are notoriously variable, and factors such as gradient, stream order, stream type, age of subwatershed development, and past management practices can and will make some streams depart from these predictions. In general, subwatershed IC causes a continuous but variable decline in most stream indicators in a stream category. Therefore, the severity of impacts tends to be greater at the high end of the IC range within each stream category.

The ICM is a simple tool that identifies three classifications of urban streams, according to their current health and future restoration potential (Figure 12). The three types of streams are as follows:

Impacted Streams have between 10 and 25% subwatershed IC, and show clear signs of declining stream health. Most indicators of stream health fall in the fair range, although some reaches may still be rated as being of good quality. These streams often exhibit the greatest restoration potential since they experience only moderate degradation, have an intact stream corridor, and usually have enough land available in the subwatershed to install restoration practices.

Non-Supporting Streams range between 25 and 60% subwatershed IC, and no longer support their designated uses[1], as defined by hydrology, channel stability, habitat, water quality and biological indicators. Subwatersheds at the lower end of the IC range (25 to 40%) may show promise for partial restoration, but are so altered that they normally cannot attain pre-development conditions for most indicators. In some circumstances, streams in the upper range of the non-supporting category (40 to 60% IC) may show some potential for stream restoration. In most circumstances, however, the primary restoration goals are to reduce pollutants, improve the stream corridor, or enhance community amenities.

[1] The term "designated uses" has a regulatory connection with respect to the Clean Water Act, in terms of a water body's capacity to support fishing, swimming, and other human uses as determined by compliance with applicable water quality standards and narrative biological criteria.

Changes to Stream Hydrology

- Increased annual storm water runoff
- Diminished baseflow (in some streams)
- Increased peak discharge for 100-year storm event
- Increased frequency of bankfull flooding

Physical Alteration of the Stream Corridor

- Stream enclosure/modification
- Loss of riparian forest continuity
- Stream interruption
- Floodplain disconnection
- Increased stream crossings

Stream Habitat Degradation

- Channel enlargement
- Greater annual sediment yield
- Declining stream habitat indexes
- Diminished large woody debris
- Increased summer stream temperatures

Declining Water Quality

- Higher concentrations of pollutants in storm water runoff
- Eutrophication
- Exceedance of water contact bacteria standards
- Potential toxicity to aquatic life
- Contaminated sediments
- Fish consumption advisories
- Higher loads of trash/debris

Loss of Aquatic Diversity

- Decline in aquatic insect diversity
- Increase in pollutant-tolerant species
- Decline in fish diversity
- Loss of capacity to support trout/salmon
- Declining riparian plant diversity

Figure 11: Five Groups of Stream Impacts Associated with Urban Subwatersheds

Urban Drainage refers to streams that have subwatersheds with more than 60% IC and where the stream corridor has essentially been eliminated or physically altered to the point that it functions merely as a conduit for flood waters. Water quality indicators are consistently poor, channels are highly unstable and both stream habitat and aquatic diversity are rated as very poor or are eliminated altogether. Thus, the prospects to restore aquatic diversity in urban drainage are extremely limited, although it may be possible to achieve significant pollutant reductions.

This chapter presents some quantitative predictions as to how specific stream indicators behave within the three stream categories of the ICM. These predictions help diagnose the severity of stream impacts, set realistic goals for restoration, and may be helpful in the design of restoration practices in the stream corridor. The scientific basis for deriving the ICM predictions is documented in Appendix A.

3.1 Changes to Stream Hydrology

The combination of IC, storm drain pipes, compacted soils, and altered flood plains dramatically changes the hydrology of urban streams. During storms, urban watersheds produce a greater volume of storm water runoff and deliver it more quickly to the stream compared to rural watersheds. As a consequence, urban streams have a distinct hydrograph, as shown in Figure 13. The urban stream hydrograph has a much higher and earlier peak discharge rate, compared to rural or undeveloped streams. In addition, stream flow drops abruptly after storms, and often steadily declines during dry weather due to a lack of groundwater recharge.

This basic hydrologic response occurs during every storm, but the effect is most pronounced during smaller, more frequent storms.

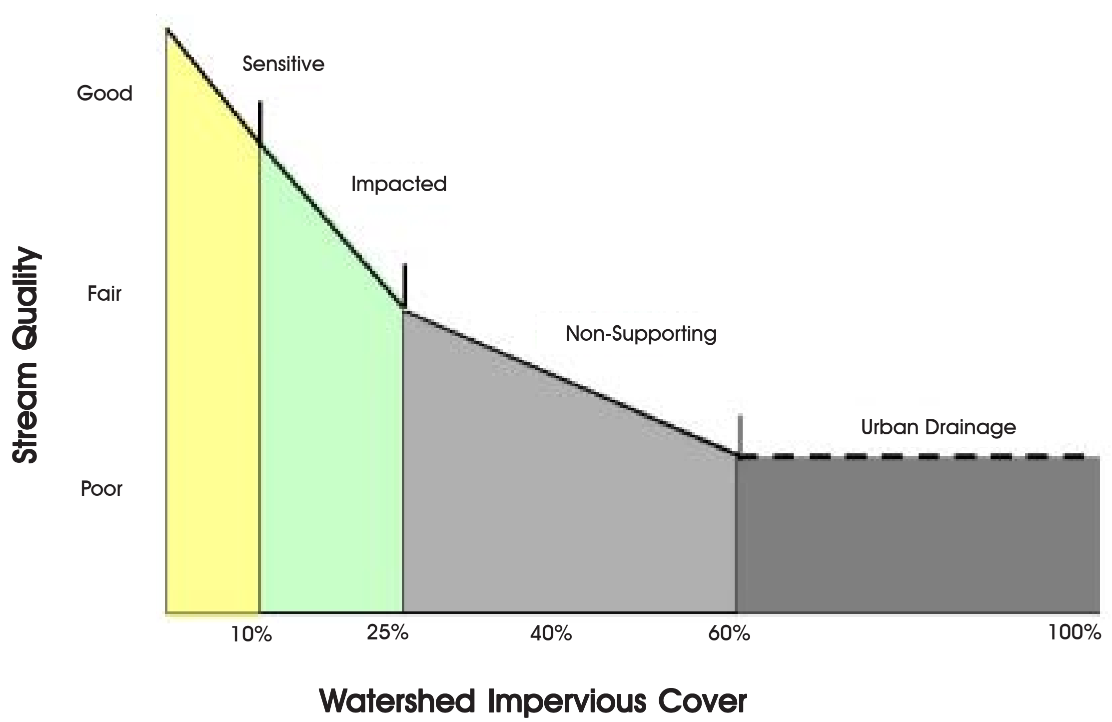


Figure 12: Representation of the Impervious Cover Model (ICM)
The ICM illustrates the relationship between subwatershed IC and expected stream quality, and defines three broad urban subwatershed categories–impacted streams, non-supporting streams and urban drainage. The prospects and strategies for restoration are often markedly different for each of the three subwatershed categories.

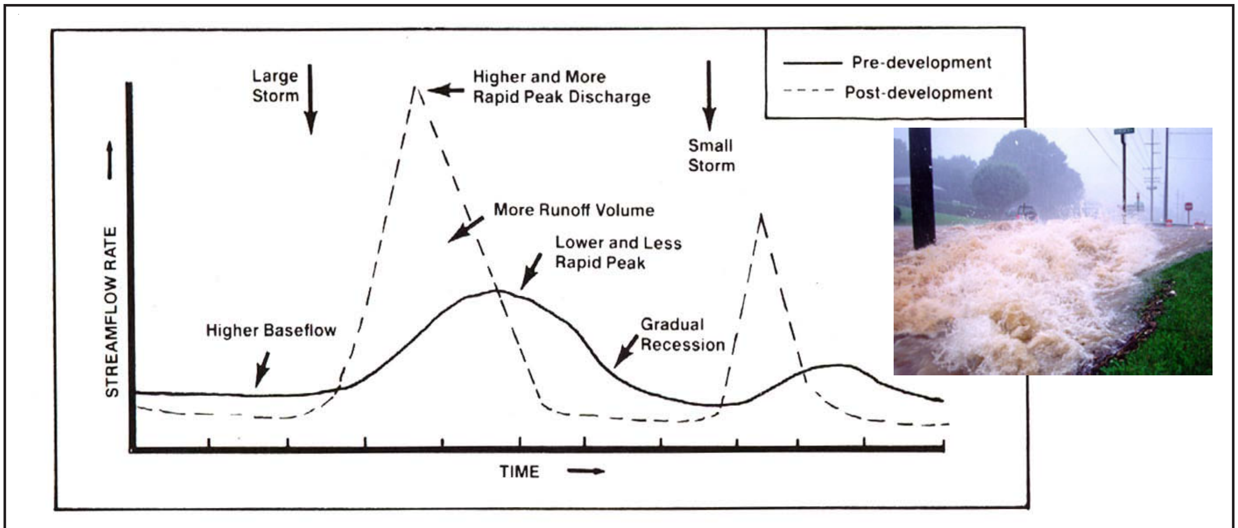


Figure 13: Comparison of Urban and Rural Hydrographs

A hydrograph shows the rate of flow in a stream over time after a rainfall event. The hydrograph of an urban subwatershed (dashed line) is compared to a rural subwatershed (solid line). Note the higher and earlier peak discharge that occurs in the urban subwatershed.

Source: Schueler, 1987

Consequently, urban streams experience an increased frequency and magnitude of flooding. Frequent flash flooding occurs after intense rain events and often causes chronic flood damage. The increased frequency of flooding from smaller storm events often has the greatest impact on streams, as it transports sediments and causes channel erosion.

Another hydrologic impact that may sometimes occur is a reduction in stream flows after extended dry weather periods. Urban headwater streams can dry out during droughts due to a lack of groundwater recharge. In other urban streams, however, dry weather stream flows may actually increase because of additional water flows from irrigation, water leaks, or sewer exfiltration in the subwatershed. Much of the tap water supply delivered in the subwatershed actually originates in other subwatersheds. Thus, when residents or businesses use tap water for irrigation or outdoor washing, some fraction of this imported "return" water reaches the storm drain system and eventually returns to the stream itself. Indeed, urban return water can substantially increase dry weather stream flow in arid and semiarid regions.

The severity of changes in urban stream hydrology can be predicted by the ICM, as described in Table 2. *Impacted streams* exhibit substantial changes in their hydrology, compared to undeveloped or rural streams, with increased runoff, flashier hydrographs and more frequent bankfull flooding. While the hydrology changes are pronounced, it may still be possible to minimize them through a combination of upstream storage retrofit practices.

Non-supporting streams are much more dominated by urban storm water runoff, with the frequency and magnitude of flooding increasing by as much as an order of magnitude. It may still be possible to partially compensate for changes in stream hydrology through a combination of upstream retrofit practices, but the sheer volume of storm water runoff makes it difficult to manage or treat the entire subwatershed. Often, the best that can be done is to shift hydrologic indicators from non-supporting to the impacted category.

As the name implies, *urban drainage* is completely dominated by storm water runoff, and these streams retain few elements of their original "natural" hydrology. Indeed, urban drainage essentially behaves as a conduit for urban storm water. Given the prodigious volume of storm water produced and the limited space available to store it, it is often impossible to meaningfully improve hydrological indicators for urban drainage. It may still be possible to prevent flood damage from extreme storms in urban drainage, but these efforts may require significant alterations to the existing stream corridor.

3.2 Physical Alteration of the Stream Corridor

Urban stream corridors are profoundly altered by land development, and the severity of the alteration can be generally predicted based on subwatershed IC. Major alterations include storm drain enclosure, culverts, flood plain encroachment, clearing and mowing, road and sewer crossings, and various engineering "improvements" designed to fix the stream (and its flood waters) in the desired place.

Cumulatively, these improvements can greatly reduce the length of the stream channel network within urban subwatersheds, with a disproportionate loss of smaller headwater streams that are enclosed by pipes, channelized or culverted. Dams, pipelines, bridges and other stream crossings also create many potential fish barriers that prevent resident and/or anadromous fish from moving freely through the stream network. Consequently, spawning success often declines sharply in urban streams.

Forest or natural cover along the stream corridor is frequently lost after subwatershed development or is confined to a narrow strip. In many cases, the forest buffers that remain are cleared and managed as turf. The progressive reduction in the continuity of natural buffers along the stream corridor has many detrimental consequences to stream ecology and aesthetics. The degree of forest buffer loss in the urban stream corridor is exemplified by the Hospital Branch subwatershed near Lewisburg, TN (Figure 14). While Hospital Branch has only 20% IC, less than half of its stream network has an adequate forest buffer. The quality of the remaining forest buffer in the urban stream corridor is often degraded by invasive plants, dumping and encroachment.

The degree of physical alteration of the urban stream corridor can be forecast in the context of the ICM, as shown in Table 3. *Impacted streams* often experience moderate interruption of the stream corridor, some loss of headwater stream channels and moderate loss of forest buffers. Because the stream corridor alterations are relatively modest in most impacted subwatersheds, they can often be directly restored using practices such as fish barrier removal, stream daylighting or riparian reforestation.

Stream corridors of *non-supporting streams* experience major alteration, with significant loss of headwater streams and forest buffers, severe flood plain encroachment, and frequent stream interruption. The alterations may be less severe, however, if a community has historically regulated its flood plains or reserved land in the stream valleys for parks.

Table 2: Hydrologic Predictions According to the ICM

Stream Hydrology Indicator	ICM Stream Classification		
	Impacted	Non-Supporting	Urban Drainage
Storm Water Runoff as a Fraction of Annual Rainfall[a]	10 to 30 %	25 to 60 %	60 to 90 %
Ratio of Peak Discharge 100 Year Storm[b]	1.1 to 1.5	1.5 to 2	2 to 3
Frequency of Bankfull Flood Events[c]	1.5 to 3 per year	3 to 7 per year	7 to 10 per year

Notes: a) Storm water runoff in undeveloped streams ranges from 2 to 5%.
b) The ratio for undeveloped streams for the 100-year storm is 1.0. Ratios are often much greater for storm events of lower return frequency.
c) Pre-development bankfull flood frequency is about 0.5 per year, or about one bankfull flood every two years.

Given the extent of alterations in non-supporting streams, it is often difficult to fully restore the entire stream corridor, although it is often possible to find some individual stream reaches within the subwatershed where the stream corridor can be repaired or restored.

Subwatersheds classified as *urban drainage* are essentially conduits for storm water and possess a stream corridor with few natural features. Typically, most first and second order streams are enclosed or channelized; much of the stream corridor is eliminated or confined to a narrow strip; and forest buffers are few and far between. The stream corridor that does remain is often intensively managed for recreation or flood control. Thus, the prospects to restore the stream corridor are limited in urban drainage subwatersheds. Some opportunities may exist to mitigate flooding

Table 3: ICM Predictions Concerning Physical Alteration of the Urban Stream Corridor

Stream Corridor Alteration Factor	ICM Stream Classification		
	Impacted	Non-Supporting	Urban Drainage
Fraction of Original Stream Network Remaining [a]	60 to 90%	25 to 60%	10 to 30%
Fraction of Riparian Forest Buffer Intact [b]	50 to 70%	30 to 60%	less than 30%
Stream Crossings [c]	1 to 2 per stream mile	2 to 10 per stream mile	No stream to cross

Notes: a) Undeveloped streams typically have 90 to 100% of original stream network remaining.
b) Undeveloped streams normally have 80 to 100% of riparian forest buffer intact.
c) Rural streams usually have less than one crossing per stream mile.

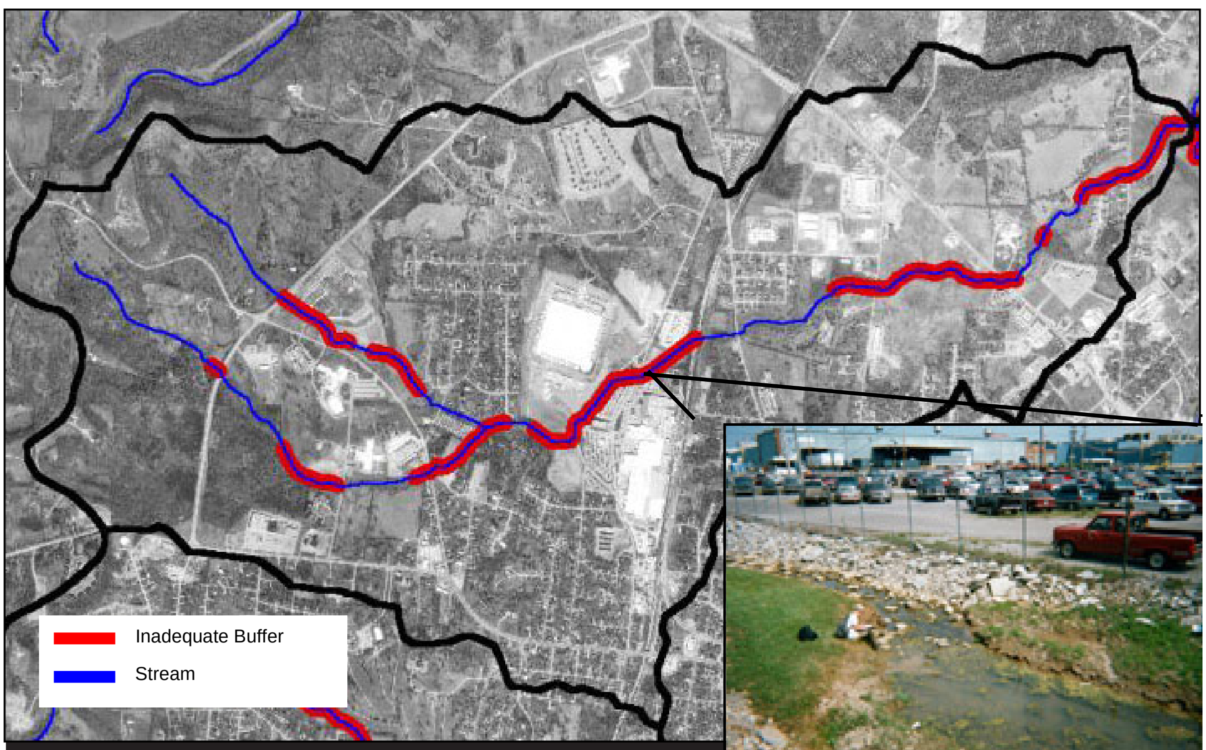


Figure 14: Loss of Riparian Forest Continuity in an Impacted Subwatershed
The loss of forest buffers along the stream network is clearly evident in this aerial photo of an impacted subwatershed in Tennessee. Red shading shows where the forest buffer has been cleared from the riparian corridor, and is an index of riparian forest continuity.

problems, restore a natural area remnant or create a greenway linking the remaining fragments of intact stream corridor. There may also be selected opportunities to restore higher order streams and rivers that escaped enclosure.

3.3 Degradation of Stream Habitat

The increased magnitude and frequency of storm water flows give urban streams more power to transport sediment and cause channel erosion. Most urban streams respond by enlarging their channel cross-section to accommodate the increased flows. Channel enlargement occurs through a combination of widening or down-cutting, depending on the stream type. The cross-section of the current channel can be two to 10 times larger than the pre-development channel, although the full adjustment process may take many decades to complete. Consequently, channel erosion is severe in urban streams, and causes extensive damage to both public infrastructure and private property.

The active phase of urban channel erosion greatly increases the sediment supply to urban streams. Urban streams commonly transport two to 10 times more sediment than rural streams. As this sediment moves through the stream, it exerts a strong influence on the streambed, causing many alternating cycles of sediment deposition and erosion.

When increased sediment transport is combined with active channel erosion and frequent flooding, it isn't surprising that many habitat features are simplified or eliminated in urban streams (Figure 15). Typically, the normal low-flow channel becomes extremely shallow and variable, and pool and riffle structure is lost. Individual habitat elements such as large woody debris, pools, channel sinuosity, meanders, and undercut banks are sharply diminished. The materials of the streambed turn over frequently, and fine sediments become embedded within coarser-grained bed materials. As a result, the highly unstable and embedded streambed becomes less suitable for fish spawning.

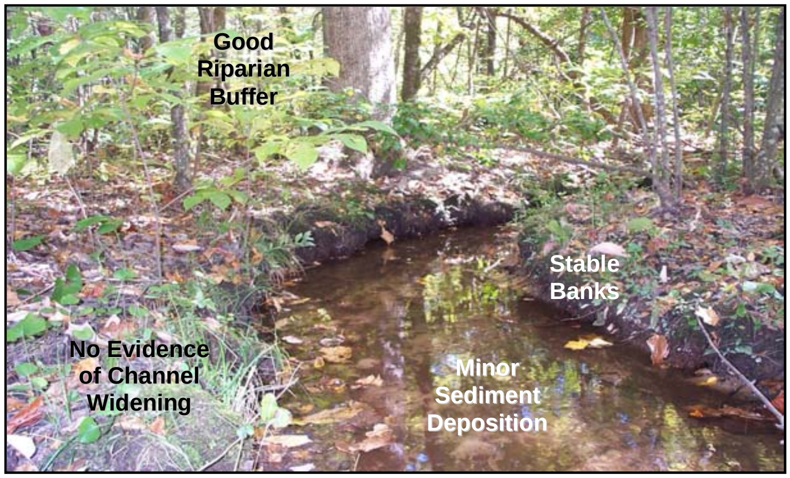
Stream habitat is typically measured by examining a composite of individual habitat metrics thought to contribute to habitat quality. Based on these assessments, most urban streams are consistently ranked as having "poor" to "fair" stream habitat. Few urban streams are ever classified as having "good" or "excellent" habitat ratings.

Finally, urban streams tend to have warmer summer temperatures than undeveloped streams, with mean temperatures increasing by two to 10 degrees Fahrenheit. Much of the stream warming is caused by the heat island effect of IC, but can be intensified by impoundments and the loss of streamside forest cover. In many regions of the country, urban stream warming makes it difficult to support trout, salmon and other cold-water adapted species.

The ICM predicts the nature and extent of habitat degradation, which can help craft realistic strategies to restore or repair urban streams (Table 4). *Impacted streams* typically possess "fair" habitat, although "good" habitat conditions may be encountered at the lower range of IC. The potential to restore many habitat elements in impacted streams is often good, if the stream corridor remains intact and upstream retrofits are built. Under these conditions, it may even be possible to systematically restore habitat throughout the stream network of an impacted subwatershed.

Non-supporting subwatersheds consistently experience severe erosion, extensive habitat degradation and frequent interruption of the remaining stream network. For these reasons, many practitioners doubt that full ecological restoration is possible within non-supporting streams (Konrad, 2003). Still, important structural and functional stream elements can be repaired, particularly if upstream retrofits create more stable hydrological conditions. Consequently, "restoration" within this class of streams involves practices that repair a specific stream problem at a defined point or reach within the stream network, which may or may not have associated ecological benefits. Common stream repairs include stabilizing eroding streambanks, removing fish barriers,

A. Reference Stream



B. Urban Stream

Figure 15: Contrast in Habitat Features Between Rural and Non-Supporting Streams
These photos compare typical habitat features in urban and rural streams, with respect to bank stability, sediment deposition, channel enlargement, and riparian cover. Also, note the difference in the depth and wetted perimeter of the baseflow channel between the two streams.

Table 4: Stream Habitat Predictions According to the ICM

Stream Habitat Indicator	ICM Stream Classification		
	Impacted	Non-Supporting	Urban Drainage
Ultimate Channel Enlargement Ratio [a]	1.5 to 2.5 times larger	2.5 to 6 times larger	6 to 12 times larger
Sediment Yield[b]	2 to 5 times greater	5 to 10 times greater	possibly lower
Typical Stream Habitat Score [c]	fair, but variable	consistently poor	poor, often absent
Presence of Large Woody Debris [d]	2 to 3 pieces per 100 feet	scarce	absent
Increased Summer Stream Temperatures [e]	2 to 4 degrees F	4 to 8 degrees F	8 + degrees F

Notes a) Ultimate channel cross-section compared to pre-development cross-section.
b) Compared to stable rural stream.
c) As computed by EPA Rapid Bioassessment Index or QHI.
d) Forested streams have 5 to 15 pieces of LWD per 100 feet of stream.
e) Compared to shaded rural stream.

preventing channel incision or recreating in-stream habitat.

Subwatersheds classified as *urban drainage* have extremely poor stream habitat in the few places where it has not been physically eliminated. Consequently, the prospects for restoring the structure and function of the urban drainage channels are very poor, although some individual reaches may show some restoration potential. In addition, habitat improvements or stream repairs may still be possible on larger streams and small rivers that may have escaped significant alteration.

3.4 Decline in Water Quality

Just about any pollutant deposited from the atmosphere or generated within a subwatershed is likely to be washed off in urban storm water runoff (Figure 16). Consequently, storm water runoff contains a wide range of pollutants that can degrade local or downstream water quality. A recent summary of national median concentrations for more than 20 pollutants frequently detected in storm water runoff is provided in Appendix A. Pollutant concentrations tend to vary with each storm event, and may also vary based on the prevailing land use, region of the country, and type of precipitation. In general, however, the unit area pollutant load delivered to a stream always increases in direct proportion to subwatershed IC.

Pollutant reduction is usually a major goal of most watershed restoration efforts. The basic strategy is to determine which pollutants are causing the water quality problems of greatest concern, isolate their major sources in the subwatershed, and then apply a combination of restoration practices to treat runoff to reduce these pollutant levels.

A comprehensive review of the concentrations, sources and water quality impacts of 10 major storm water pollutants found in urban storm water can be found in CWP, 2003. These pollutants include sediment, nutrients, trace metals, hydrocarbons, bacteria, organic carbon, pesticides, deicers, and trash and debris.

The severity of water quality problems in urban streams can be reliably predicted with knowledge of subwatershed IC. From the perspective of the ICM, it is important to examine five common water quality problems: eutrophication, exceedance of bacteria standards, aquatic life toxicity, sediment and fish tissue contamination, and trash and debris loads (Table 5).

Eutrophication

High levels of phosphorus and nitrogen in urban storm water runoff can cause eutrophication in streams and contribute to algal blooms in downstream lakes and estuaries. The annual nutrient load produced by urban subwatersheds can be as much as six times higher than rural ones, making it difficult to completely reverse the symptoms of eutrophication.

Impacted subwatersheds generate comparatively modest nutrient loads, and it may be possible to reduce these loads to rural background levels through widespread implementation of restoration practices. Achieving nutrient reduction goals in *non-supporting subwatersheds* is more problematic. The crux of the problem is that nutrient loads in these subwatersheds are two to four times greater than rural subwatersheds, yet current

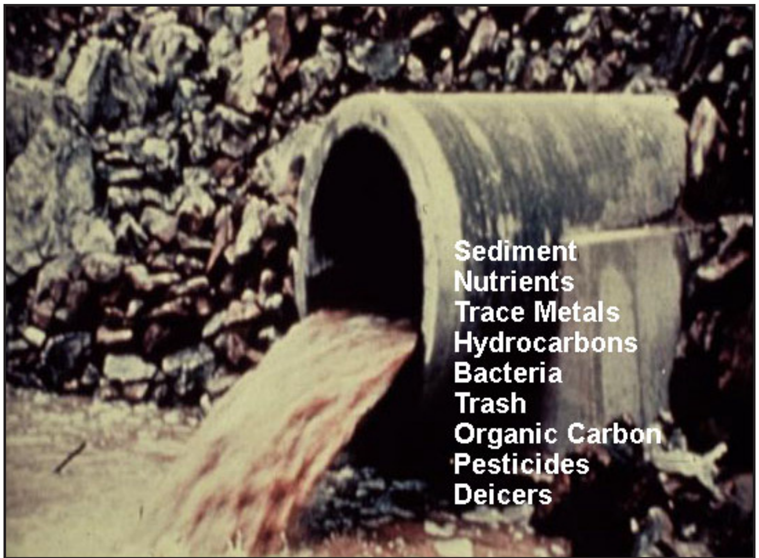


Figure 16: Nine Major Pollutant Categories Found in Urban Storm Water Runoff

Table 5: Water Quality Predictions According to the ICM			
Water Quality Indicator	**ICM Stream Classification**		
	Impacted	**Non-Supporting**	**Urban Drainage**
Annual Nutrient Load [a]	1 to 2 times higher than rural background	2 to 4 times higher than rural background	4 to 6 times higher than rural background
Violations of Bacteria Standards [b]	Frequent violations during wet weather	Continuous violations during wet weather; Episodic violations during dry weather	Continuous violations during wet weather, frequent violations during dry weather
Aquatic Life Toxicity [c]	Acute toxicity rare	Moderate potential for acute toxicity during some storms and spills	High potential for acute toxicity during dry and wet weather
Contaminated Sediments	Sediments enriched but not contaminated	Sediment contamination likely, potential risk of bioaccumulation	Contamination should be presumed
Fish Advisories [d]	Rare	Potential risk of bioaccumulation	Should be presumed
Trash and Debris [e]	1 to 2 tons per square mile	2 to 5 tons per square mile	5 to 10 tons per square mile

Notes a) Annual load of phosphorus or nitrogen produced by a rural subwatershed.
b) Rural stream might violate standards during 10 to 20% of storms.
c) Acute toxicity would be very rare in a rural stream.
d) Enrichment in comparison to sediment quality of rural stream.
e) Based on trash loading estimates from various CA, MD, and NY trash studies and TMDLs.

restoration practices can generally only reduce nutrient load by about 40 to 60% (even assuming that the subwatershed is fully treated with retrofits and source controls). Nevertheless, nutrient reduction efforts may still be warranted in non-supporting subwatersheds as one part of a comprehensive watershed-wide nutrient reduction strategy.

The disparity between the nutrient load produced and the capacity to reduce it is even greater in subwatersheds classified as *urban drainage*. Given the intensity of development in urban drainage subwatersheds, it is often a challenge to find enough feasible retrofit sites to get full treatment of all nutrient sources. Still, nutrient reduction may still make sense in an urban drainage subwatershed if it cost-effectively contributes to a watershed-wide reduction strategy.

Bacterial Contamination

Fecal coliform bacteria levels found in storm water runoff routinely exceed water quality standards, thereby limiting or preventing water contact recreation, shellfish harvesting or swimming in urban waters during and after storm events. Bacteria levels can sometimes violate water quality standards during dry weather periods as a result of sewage leaks, overflows or illicit discharges. The degree to which bacteria impairs designated uses in urban waters is a direct function of IC and can be interpreted in the light of the ICM (Schueler, 1999).

Streams within *impacted subwatersheds* will frequently violate bacteria standards during some storm events, but usually support water contact recreation during dry weather periods, particularly at the lower end of the IC range. Often, impacted streams can reliably meet standards when storm water retrofit and bacterial source controls are applied to the subwatershed.

Streams in *non-supporting subwatersheds* continuously violate standards during wet weather conditions unless favorable dilution or mixing conditions are present. Non-supporting streams may also episodically violate bacteria standards during dry weather periods, as a result of sewage leaks and overflows. Bacteria standards can seldom be attained in non-supporting streams during wet weather conditions even with extensive subwatershed treatment. The main reason is that bacteria concentrations are so high that they would require a 99% removal rate in order to achieve standards. Such a high level of treatment cannot be achieved with current restoration practices (Schueler, 1999). However, if bacteria sources are found and eliminated from the sewer and storm drain network, standards may be achievable during dry weather conditions.

Subwatersheds that are classified as *urban drainage* continuously violate bacteria standards during wet weather conditions and frequently violate them during dry weather, as well. Given the sheer number and diversity of bacteria sources, it is not realistic to expect compliance with bacteria standards in urban drainage “streams.” However, bacteria source controls may still be warranted if they contribute to a larger watershed bacteria-reduction strategy.

Aquatic Life Toxicity

Storm water runoff contains concentrations of copper, chlorine, zinc, cadmium, lead, hydrocarbons, and deicers that can potentially be toxic to aquatic life in urban streams. In addition, numerous pesticides have been detected during storm flow and dry weather flow within urban streams, including several known to cause mortality in aquatic life. Other toxins may enter urban streams as a result of spills, accidents, leaks and illicit discharges from storm water hotspots, which produce higher levels of storm water pollution and/or present a higher risk for spills, leaks and illicit discharges. In general, the number and diversity of storm water hotspots increase with the intensity of subwatershed development. Consequently, the risk of potential toxicity to aquatic life can be interpreted within the context of the ICM.

Most scientists agree that acute toxicity to aquatic life is rare in *impacted streams*, although others suggest that some pollutants might cause chronic toxicity. Pollutant levels in urban storm water are typically below the thresholds for acute toxicity, although they may exceed standards for brief periods of time. The greatest risk of aquatic life toxicity in impacted streams is from spills, accidents and discharges. This risk can be sharply reduced if pollution prevention practices are implemented at storm water hotspots in impacted subwatersheds.

Non-supporting subwatersheds exhibit moderate potential for acute toxicity during some storms and spill events. The toxins of greatest concern will often vary in non-supporting subwatersheds, and depend on the prevailing mix of land use and hotspots. The risk of potential toxicity to aquatic life in non-supporting streams can be reduced if retrofit and pollution prevention practices are widely applied across the subwatershed. The issue of toxicity in *urban drainage* is often moot, since other stressors have already diminished the diversity of aquatic life (i.e., sensitive fish and insect species are often eliminated). Pollution prevention practices and retrofits may be warranted in urban drainage subwatersheds if they reduce toxin loads to downstream aquatic ecosystems.

Sediment Contamination

Many pollutants are attached to sediments borne in storm water runoff, which are eventually deposited in slow-moving waters such as lakes, rivers, estuaries and wetlands. Urban sediments have a diagnostic signature of contamination, with enriched levels of copper, cadmium, lead, mercury, zinc, organic carbon, hydrocarbons and pesticides. In addition, long-banned compounds such as DDT, dieldrin, and PCBs are often detected in urban sediments.

The effect of sediment contamination on aquatic life is poorly documented, but clear evidence exists that metals, pesticides and hydrocarbons bioaccumulate in larger fish and other aquatic life in urban streams. For example, the USGS (2001) found that 100% of fish sampled in urban streams had detectable levels of pesticide in their tissues. Even more troubling was the finding that 20% of the fish tissue samples exceeded recommended levels for fish-eating wildlife (such as raccoons, kingfishers, ospreys and eagles). Pollutant levels in fish tissue may sometimes exceed action levels set to protect human health in highly urban subwatersheds. When these occur, health authorities issue advisories to prevent or restrict fish consumption from local waters.

The severity of sediment contamination can be evaluated within the context of the ICM. Sediment contamination is usually not a major problem for *impacted* subwatersheds, although deposited sediments will usually contain higher levels of trace metals and hydrocarbons than would be found in a rural stream. The potential for sediment contamination and subsequent bioaccumulation in fish and other aquatic life is much greater in *non-supporting subwatersheds.* The risk is greatest for lakes, coves and waterfronts that are small in relation to the area of their contributing non-supporting subwatershed.

In general, it should be presumed that bottom sediments from *urban drainage subwatersheds* will be contaminated with some pollutants, and that these may bioaccumulate within whatever remains of the fish community. Consequently, human consumption of fish from urban drainage subwatersheds should be avoided.

Trash and Debris Large quantities of litter, trash and debris wash through the storm drain system into streams and receiving waters. Often, the problem is exacerbated by illegal dumping. While trash and debris are an unsightly annoyance in other settings, they are a major problem in urban subwatersheds. The prodigious loads of trash and debris generated by urban subwatersheds can diminish the scenic character of urban waters and waterfronts, interfere with designated uses such as swimming or boating, and severely detract from public attitudes about stream quality.

While trash is often noticed, it is seldom measured in urban streams. Recent preliminary estimates of trash generation rates for urban streams range from one to 10 tons of trash and debris per square mile of urban subwatershed (see Appendix A). Trash and debris loads appear to be related to subwatershed IC. Within the context of the ICM, the following predictions can be made with respect to trash and debris and its management.

Trash is noticeable in *impacted subwatersheds*, and often concentrates in debris jams and backwaters. However, generation rates are relatively modest, particularly if the impacted subwatershed is primarily residential. Cleanups and education can make a real difference in the appearance of impacted streams, as long as they are frequently repeated.

Trash can become a moderate to severe problem within *non-supporting and urban drainage subwatersheds*. The higher rate of trash generation means that creeks, shorelines, and waterfronts will receive a significant load of trash and debris after every major storm. Even regular stream cleanups may not keep pace with this increased supply. Additional measures such as booms, catch basin clean outs, litter enforcement, storm drain stenciling, dumpster management or the operation of trash skimmers may be needed to control the trash problem.

3.5 Loss of Aquatic Diversity

The decline in physical, hydrologic and water quality indicators collectively diminishes the quality and quantity of available habitat in urban steams. As a result, urban streams experience reduced aquatic diversity, a shift toward more pollution-tolerant species, and a progressive loss of ecosystem structure and function (CWP, 2003).

This trend is exemplified by aquatic insects, which often form the base of the stream food chain in many streams in North America. In general, aquatic insect diversity declines as subwatershed IC increases. A typical example of this relationship is provided in Figure 17, which compares aquatic insect diversity scores for a large number of subwatersheds with different IC in suburban Northern Virginia. While some scatter is always seen in such data, the trend toward reduced aquatic insect diversity with progressively greater IC is clearly evident.

Under current patterns of development, urban streams lose their potential to have "good" or "excellent" aquatic insect diversity at about 20% subwatershed IC, and lose the potential to achieve "fair" diversity scores at about 30% subwatershed IC. This basic pattern in aquatic insect diversity has been reinforced by more than 20 urban stream studies (CWP, 2003).

Other researchers have noted that habitat- or pollution-sensitive species are eliminated from the aquatic insect community in highly urban watersheds. The most common method used to assess this change is the EPT index, which looks at the proportion of sensitive stonefly, mayfly and caddisfly species found in the aquatic insect community (Table 6).

A similar decline is also observed for fish diversity in urban streams. Sharp drops in fish diversity scores are universally reported for urban streams, with the best index scores ranging from "fair" to "very poor." The health of the fish community is also diminished, with lesions and bioaccumulation commonly reported. The fish community in urban streams also tends to be dominated by pollution-tolerant or non-native species. Sensitive fish species that require cold water or a clean stream bed usually disappear as subwatershed IC increases.

Consequently, it is difficult to maintain a self-sustaining trout or salmon population in many urban streams. Likewise, poor stream bed quality and frequent stream interruption make urban streams a poor spawning environment for anadromous fish that move from estuaries or the oceans to spawn.

Although urban stream ecology remains a very young science, researchers have discovered that important functional elements of stream ecosystems are altered by subwatershed development (Paul and Meyer, 2001; Palmer *et al.*, 2002; Meyer and Couch, 2001). For example, stream researchers have found that in-stream processes such as leaf pack decay, nutrient uptake, retention time and carbon processing occur at different rates in urban

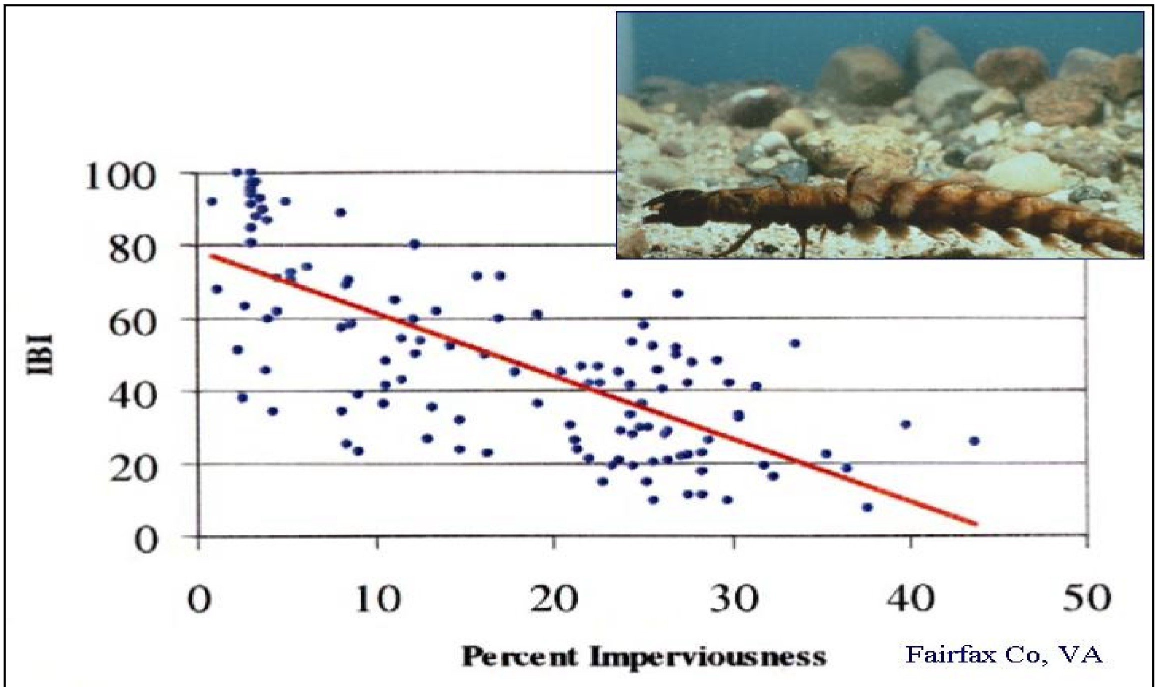


Figure 17: Relationship Between Subwatershed IC and Aquatic Insect Diversity
This is one of many studies that shows the decline in aquatic insect diversity as a function of subwatershed IC (Fairfax County, 2000). While there is always some variability in aquatic insect data, note how diversity scores rarely exceed 60% B-IBI or "fair" once subwatershed IC exceeds 20%.

Table 6: Predictions on Aquatic Diversity According to the ICM			
Aquatic Diversity Indicator	ICM Stream Classification		
	Impacted	Non-Supporting	Urban Drainage
Aquatic Insect Diversity [a]	fair to good	poor	very poor
EPT Taxa [b]	40 to 70%	20 to 50%	0 to 20%
Fish Diversity [c]	fair to good	poor	very poor
Trout or Salmon [d]	limited potential	temporary use only	no potential
Riparian Plant Diversity	stressed, with reduced native plant diversity	simplified community with many exotic species	isolated remnants; dominated by exotics

Notes a) As measured by Benthic Index of Biotic Integrity. Scores for rural streams normally range from "good" to "very good."
b) Aquatic insect metric that looks at sensitive stonefly, caddisfly and mayfly species; values shown are percent of score for undeveloped reference stream or a "put and take" fishery
c) As measured by fish Index of Biotic Integrity. Scores for rural streams typically range from "good" to "excellent."
d) Ability to maintain a self-reproducing population.
e) As compared to flood plain forest or wetlands plant community adjacent to rural stream.

streams compared to rural or undeveloped ones. It is too early to tell how these changes in ecosystem function will influence the prospects for urban stream restoration.

An important but frequently overlooked aspect of stream corridor biodiversity is the simplification of plant diversity in the flood plains and wetlands. Both plant communities suffer from filling and encroachment, and remaining fragments continue to be disturbed by increased water fluctuations, falling water tables, exotic plants, deer browsing and human disturbance. Consequently, wetland and flood plain plant communities often experience significant changes in species composition, with increased invasive or exotic species, declining regeneration of native species, and longitudinal shifts in species along the stream corridor (Brush and Zipperer, 2002; Groffman *et al.* 2003).

The loss of aquatic diversity in the urban stream corridor can be interpreted in the light of the ICM (Table 6). As with other indicators, *impacted streams* experience a fairly moderate decline in aquatic diversity, with diversity scores consistently ranking as "fair" to "good." Thus, prospects for partial recovery are good if restoration practices can be applied comprehensively to both the stream corridor and upland areas of the subwatershed. It may even be possible to partially restore a trout, salmon or anadromous fishery, particularly at the low end of the IC range of impacted streams.

Full restoration of aquatic diversity in *non-supporting* streams is probably an elusive goal, given the many different stressors affecting the stream and its flood plain. Most diversity indicators are solidly in the "poor" range for non-supporting streams. If restoration practices are comprehensively applied across a non-supporting subwatershed, it might be possible to shift the communities into the "fair" range, but it is doubtful whether "good" or "excellent" diversity can ever be attained. Improved diversity is possible, however, if success is defined in the context of a "good" urban stream instead of an unattainable high quality undeveloped stream. For example, while it may be impossible to support a self-sustaining trout population in a non-supporting stream, it may be possible to support a "put and take" trout fishery with annual stocking. Similarly, it may still make sense to remove fish barriers in non-supporting streams, even if actual spawning success will vary greatly from year to year.

Subwatersheds classified as *urban drainage* have "poor" to "very poor" aquatic diversity in the portions of the stream network that still support stream habitat. As noted earlier, urban drainage is frequently interrupted, which makes natural recolonization difficult or impossible. Consequently, prospects for restoring much aquatic diversity in urban drainage is extremely limited, although some individual stream reaches may show modest restoration potential. The best candidates are larger streams and small rivers that may have escaped significant alteration and natural area remnants along the stream corridor.

3.6 Summary

The ICM sets benchmarks that define stream quality expectations for each of the three urban stream categories. As such, the ICM can generally predict the severity of stream impacts, and set realistic goals for subwatershed restoration. It bears repeating that the ICM is a guide and not a guarantee. Some urban streams will depart from these expectations, and these outliers are often of considerable interest when it comes to restoration design. The next chapter reviews the full range of restoration practices that can be used to compensate for the impact of subwatershed development.

Chapter 4: The Range of Subwatershed Restoration Practices

The term "restoration practice" is defined as the application of structural or non-structural techniques in urban subwatersheds to improve stream health, as measured by improvements in physical, hydrological, chemical, ecological or social indicators. At least 130 different techniques can potentially be used to restore urban subwatersheds. These restoration practices can be broadly classified into seven major groups, which are reviewed in this chapter (Figure 18):

1. Storm Water Retrofit Practices
2. Stream Repair Practices
3. Riparian Management Practices
4. Discharge Prevention Practices
5. Pervious Area Management Practices
6. Pollution Source Control Practices
7. Municipal Practices and Programs

The choice of which combination of practices to apply depends on your restoration goals, along with the restoration potential and development intensity within your subwatershed. In general, the first four types of restoration practices are applied to the remaining stream corridor. The remaining three restoration practices are usually applied to upland areas in the subwatershed, although some on-site storm water retrofits can also be installed in upland areas.

This chapter describes each major group of restoration practices, briefly reviews the specific strategies and techniques for implementing them, and discusses how restoration practices can meet subwatershed restoration goals.

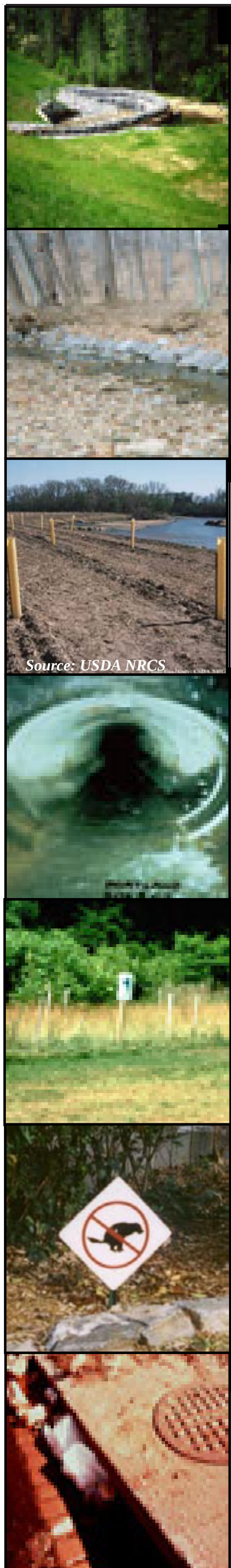
4.1 Storm Water Retrofit Practices

Storm water retrofits are structural practices installed within the stream corridor or upland areas to capture and treat storm water runoff before it is delivered to the stream. Storm water retrofits are the primary practice for restoring subwatersheds, since they can remove and/or treat storm water pollutants, minimize channel erosion, and help restore stream hydrology. Retrofits can be further classified by the subwatershed area they treat. *Storage retrofits*, such as ponds, wetlands, filtering and infiltration practices, can typically treat subwatershed areas ranging from five to 1,000 acres.

On-site retrofits capture runoff from individual source areas, such as rooftops, parking lots and street sections. Residential on-site retrofits are designed to treat areas as small as a few hundred square feet, whereas nonresidential retrofits normally serve areas up to two acres in size. Manual 3 provides extensive guidance on 17 different retrofit techniques that can be applied in urban subwatersheds; a summary list is provided in Appendix B.

Storage Retrofits

A typical example of a storage retrofit is the pond/wetland system constructed within an older detention pond shown in Figure 19. This retrofit was designed to remove pollutants from storm water runoff, reduce downstream channel erosion, and provide local wildlife habitat. As the name implies, storage retrofits may require several acre-feet of storage to effectively perform their restoration function. Therefore, the best sites for storage retrofits are found within existing detention ponds, above roadway embankments and culverts, within highway rights-of-way, within large parking



Storm Water Retrofits

- Storage retrofits
- On-site non-residential retrofits
- On-site residential retrofits

Stream Restoration

- Stream clean-ups
- Stream repair practices
- Comprehensive restoration practices

Riparian Management

- Site preparation
- Active reforestation
- Park or greenway plantings
- Natural regeneration
- Riparian wetland restoration

Discharge Prevention

Finding, fixing or preventing:
- Illicit sewage connections
- Commercial and industrial illicit connections
- Failing sewage lines
- Industrial and transport spills

Pervious Area Restoration

- Land reclamation
- Upland revegetation/reforestation
- Management of natural area remnants

Pollution Source Control

- Residential source control
- Hotspot source control

Municipal Practices

- Street and storm drain practices
- Best practices for development/ redevelopment
- Stewardship of public land
- Municipal stewardship programs
- Watershed education and enforcement

Figure 18: Seven Groups of Practices Used to Restore Urban Watersheds

Restoration plans are about choosing and applying the right combination of these seven practices in a subwatershed that can meet restoration goals.

lots, and at golf courses. New storage retrofits can also be constructed at existing storm water outfalls, if enough adjacent land is available to provide the required storage.

Many storage retrofits must be constructed within a subwatershed to meet restoration or treatment goals. The process of finding and evaluating candidate sites for storage retrofits is known as a "retrofit inventory." In general, site constraints and land availability make it impossible to obtain full treatment with storage retrofits across a subwatershed, but it is often possible to find enough storage to reduce pollutant loads to meet many subwatershed goals.

On-site Nonresidential Retrofits

Commercial, industrial and institutional sites can also provide opportunities to treat storm water runoff. The objective of nonresidential on-site retrofits is to capture and treat storm water from larger rooftops, parking lots, and other source areas. Common examples include the construction of bioretention islands within existing parking lots, green roofs, and storm water planters to treat rooftop runoff. Often, on-site nonresidential retrofits are often combined with storage retrofits to achieve comprehensive treatment across a subwatershed.

On-site Residential Retrofits

Rain barrels and rain gardens are common examples of on-site residential retrofit practices. On-site retrofits are typically installed on individual homes or yards to store or infiltrate runoff from rooftops, driveways or yards. On-site retrofits promote infiltration, which can reduce storm water runoff, treat storm water pollutants at their source, and increase groundwater recharge. Because each individual on-site retrofit treats such a small area, dozens or hundreds are needed to make a measurable difference at the subwatershed level. Consequently, widespread homeowner implementation of on-site retrofits requires targeted education, technical assistance and financial subsidies. On-site retrofits are often combined with storage retrofits to increase the extent of subwatershed treatment.

Figure 19: Example of a Storage Retrofit Pond
The top photo shows an old flood detention pond that was converted into a shallow marsh pond system to remove pollutants and protect downstream banks (bottom photo). This storage retrofit, known as Rolling Stone, was constructed in the late 1980s and treats about 75 acres of upstream drainage.

4.2 Stream Restoration

Stream restoration practices include a large group of techniques used to enhance the appearance, structure or function of urban streams. These practices range from simple stream cleanups and basic stream repairs to extremely sophisticated stream restoration techniques. Stream restoration practices are often combined with storm water retrofits and riparian management practices to meet subwatershed restoration goals. Manual 4 provides detailed guidance on 33 different stream restoration techniques that can be applied in urban subwatersheds; a summary list is provided in Appendix B.

Stream Cleanups

These techniques involve regular pickup and disposal of trash, debris, litter, and rubble from the stream or its corridor, usually with volunteer help. While stream cleanups are often cosmetic and temporary, they are extremely effective tools for involving and educating the public about urban stream degradation. In addition, public attitudes toward urban creeks are often influenced by the presence or absence of trash and debris. Well-organized and frequent stream cleanup programs can remove impressive quantities of trash and debris from the stream corridor, thus preventing its movement to downstream waters.

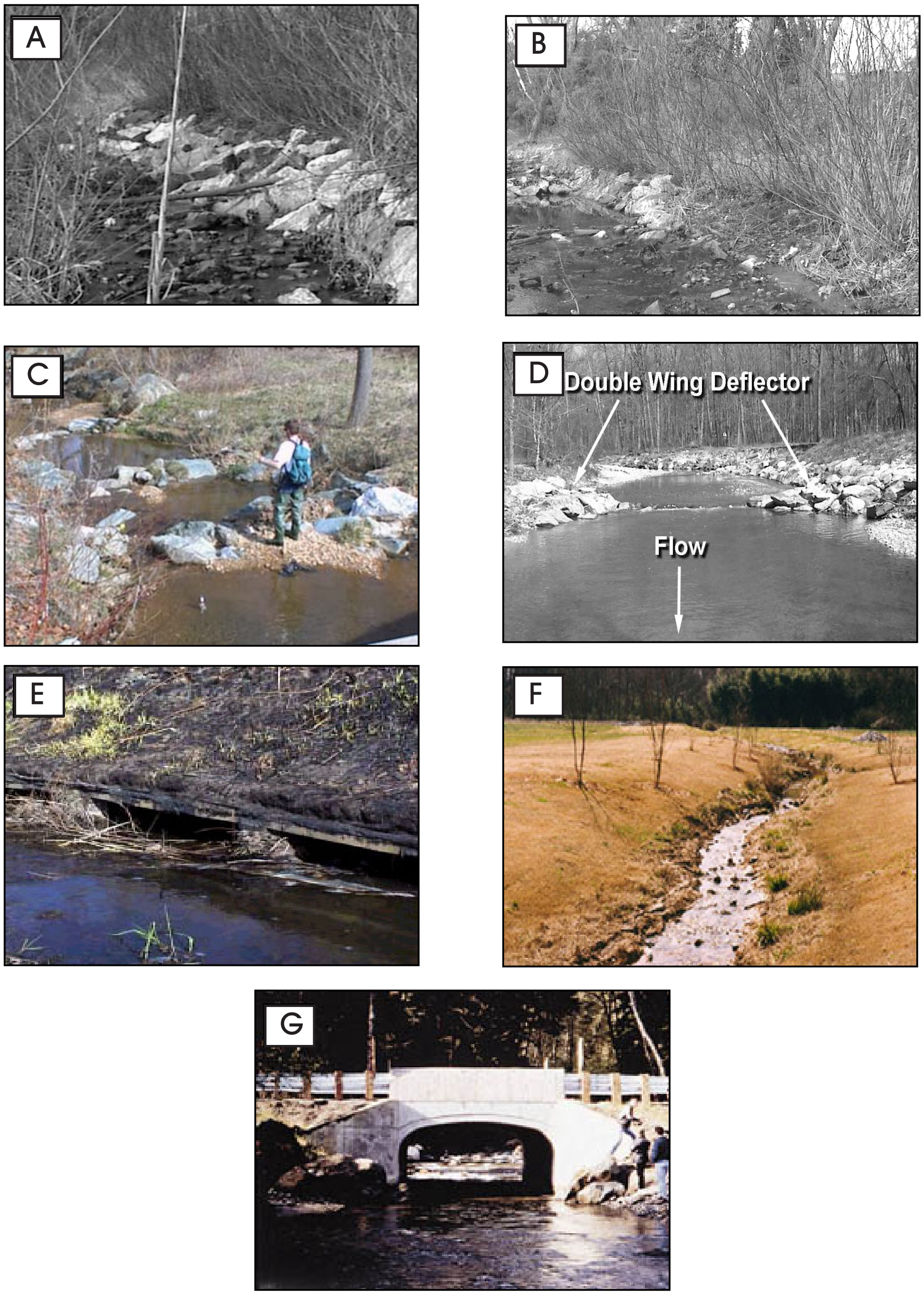


Figure 20: The Seven Basic Types of Stream Repair Techniques
Stream repair techniques are designed to fix a problem at a defined point along the stream. They can be organized according to the seven basic problems they attempt to fix : hard bank techniques to stabilize eroding banks (Panel A), soft or deformable bank stabilization techniques (Panel B), grade controls to stop channel incision (Panel C), flow deflectors to concentrate the low flow channel (Panel D), techniques to enhance stream habitat features (Panel E), storm water flow diversions (Panel F) and techniques to remove or mitigate fish barriers (Panel G).

Stream Repair Techniques

Techniques from this large group repair a specific stream problem at a defined point or stream reach. The primary goal may be to stabilize an eroding stream bank, remove a fish barrier, daylight a storm water pipe, create in-stream fish habitat, or control channel incision (Figure 20). Stream repair techniques can be classified by primary design objective:

· Hard bank stabilization
· Soft bank stabilization
· Grade control
· Flow deflection
· In-stream habitat enhancement
· Flow diversion
· Fish barrier removal

Stream repair techniques are inherently limited by their in-stream location, which may result in the treatment of symptoms but not the underlying causes.

Comprehensive Restoration Practices

This technique takes a more sophisticated and comprehensive approach toward stream restoration. The goal is to design a more natural geometry and habitat structure for the stream channel and banks consistent with its current hydrology and sediment transport dynamics. The broad objectives for these techniques are to restore more natural channel morphology and improve habitat conditions for aquatic life. This may entail natural channel design, dechannelization, or multiple applications of many individual stream repair techniques. Urban subwatersheds are an extremely challenging environment for comprehensive stream restoration, given the dynamic changes in hydrology and sediment transport caused by upstream development. A stable channel form that still experiences altered hydrology and sediment transport may not be hospitable to native aquatic species.

Whether the ultimate goal of comprehensive stream restoration is recovering a trout or salmon population or enhancing fish diversity, meeting this goal requires integrating stream restoration efforts with other restoration practices in the stream corridor and subwatershed. An excellent example of a comprehensive approach to stream restoration is Wheaton Branch in Montgomery County, Maryland (Figure 21).

4.3 Riparian Management

Riparian management practices involve eight basic techniques to restore the quality of forests and wetlands within the remaining stream corridor. The overall goal of riparian management is to improve the continuity of streamside vegetation to maximize the many benefits that buffers provide (e.g., pollutant removal, shading, large woody debris, etc.). Given that urban stream corridors are heavily used and have multiple owners, many individual riparian management projects may need to be linked together to create a better riparian zone. Each riparian management project must be designed to address the unique stresses and disturbances that occur within the urban stream corridor, and maximize storm water infiltration and subsequent pollutant removal. Manual 5 offers detailed guidance on eight riparian management techniques to revegetate the stream corridor; a summary list is provided in Appendix B.

Site Preparation

While there may be many potential reforestation sites in the urban stream corridor, they are often highly impacted by dumping, soil compaction, hill-slope erosion, mowing, invasive plants and other disturbances. Site preparation is usually needed to make a riparian site suitable for successful revegetation or reforestation. Site preparation techniques include removal of trash and rubble, control of invasive plant species, restoration of urban soils, control of hill-slope erosion, and the capture and distribution of storm water evenly across the riparian zone.

Once sites are adequately prepared, they can be revegetated to improve the quality and functional value of the streamside zone, based on the intended management use of the stream corridor. Four basic strategies for revegetating the riparian zone are shown in Figure 22 and described below.

Active Reforestation

These planting techniques are designed to maximize the ecological benefits of a forested flood plain by creating a mature and self-sustaining native plant community.

Parks or Greenways

These plantings are applied when the stream corridor is used for recreational activities such as hiking, biking or nature enjoyment. The

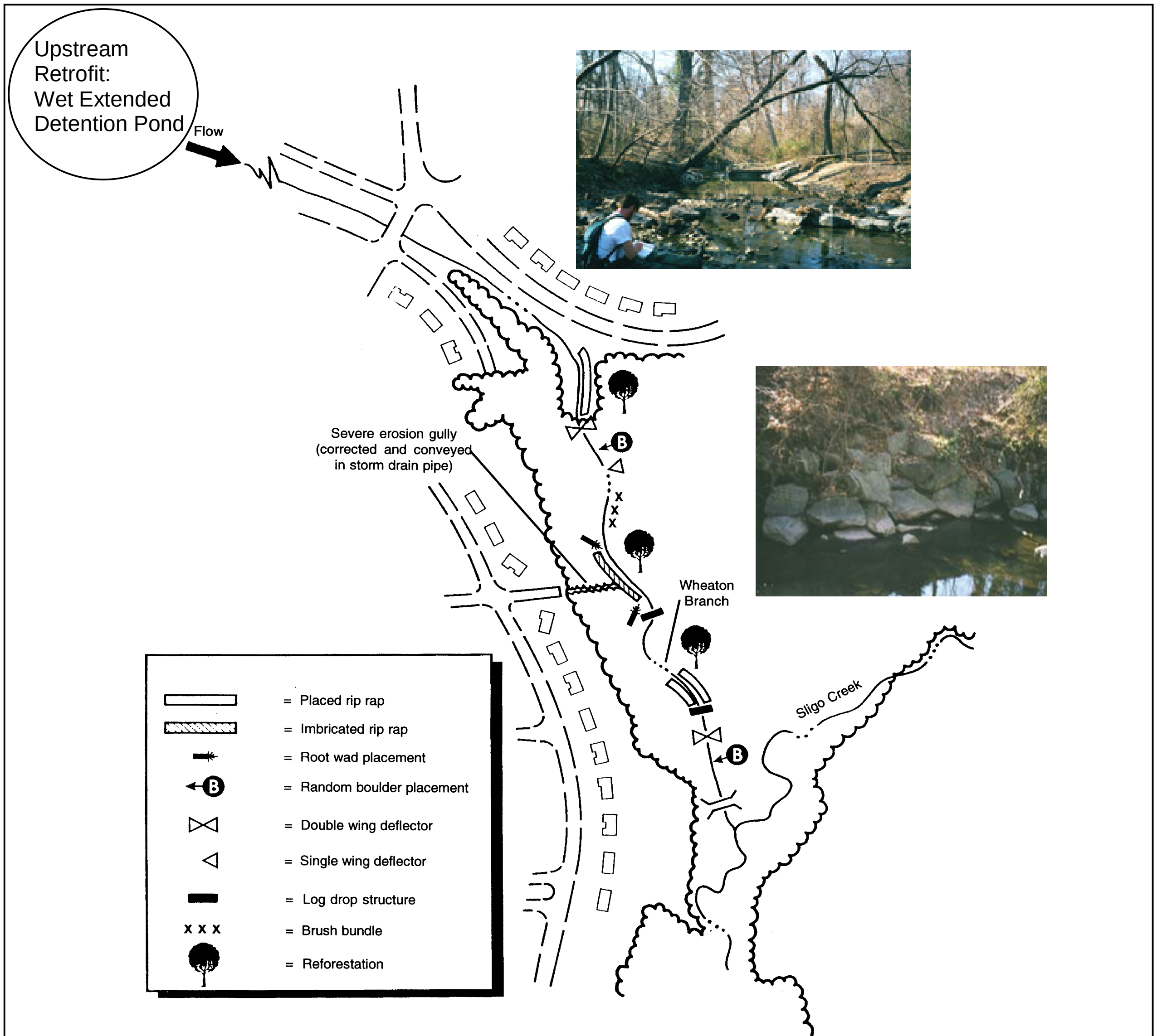


Figure 21: Example of Comprehensive Stream Restoration Approach
The diagram shows the combination of stream restoration techniques employed to restore Wheaton Branch in Montgomery County, Maryland. A key element of the project was the construction of an upstream storage retrofit used to remove pollutants and control hydrology, along with riparian reforestation and restocking of native fish species. The restoration project was built in the late 1980s, and resulted in improved fish and aquatic diversity in this formerly non-supporting stream.

planting plans within these park or greenway settings seek to expand natural vegetative cover while still accommodating the needs of park users.

Natural Regeneration

This technique allows vegetation to grow back in the stream corridor by stopping mowing operations. Although natural regeneration is simple and inexpensive, it can take a long time to establish a mature streamside forest along the stream corridor. Natural regeneration may also result in a plant community that could be dominated by invasive or exotic plant species.

Riparian Wetland Restoration

These techniques are used to enhance or restore degraded wetland communities found along the flood plain. Wetlands are frequently associated with stream corridors because of the close hydrologic connection of the stream with its flood plain. In urban subwatersheds, however, the stream and its flood plain may become disconnected. This occurs when the elevation of the stream channel drops due to severe channel erosion, which leaves the flood plain wetlands high and dry (Groffman *et al*, 2003). Consequently, riparian wetland restoration can involve engineering techniques

Figure 22: Four Strategies to Establish Vegetation in the Riparian Area
The strategy to establish riparian vegetation depends on the condition of the stream corridor, its ownership and intended management use. Strategies include active reforestation (Panel A), more limited park/greenway plantings (Panel B), natural regeneration (Panel C) and restoration of riparian wetlands/forests (Panel D).

to reconnect the stream with its flood plain or redirect urban storm water generated from outside the stream corridor to create surface wetlands.

4.4 Discharge Prevention Practices

Discharge prevention practices prevent sewage and other pollutants from entering the stream from illicit discharges, sewage overflows, or industrial and transport spills. Discharges can be continuous, intermittent, or transitory, and depending on the volume and type, can cause extreme water quality problems in a stream. Sewage discharges can directly affect public health (bacteria), while other discharges can be toxic to aquatic life (e.g., oil, chlorine, pesticides, and trace metals). Discharge prevention focuses on four types of discharges that can occur in a subwatershed, as described below.

Illicit Sewage Discharges

Sewage can get into urban streams when septic systems fail or sewer pipes are mistakenly or illegally connected to the storm drain pipe network. In other cases, “straight pipes” discharge sewage to the stream or ditch without treatment, or sewage from RVs or boats is illegally dumped into the storm drain network. Research has shown that sewage is the most common type of illicit discharge in most communities (Brown *et al*., 2004). These discharges can be detected by screening storm water outfalls with dry weather flow for water quality parameters that indicate suspected sewage contamination. More detailed diagnostic tests are often needed to trace the problem up the pipe network and isolate the specific home or business connection that is discharging sewage or septage.

Commercial and Industrial Illicit Discharges

Some businesses mistakenly or illegally use the storm drain network to dispose of liquid wastes that can exert a severe water quality impact on streams. Examples include shop drains that are connected to the storm drain system; improper disposal of used oil, paints, and solvents; and disposal of untreated wash water or process water into the storm drain system. A large number of commercial, industrial, institutional, municipal, and transport-related sites have the potential to generate these discharges on an intermittent or transitory basis. Brown *et al*. (2004) and Manual 8 provide detailed guidance on how to identify generating sites, and describe education and enforcement methods for eliminating illicit discharges.

Failing Sewer Lines

Sewer lines often follow the stream corridor, where they may leak, overflow or break, sending sewage directly to the stream. The frequency of failure depends on the age, condition and capacity of the existing sanitary sewer system. The vigilance of the local sewer authority is also important to minimize failure. Regular inspection of sewer lines, prompt response to overflows and leaks, and ongoing repairs to the sewer infrastructure can sharply reduce sewage discharge.

Industrial and Transport Spills

Tanks rupture, pipelines break, accidents cause spills, and morons dump pollutants into the storm drain system. It is only a matter of time before these events occur in most urban subwatersheds, allowing potentially hazardous materials to move through the storm drain network and reach the stream. Since spills are unpredictable, they can only be managed by maintaining an emergency response system that quickly reacts to spills and contains the damage. Spill response plans are needed for storm water hotspots, many industrial sites, and the road system of the subwatershed.

Manual 6 provides general guidance on the range of techniques to find, fix or prevent all four types of discharges in an urban subwatershed. A condensed list of the discharge prevention techniques profiled in the manual can also be found in Appendix B.

4.5 Pervious Area Management

Municipalities often own or manage as much as 10% of total subwatershed area in parks, open lands, golf courses, schools and tax delinquent parcels. Some of these areas are prime candidates for land reclamation, which improves soil quality by amending it to increase its capacity to infiltrate rainfall, and create better conditions for healthy plant growth. Manual 7 offers guidance on eight pervious area management techniques; Appendix B provides a condensed summary list.

Land Reclamation

Because urban soils are extremely compacted, they often have poor vegetative cover and infiltration capabilities. Consequently, many pervious areas in urban subwatersheds produce more storm water runoff and sediment than undeveloped areas. Land reclamation seeks to restore soil quality on tracts of land that are vacant, abandoned or unused, or within individual yards. This technique includes compost and other soil amendments, tilling, and aeration. In many ways, land reclamation practices are similar to rain gardens and other residential on-site retrofit practices. Land reclamation is a relatively new urban restoration technique, and its subwatershed benefits can only be realized when it is widely implemented across a subwatershed.

Upland Revegetation

Once soil quality has been restored, trees or other forms of native cover can be planted to measurably increase overall forest cover within a subwatershed. The canopy interception and infiltration created by expanded forest cover can improve stream hydrology and reduce the urban heat island effect. It should be noted that prairie, meadows or grasslands may be the ideal native vegetative cover in some regions of the country. In any event, revegetation must be conducted at a widespread scale in a subwatershed to provide measurable hydrologic and water quality benefits.

Management of Natural Area Remnants

This practice enhances the quality of remaining forest fragments, wetlands and other natural area remnants in the upland areas of the subwatershed. Like their counterparts along the stream corridor, natural area remnants are frequently impacted by dumping, soil compaction, erosion, invasive plants and storm water runoff. This practice usually involves an ecological assessment of the natural area remnant to identify key stressors, followed by a restoration plan to improve its ecological structure and function.

4.6 Pollution Source Control Practices

Source control is a broad restoration practice that seeks to prevent pollution from residential neighborhoods or storm water hotspots. Which source control practices are applied depends on the pollutants of concern and the major pollutant source areas identified in the watershed. Source control practices focus educational, enforcement, and technical resources on changing the resident behaviors or business operations that are causing the pollution. Manual 8 provides extensive information on 21 stewardship practices that can be applied in residential neighborhoods, along with 15 pollution prevention techniques used to control storm water hotspots. A list of source control practices profiled in the manual can be found in Appendix B.

Residential Stewardship

Subwatershed residents engage in many behaviors that can influence stream quality. You may want to focus on changing negative behaviors such as over-fertilizing, oil dumping, littering, or excessive car washing and pesticide use. Alternatively, your focus may be on encouraging positive behaviors such as tree planting, properly disposing of household hazardous wastes, and picking up after pets. In either case, residential stewardship involves designing a targeted education campaign that delivers a specific message and changes resident behavior (Swann, 2000). Often, the educational campaign is supported by incentives and the provision of convenient municipal services such as free compost for soil amendments, free lawn soil testing, advice on nontoxic ways to deal with pests, or oil recycling directories.

To devise an effective neighborhood stewardship program, it is important to understand the range of homeowner behaviors that contribute to storm water pollution. Since each neighborhood has its own distinctive character, it is helpful to assess homeowner behaviors and pollution sources at the neighborhood scale (Figure 23). The Neighborhood Source Assessment (NSA) component of the USSR survey, described in Manual 11, systematically examines five common pollution source areas in every neighborhood:

Overall Neighborhood Character: What is the average age, lot size and construction activity within the neighborhood? Are there septic systems that could become a pollution source? Is there an active homeowner or civic association to help with outreach?

Lawn and Yard Practices: What proportion of lawns in the neighborhood is intensively managed from the standpoint of fertilization, pesticide use, and irrigation? What opportunities exist in the yards to expand natural landscaping, tree canopy, and backyard composting?

Rooftops: Are the rooftops directly connected to the storm drain system, and, if so, what is the potential to disconnect, capture or treat rooftop runoff?

Sidewalks, Driveways and Curbs: Are pollutants, pet waste, or organic matter accumulating on these surfaces? What can be inferred about driveway cleaning, car maintenance and other housekeeping practices in these areas?

Stewardship of Common Areas: Is community open space present in the neighborhood in the form of storm water ponds, buffers, flood plains, forest conservation areas, or streetscapes,? If so, what are the prevailing vegetative management, maintenance and housekeeping practices in these common areas?

Most subwatersheds contain multiple neighborhoods that can differ sharply in both the potential severity of their pollution sources and opportunities for neighborhood restoration.

Hotspot Source Control

This restoration practice involves applying pollution prevention practices at commercial, industrial, institutional, municipal, and transport-related sites that are suspected or confirmed storm water hotspots. Pollution prevention practices may be legally required under local or state storm water permits at many of these hotspots. While dozens of

Figure 23: Pollution Source Control Opportunities in Residential Neighborhoods
Nearly two dozen pollution source control opportunities can exist within a residential neighborhood. They can be systematically evaluated by looking at lawns and yard practices, rooftop connections, the condition of sidewalks, driveways and curbs, and the management of any common areas.

pollution prevention techniques are available, managers must identify the unique combination of techniques that will address the actual pollution problems encountered at each site. Thus, the first step in hotspot source control involves a thorough investigation of storm water problems, spill risks, and pollution sources at the site. A Hotspot Source Investigation (HSI) evaluates current operations with respect to six potential pollution sources (Figure 24):

Vehicular Sources: Are vehicles washed, fueled, repaired, or stored at the site that could serve as a potential source of pollution?

Material Handling: Are pollutants being stored or loaded outside where they may be exposed to rainfall?

Waste Management: Can any wastes produced at the site get into the storm drain system? (e.g., trash dumpsters, used oil, product disposal).

Physical Plant Practices: Do any of the maintenance practices for the building and parking lots have the potential to pollute storm water?

Turf and Landscaping: Are the fertilizers or pesticides used to maintain the grounds a potential pollution source?

Miscellaneous Sources: Are there unique operations at the site that can produce pollution? (e.g., marinas, swimming pools, and golf courses)

A unique combination of pollution prevention practices is prescribed for each storm water hotspot based on the HSI. This prescription may involve structural and nonstructural techniques, along with the employee training needed to make them happen. Guidance on conducting an HSI can be found in Manual 11.

Figure 24: Investigating Potential Storm Water Hotspots
Storm water hotspots are sites that produce higher levels of storm water pollution and/or a greater risks of spills, leaks and discharges, and are created by vehicles, outdoor storage, waste management, plant maintenance, grounds care and other site operations and practices.

4.7 Municipal Practices and Programs

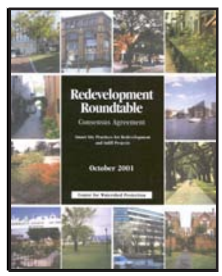
Municipalities can play at least six pivotal roles in subwatershed restoration. First, communities maintain much of the physical infrastructure in a subwatershed, including roads, sewers, and storm drain systems. In many cases, communities can reduce or prevent pollutants from entering the subwatershed by changing their infrastructure maintenance policies. Second, maintenance practices set the rules governing how development and redevelopment proceed. When crafted properly, these rules can actively promote better development practices that support long-term subwatershed restoration goals.

Third, municipalities are usually a significant landowner in most subwatersheds, and can practice better stewardship on the lands they own or control. Fourth, municipalities operate certain facilities that are well-known storm water hotspots. Common examples include solid waste facilities, public works yards, fleet storage lots and maintenance depots. Many of these operations are required to implement source control or pollution prevention practices (see Practice 6). Fifth, municipalities can act as the direct service provider to help residents and businesses practice better stewardship. Examples include local programs to conveniently dispose of yard wastes, used oil or household hazardous wastes.

Lastly, municipalities can play a strong role in both education and enforcement to promote better stewardship by residents and businesses. More guidance on municipal practices and programs that can support subwatershed restoration can be found in Manual 9; a condensed list is presented in Appendix B.

Street and Storm Drain Practices

Municipalities own and maintain much of the road and storm drain infrastructure in a subwatershed. Routine maintenance practices such as road and bridge repairs, snow removal and road salting can cause storm water pollution unless employees are properly trained on best practices. On the other hand, municipal maintenance practices such as street sweeping, catch basin cleanouts, and streetscaping can help remove pollutants from subwatersheds. The degree of pollutant reduction depends on how frequently and systematically each practice is implemented across a subwatershed.



Best Practices for Development or Redevelopment

Urban subwatersheds undergo a continual process of development and redevelopment. Indeed, it has been estimated that an urban subwatershed will completely redevelop over a 50 year timeline (GVSDD, 2002), presenting an excellent long-term opportunity to retrofit better storm water practices during the redevelopment process. By crafting better criteria for development and redevelopment, communities can actively promote “smart site practices” that support long-term subwatershed restoration goals. Smart site practices are innovative techniques to create green space and creatively treat storm water at redevelopment and infill sites (Kwon, 2001). They can be applied to both private and public sector redevelopment projects in highly urban subwatersheds.

Stewardship of Public Land

It is not uncommon for a municipality to own or control as much as 10% of all the land within a subwatershed, when all of the parks, schools, golf courses, rights of way, easements, open space, municipal buildings and tax delinquent parcels are combined. Even more land may be owned or controlled by local utilities or state and federal agencies. While this land reserve is quite large, it is widely dispersed and managed by many entities for many different purposes. This restoration practice seeks to educate municipal landowners about subwatershed restoration goals and enlist them as partners in the restoration effort. The partners who manage the lands held in public trust can improve their land stewardship and provide demonstration sites for both stream corridor and subwatershed restoration practices. An example of public lands stewardship is the reforestation of the grounds of a local middle school.

Municipal Stewardship Programs

Municipalities provide many direct services that can improve stewardship by residents and businesses alike. Some of these programs may be required under their NPDES storm water permit or by state regulation, while others are local initiatives to increase local watershed awareness. Examples of municipal stewardship include programs organized to do the following:

· Enforce illegal dumping
· Stencil storm drains
· Adopt a stream
· Collect household hazardous wastes
· Collect used oil for recycling
· Provide lawn care advice
· Provide soil testing or compost
· Disconnect residential rooftops
· Inspect septic systems
· Citizen hotlines

These programs are intended to make each act of personal stewardship as easy and convenient as possible to achieve the greatest pollutant reduction for the subwatershed. Stewardship programs require a carefully targeted education campaign to increase participation, as well as an efficient and timely delivery service.

Watershed Education and Enforcement

Municipalities can wield both carrots and sticks to promote pollution prevention practices and respond to severe water quality problems. Municipal education efforts can include basic outreach, subsidies, discounts, and recognition programs. Enforcement methods can include inspections, new regulations, certification, and civil enforcement proceedings. The full range of carrots and sticks available to a municipality is described in Manual 8.

4.8 Choosing the Right Combination of Restoration Practices for a Subwatershed

The range of practices that can potentially restore urban subwatersheds is impressive, but also daunting. From a planning standpoint, subwatershed restoration potential is basically governed by the size of the remaining stream corridor, and the amount of subwatershed area that can be effectively treated. Since both factors are closely related to impervious cover, a general sense of restoration potential can be inferred from the subwatershed ICM classification.

The basic relationship is presented in Figure 25, which shows how subwatershed IC influences the feasibility of implementing restoration practices. The chart indicates the degree to which a given restoration technique can be implemented across each ICM

Restoration Practice	Subwatershed Impervious Cover			
	10 to 25%	25 to 40%	40 to 60%	60 to 100%
Storm Water Retrofit Practices				
Storage Retrofit	●	⦿	○	×
On-site Non-Residential Retrofits	●	●	⦿	○
On-site Residential Retrofits	●	●	⦿	○
Stream Restoration Practices				
Stream Clean-ups	●	●	⦿	×
Stream Repairs	●	⦿	⦿	○
Comprehensive Restoration	⦿	○		×
Riparian Management Practices				
Site Preparation	●	⦿	○	×
Active Reforestation	●	●	⦿	×
Park/Greenway Plantings	●	⦿	⦿	×
Natural Regeneration	●	⦿		×
Riparian Wetland Restoration	●	⦿		×
Discharge Prevention Practices				
Illicit Sewage Connections	●	●	●	●
Other Illicit Connections	⦿	●	●	●
Failing Sewage Lines	●	●	●	●
Industrial and Transport Spills	⦿	●	●	●
Pervious Area Management Practices				
Land Reclamation	●	●	⦿	○
Upland Revegetation	●	●	⦿	○
Natural Area Remnant Management	●	●	⦿	○
Pollution Source Control Practices				
Residential Source Controls	●	●	●	⦿
Hotspot Source Controls	⦿	●	●	●
Municipal Practices and Programs				
Street and Storm Drain Cleaning	⦿	⦿	⦿	●
Best Practices for Redevelopment	●	●	●	●
Stewardship of Public Land	●	●	⦿	○
Municipal Stewardship Programs	●	●	●	●
Education and Enforcement				

KEY
● Technique is normally feasible and can be widely applied across subwatershed
⦿ Technique is often feasible, depending on subwatershed characteristics
○ Individual sites can be found, but widespread implementation across subwatershed is limited
× Technique is generally not feasible in the subwatershed

Figure 25: General Feasibility of Retrofit Practices at Different Levels of Subwatershed IC

This chart provides general guidance on the subwatershed conditions where the restoration techniques can be most widely applied. Actual restoration potential should always be assessed in the field, but the ability to widely implement some restoration techniques is often limited in the most intensely developed subwatersheds, due to lack of available land in the stream corridor or upland areas.

subwatershed category. Note that the non-supporting subwatershed category has been divided into a lower range (25 to 40% IC) and an upper range (40 to 60% IC). As can be seen, restoration practices become less feasible as subwatershed IC increases. This is particularly true for stream corridor restoration practices such as storm water retrofits, stream restoration and riparian reforestation.

All seven restoration practices are potentially feasible within impacted subwatersheds, and many of these practices continue to be feasible in the lower range of the non-supporting category. Obviously, their actual feasibility cannot be determined until systematic desktop and field surveys are conducted in a subwatershed.

By contrast, stream corridor restoration practices are seldom feasible in the upper range of non-supporting subwatersheds (40 to 60% IC) and are rarely feasible in urban drainage subwatersheds. These subwatersheds may be suitable for upland practices that reduce or prevent pollution, such as discharge prevention, municipal practices, and pollution source controls.

The feasibility of restoration practices strongly influences the ability to meet various water quality, biological and social goals in each class of subwatershed. Figure 26 illustrates the general ability to meet various goals at different levels of subwatershed imperviousness. The chart is based on past experience assessing restoration potential in many subwatersheds across the country, and is only intended as a general planning guide, as exceptions can and will occur. Still, the chart is a useful framework for analyzing how impervious cover influences the ability to meet subwatershed goals.

Restoration Goals for Impacted Subwatersheds

Impacted subwatersheds usually have the greatest restoration potential, since they experience only moderate stream degradation, have an intact stream corridor, and normally have enough land available in the subwatershed to install restoration practices. Consequently, many restoration goals can be achieved in impacted subwatersheds, assuming that enough feasible retrofit sites can be found to assure widespread treatment. If this can be done, it may be possible to set goals to actually *improve* physical, biological and water quality indicators for impacted subwatersheds, particularly at the low end of its IC range. Thus, it may be possible to systematically restore habitat throughout the stream network, reduce pollutant loads to rural background levels, meet water contact recreation standards during dry weather periods, partially recover aquatic diversity, and possibly even restore a fishery. Similarly, it is reasonable to expect that many community goals, such as stream corridor enhancement, can still be achieved in impacted subwatersheds.

Restoration Goals for Non-supporting Subwatersheds

Fewer restoration goals can be achieved in non-supporting subwatersheds, although some subwatersheds at the lower end of the IC range (25 to 40% IC) may show promise for partial restoration if they can be extensively treated with retrofits and pollution source controls. The primary restoration goal in many non-supporting subwatersheds is to reduce pollutant loads by comprehensively applying storage and on-site retrofits, discharge prevention, source control and municipal practices. Full restoration of aquatic diversity can be an elusive goal, although it may be possible to find some individual stream reaches that can be repaired. In addition, it may still be possible to meet community goals for the stream corridor, such as recreation, flood control, and aesthetics.

Subwatershed Restoration Goals	Percent Subwatershed Impervious Cover			
	10 to 25	25 to 40	40 to 60	60 to 100
Water Quality				
Reduce pollutants of concern	●	●	●	⦿
Prevent illegal discharges/spills	⦿	●	●	⦿
Meet water quality standards	●	⦿	○	×
Reduce sediment contamination	●	●	⦿	×
Allow water contact recreation	●	●	⦿	×
Protect drinking water supply	⦿	○	×	×
Biological				
Restore aquatic diversity	●	⦿	×	×
Restore wetlands/natural areas	●	⦿	⦿	×
Expand forest cover	●	●	●	⦿
Restore/reintroduce species	●	⦿	×	×
Improve fish passages	●	●	⦿	×
Enhance wildlife habitat	●	●	⦿	×
Remove invasive species	●	●	×	×
Keep shellfish beds open	⦿	×	×	×
Enhance riparian areas	●	●	⦿	○
Physical/Hydrological				
Increase groundwater recharge	●	⦿	⦿	×
Reduce channel erosion	●	⦿	×	×
Reclaim stream network	●	⦿	×	×
Reduce flood damage	●	●	⦿	○
Reconnect with floodplain	●	⦿	×	×
Restore physical habitat	●	○	×	×
Protect municipal infrastructure	●	●	⦿	⦿
Community				
Eliminate trash/debris	●	●	●	●
Create greenways/waterfront access/open space	●	●	●	⦿
Revitalize neighborhoods	●	●	●	●
Improve aesthetics/beautification	●	●	●	●
Increase citizen awareness	●	●	●	●
Improve recreation	●	●	●	●
Increase angling opportunities	●	●	⦿	×

● Goal can often be achieved in many subwatersheds
⦿ Goal can be achieved in some subwatersheds depending on degree of treatment
○ Goal can possibly be achieved in unusual circumstances
× Goal generally not achievable

Figure 26: General Ability to Meet Subwatershed Goals at Different Levels of Subwatershed IC

This planning chart indicates how subwatershed impervious cover influences the degree of potential treatment, and ultimately the ability to meet specific subwatershed goals. Actual treatment potential for any subwatershed should always be determined through desktop analyses and field assessments. The chart simply indicates that the some restoration goals or objectives cannot always be attained in the most intensely developed subwatersheds, due to inadequate levels of treatment.

Restoration Goals for Urban Drainage Subwatersheds

Given the intensity of development in urban drainage subwatersheds, it is hard to find enough feasible retrofit sites to meet most biological goals. Thus, the prospects for restoring aquatic diversity or stream habitat in urban drainage subwatersheds are extremely limited, although some individual reaches may show modest restoration potential. Some opportunities may exist to mitigate flooding problems, restore natural area remnants or create greenways to link remaining fragments of intact stream corridor. It is also possible to achieve incremental reductions in downstream pollutant export in urban drainage subwatersheds, although it may not be realistic to expect major water quality improvements within the "streams" themselves.

The next two chapters describe the methods used to discover the actual restoration potential for all three types of subwatersheds.

Chapter 5: Envisioning Restoration

The most important skill in urban watershed restoration is an ability to envision restoration opportunities within the stream corridor and upland areas. It takes a practiced eye to find these possibilities in a landscape dominated by the built environment. Still, many good restoration opportunities can be discovered. This brief chapter describes how and where to find restoration opportunities in your subwatershed.

Subwatersheds are a complex mosaic of both impervious and pervious cover. The best restoration opportunities are usually found in the remaining pervious areas. As much as three to 5% of subwatershed area may be needed to locate enough restoration practices to repair or improve stream conditions. Further, this land must be located in the right place and be controlled by willing landowners. Lastly, restoration sites are distributed across dozens and sometimes hundreds of small parcels within a subwatershed. While a quick glance at a city map might make this land requirement seem unattainable in most impacted and non-supporting subwatersheds, many excellent restoration opportunities can be discovered with a practiced eye, some imagination, and a lot of detailed map work.

The process of discovering these opportunities is called "envisioning restoration," and consists of two basic techniques: intensively analyzing maps and aerial photographs, and conducting a rapid reconnaissance of actual conditions in the subwatershed. Both techniques are as much a skill as a science, and certainly no computer model can do the same jobs. Detailed methods for systematically envisioning restoration are outlined in Manuals 2, 10, and 11. Table 7 summarizes the 11 places to envision restoration in any subwatershed, and the remainder of the chapter reviews key features to look for in the stream corridor and its subwatershed.

5.1 The Remnant Stream Corridor

The first place to explore is the remaining stream corridor (Figure 27). Normally, the stream corridor comprises about three to 5% of the total area of an undeveloped subwatershed, but it can be much smaller in highly urban subwatersheds due to encroachment. Indeed, the stream corridor can be eliminated in some ultra-urban subwatersheds. Still, the stream corridor is the first place to envision restoration.

Regrettably, the urban stream network is poorly portrayed on most maps, and many first and second order streams are not shown. Stream interruptions, crossings and channel alterations are not depicted, and the width and condition of the stream corridor are seldom delineated with any accuracy (indeed, it is usually shown on maps as undefined white space between buildings, streets and parking lots). Aerial photographs that show current vegetative condition are the best tool for defining the approximate boundaries of the stream corridor.

Table 7: Eleven Places to Envision Restoration in a Subwatershed
1. Remnant Stream Corridor
2. Existing Storm Water Infrastructure
3. Open Municipal Land
4. Natural Area Remnants
5. Road Crossings and Rights-of-way
6. Large Parking Lots
7. Storm Water Hotspots
8. Residential Neighborhoods
9. Large Parcels of Institutional Land
10. Sewer Network
11. Streets and Storm Drains

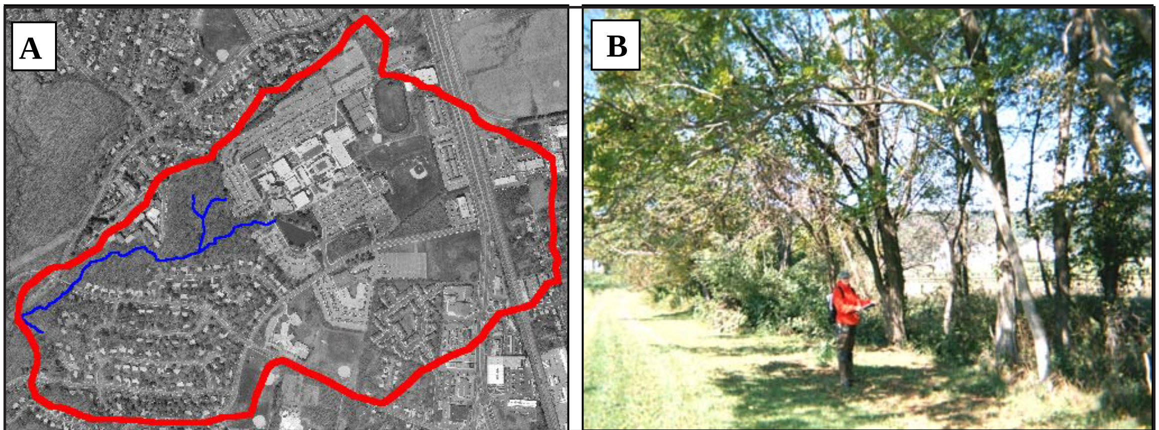


Figure 27: Envisioning Restoration in the Remnant Stream Corridor
Despite having 20% IC, this subwatershed has a relatively intact stream corridor (Panel A), where many potential sites where storm water retrofits, stream restoration and riparian reforestation projects can be investigated (Panel B).

While maps and photos are a starting point, the stream corridor can only be truly seen by walking the entire stream network. The Unified Stream Assessment (USA), described in Manual 10, has been developed as a tool to systematically evaluate the remaining stream area. The stream corridor is an important place to envision restoration because it is the transition zone between the upland storm drain network and the urban stream. Within this narrow zone, there is often enough available land to install restoration practices to repair or improve stream conditions. These include storage retrofits, riparian management and discharge prevention practices

5.2 Existing Storm Water Infrastructure

The next place to envision restoration in a subwatershed is the existing storm water infrastructure (Figure 28). Each subwatershed has a vast network of catch basins, storm drains, outfall pipes, detention ponds, flood ways and storm water practices that convey storm water. The existing storm water system is attractive for restoration for two reasons. First, as much as 3% of total subwatershed area may be devoted to the storm water system (although often at the expense of the existing stream corridor). Second, since land is already devoted to storm water management, it is much easier to get approval from owners to retrofit it.

The restoration potential of a storm water infrastructure depends largely on its age. Storm water systems constructed prior to 1970 are mostly underground, with limited surface land devoted to flood control projects. Systems from 1970 to 1990 were often built with storm water detention ponds designed to control peak flood discharges. Detention ponds, which are often quite large, greatly add to the surface land available for potential restoration, and are always a favorite target for storage retrofits. Systems designed over the last decade reflect the growing trend toward the treatment of storm water quality, and may contain dozens of storm water treatment practices of all different sizes and types. The surface land area devoted to storm water practices can consume as much as three to 5% of subwatershed area, depending on local storm water criteria. These newer practices are a particularly attractive retrofitting target.

A good map of the urban storm water pipe system is extremely helpful, if available. Several locations on these maps deserve close scrutiny: outfalls where storm water pipes discharge, open land adjacent to these outfalls, and any surface land devoted to storm water detention and/or treatment. These locations are

Figure 28: Envisioning Restoration Within Existing Storm Water Infrastructure
Older storm water detention ponds are a favorite target for conversion to storage retrofits practices (Panel A). Another good location to investigate potential storage retrofits is the point where storm water pipes outfall in the stream corridor (Panel B).

prime candidates for storage retrofits and stream daylighting practices. Storm water outfalls are also the starting point to look for illicit discharges that may be flowing through the storm drain system.

In reality, the storm water pipe network is poorly mapped in most communities, and often reflects a confusing blend of pipes and structures built in many different eras. So once again, field reconnaissance is necessary to see how it actually works. In practice, the many routes that storm water travels to get to the stream corridor must be traced by working up from each storm drain outfall.

5.3 Open Municipal Land

The next place to envision restoration is in large parcels of open municipal land, such as parks, public golf courses, schools, rights-of-way or protected open space (Figure 29). Municipal lands are attractive areas for restoration because of their large size and ownership. While municipal lands are managed for different purposes, portions of each parcel may be good candidates to creatively locate all seven restoration practices. In addition, open lands are easy to distinguish on either aerial photographs or tax maps, and are easy to confirm in the field.

5.4 Natural Area Remnants

The next place to envision restoration is in the larger natural area remnants in the subwatershed (Figure 30). Forest and wetland fragments are frequently located near the stream corridor, and the larger contiguous parcels are hard to miss when looking at an aerial photograph or resource inventory map. Larger remnants and their adjacent margins always deserve close scrutiny in the field. A two-acre size threshold is often used to select parcels for field analysis. Natural area remnants are not a preferred location for intrusive restoration practices (such as a large storage retrofit), but may be good targets for forest or wetland restoration. In addition, the possibility of expanding natural areas or linking them to the stream corridor or other remnants should always be considered.

5.5 Road Crossings and Highway Rights-of-Way

Road crossings and rights-of-way are always worth exploring for restoration opportunities (Figure 31). Stream crossings are quite easy to spot on aerial photos or regular maps. Two specific areas of the map should be located: the points where roads cross the stream corridor, and large rights-of-way, such as cloverleaf interchanges and highway access ramps.

Each road crossing presents both a problem and an opportunity. Bridges and culverts that cross the corridor are always suspected barriers to fish migration, but they may also unintentionally act as a useful grade control in a rapidly incising stream. Also, road designers like to maintain grade when crossing streams, so they often build earthen embankments across the flood plain to approach the bridge and culvert. In very small streams, these crossings can be modified to provide temporary storage and treatment of storm water upstream of the crossing. Lastly, road crossings often provide the best access to the stream corridor for stream assessments, cleanups and construction equipment.

Larger highways often have fairly large parcels of unused land near interchanges in the form of cloverleafs and approach ramps. These parcels can be an ideal location both for storage retrofits and reforestation, because they receive polluted runoff from the highway and generally serve no other purpose.

5.6 Large Parking Lots

Large parking lots really stand out in an aerial photograph or land use map (Figure 32) and are of great interest for several reasons. First, they produce more storm water runoff and pollution on a unit area basis than any other land use in a subwatershed. As such, they are obvious targets for on-site or storage retrofits. Second, large parking lots generally signal the presence of large clusters of commercial, industrial or institutional lands often associated with storm water hotspots. While these areas can be easily identified from a desktop, it is usually necessary to visit each one to determine its actual potential for retrofitting or source control. In particular, it is important to assess how storm water is currently handled in the parking lot, and look for unused land adjacent to the lot that may be suitable for a retrofit.

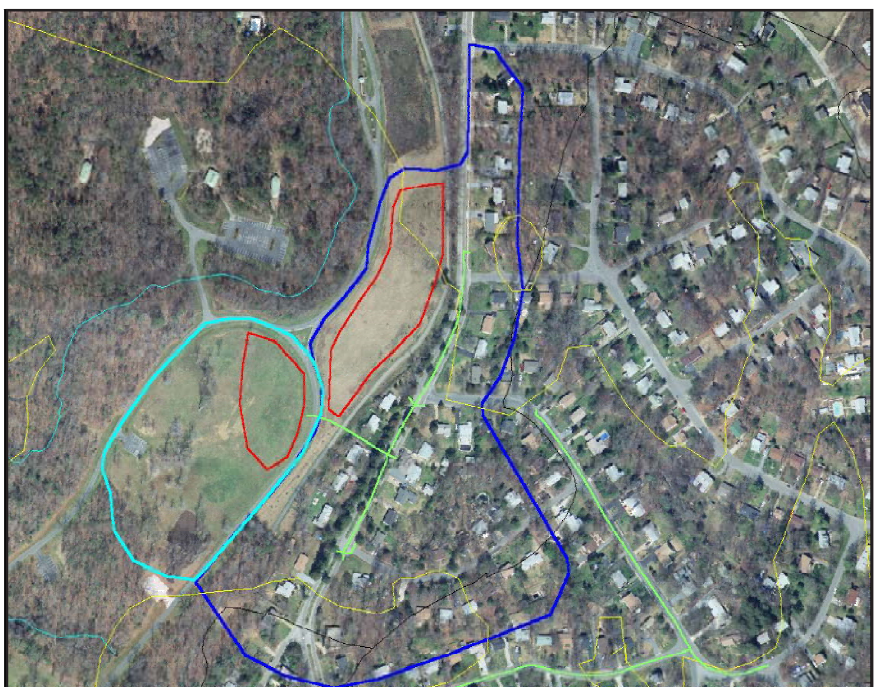


Figure 29: Envisioning Restoration on Open Municipal Lands
Portions of open municipal land are often good candidates for locating restoration practices, particularly along the property margins. Parks, schools and ballfields (shown in photo) are always worth evaluating in any subwatershed.

Figure 30: Envisioning Restoration in Natural Area Remnants
Many natural areas still remain even in highly urban subwatersheds (Panel A), although these fragments are often highly stressed, and may require active restoration or intensive management to improve their subwatershed value (Panel B).

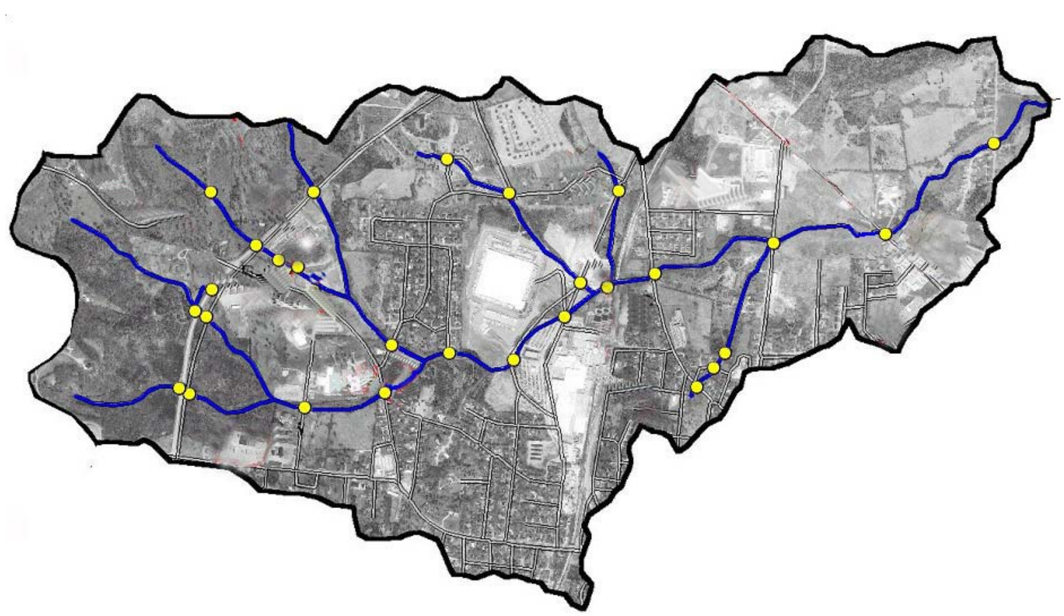


Figure 31: Envisioning Restoration at Road Crossings and Rights-of-Way
Road crossings are always of particular interest in a subwatershed. This photo shows the 28 roads crossing in this small subwatershed. Each crossing can be a potential fish barrier, storage retrofit site, stream grade control, or access point to the stream corridor.

5.7 Storm Water Hotspots

The next place to envision restoration is in the many storm water hotspots in a subwatershed. Storm water hotspots are the commercial, industrial, institutional, municipal, and transport-related land uses that tend to produce higher levels of storm water pollution, or present a higher risk for spills, leaks and illicit discharges (Figure 33). The number, type and distribution of storm water hotspots vary enormously between subwatersheds. Hotspots are exceedingly hard to find, and many are quite small and out of the way. Maps and aerial photos are of little value in finding them; instead, they can be found by searching databases that contain standard business codes or permits, or by driving the entire subwatershed looking for them, or both. The USSR, described in Manual 11, was designed to find these elusive hotspots and target appropriate pollution prevention practices.

5.8 Residential Neighborhoods

Residential neighborhoods are the next place to envision restoration. They are easy to see on a map, but must be visited to be truly understood (Figure 34). Each residential neighborhood has a distinctive character in terms of age, lot size, tree cover, lawn size, and general upkeep. In addition, neighborhoods tend to be rather homogenous when it comes to resident behavior, awareness and participation in restoration efforts. Each unique neighborhood characteristic directly affects the ability to widely implement residential restoration practices, such as on-site retrofits and residential stewardship practices. In general, it is not easy to discern neighborhood characteristics from a map or even an aerial photograph. Instead, the Neighborhood Source Assessment (NSA) component of the USSR can be used to collect quantitative data on neighborhood characteristics to determine their restoration potential.

5.9 Large Institutional Land Owners

Large institutional land owners have the last remaining land worth prospecting for restoration potential in a subwatershed (Figure 35). Examples include hospitals, colleges, corporate parks, private golf courses, cemeteries and private schools. Inspection of aerial photos may reveal that institutions have underutilized areas on their grounds with restoration potential. These sites can be problematic, since it may be hard to expend local funds to improve private lands. Also, some landowners may be reluctant to bear the cost and maintenance burden associated with restoration projects. However, other

Figure 32: Envisioning Restoration in Large Parking Lots
Large parking lots produce the highest unit area storm water runoff and pollutant loadings of any subwatershed land use, and stand out in most aerial photographs (Panel A). Each large parcel should always be investigated to see if storage or on-site retrofit practices can mitigate their impact on the stream (Panel B).

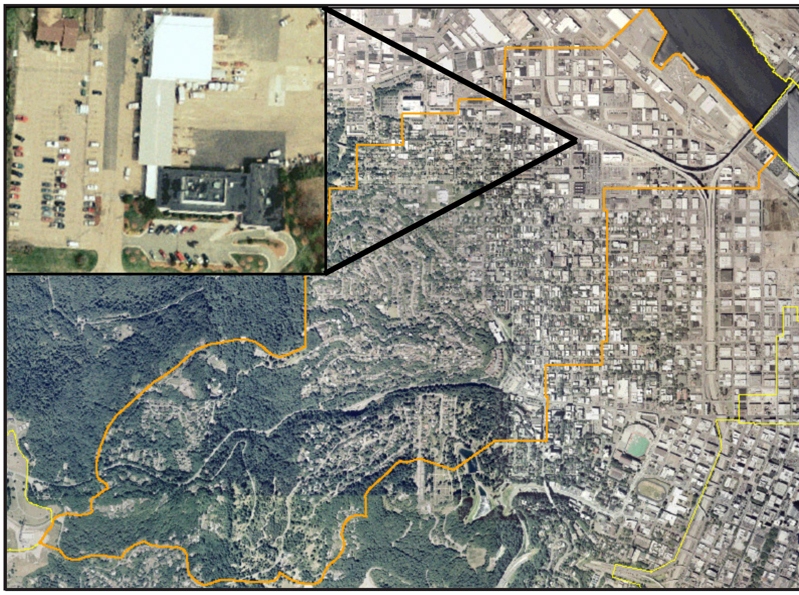


Figure 33: Envisioning Restoration for Storm Water Hotspots
Storm water hotspots are very hard to find, given their small size and uneven distribution in most urban subwatersheds. Field investigations are almost always needed to confirm locations of severe hotspots, although analysis of business or permit databases can be used to narrow the search.

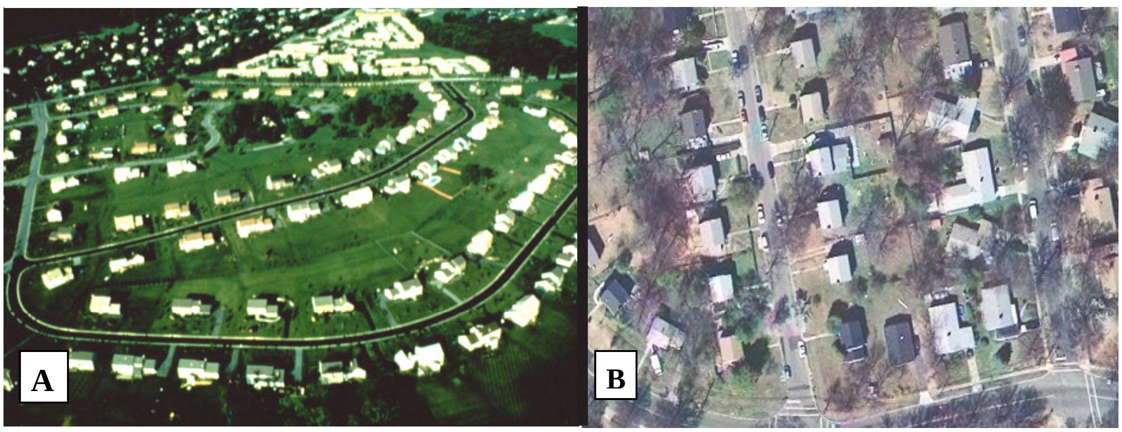


Figure 34: Envisioning Restoration in Residential Neighborhoods
Each residential neighborhood has its own distinctive character, based on its age, lot size, vegetative cover and housekeeping. These characteristics greatly influence opportunities for residential source control, which is evident when a large lot suburban neighborhood (Panel A) is compared to small lot urban neighborhood (Panel B).

Figure 35: Envisioning Restoration on Large Parcels of Institutional Land
Institutions such as this college campus, may have unused land on their property that may be suitable for locating subwatershed restoration practices.

institutional landowners are actively involved in the community and may be willing to partner in restoration efforts.

5.10 The Sewer System

The sewer system is always an important place to envision restoration potential, although it is intrinsically difficult to see since most of it is located underground (Figure 36). Most communities have good maps of their sewer pipe networks, although older portions may be much less reliable. The key factor to determine is whether the sewer system is a source of sewage discharges to the stream corridor that it often parallels. The severity of sewage discharge depends on the age, condition, and capacity of the sewer network. In addition, urban watersheds are not always fully sewered; some are partly served by existing or relict septic systems, which can be a source of pollution.

5.11 Streets and Storm Drain Inlets

The last area to envision restoration potential includes the street surfaces and storm drain inlets of a subwatershed (Figure 37). Pollutants tend to accumulate on street surfaces and curbs, and may be temporarily trapped within storm drain catch basins and sumps. These storage areas often represent the last chance to remove pollutants and trash before they wash into the stream. Municipal maintenance practices, such as street sweeping, catch basin clean-outs and storm drain stenciling, can potentially remove some fraction of these pollutants, under the right conditions. These municipal practices are particularly well-suited for highly urban subwatersheds that have many streets, but few other feasible restoration options.

While good street maps are almost always available, accurate maps of storm drain inlet locations can be much harder to find. The Streets and Storm Drains (SSD) component of the USSR helps to qualitatively assess the degree of actual pollutant accumulation within streets, curbs and catch basins in the subwatershed. The SSD also looks at feasibility factors, such as parking, traffic, access and pavement condition, that will determine if street sweeping or catch basin clean-outs will be effective or practical in a particular subwatershed.

5.12 Summary

This chapter described how and where to search for restoration potential in urban subwatersheds. Each subwatershed has a different combination of opportunities and thus different restoration potential. The next chapter describes a framework for translating these possibilities into a realistic subwatershed plan.

Figure 36: Envisioning Restoration in the Sewer System
While the sewer system is mostly underground (Panel A), manholes (Panel B) and sewer crossings near the stream corridor (Panel C) should always be investigated to check for potential sewage leaks and discharges.

Figure 37: Envisioning Restoration on Streets and Storm Drain Inlets
Pollutants and trash can accumulate on street surfaces and curbs (Panel A) or within storm drain catch basins and sumps (Panel B). Street sweeping and catch basin cleanouts may be the last chance to remove these pollutants in highly urban subwatersheds with few other restoration options.

Chapter 6: A Framework for Small Watershed Restoration

This chapter outlines a framework to guide you through actions needed to develop, adopt, implement and track a small watershed restoration plan. Developed over the last decade, this general framework applies to urban subwatersheds, but can also be applied at the watershed level. The framework is particularly useful for organizing the many different tasks needed to produce effective watershed restoration plans, regardless of whether the plan is prepared by a municipality, watershed group, private consultant, or a combination of all three.

The eight steps of the framework are shown in Figure 38. As many as four different tasks are needed to complete each step, including a desktop analysis, field assessment, stakeholder involvement and management product (Figure 39).

Desktop analysis tasks help organize, map and interpret subwatershed information to make better restoration decisions. Rapid *field assessment* occurs in both the stream corridor and subwatershed, and is used to identify restoration opportunities, design and rank individual restoration projects, and measure improvements in stream health. *Stakeholder involvement* helps identify stakeholders and structure their involvement in the restoration planning process. Lastly, *management products* document key decisions made during each step of restoration plan development.

This chapter provides a condensed overview of the planning framework; Manual 2 provides much greater detail on the specific methods used in each step. You should regard the framework as a starting point to structure your efforts, and adapt it to fit your unique goals, budget constraints and partners. For example, if you have already decided which subwatershed(s) to restore, you should skip steps 1 and 2. Also, while our approach outlines the simplest, fastest and least expensive way to perform each task, you may choose more sophisticated methods in order to justify the community investment in watershed restoration.

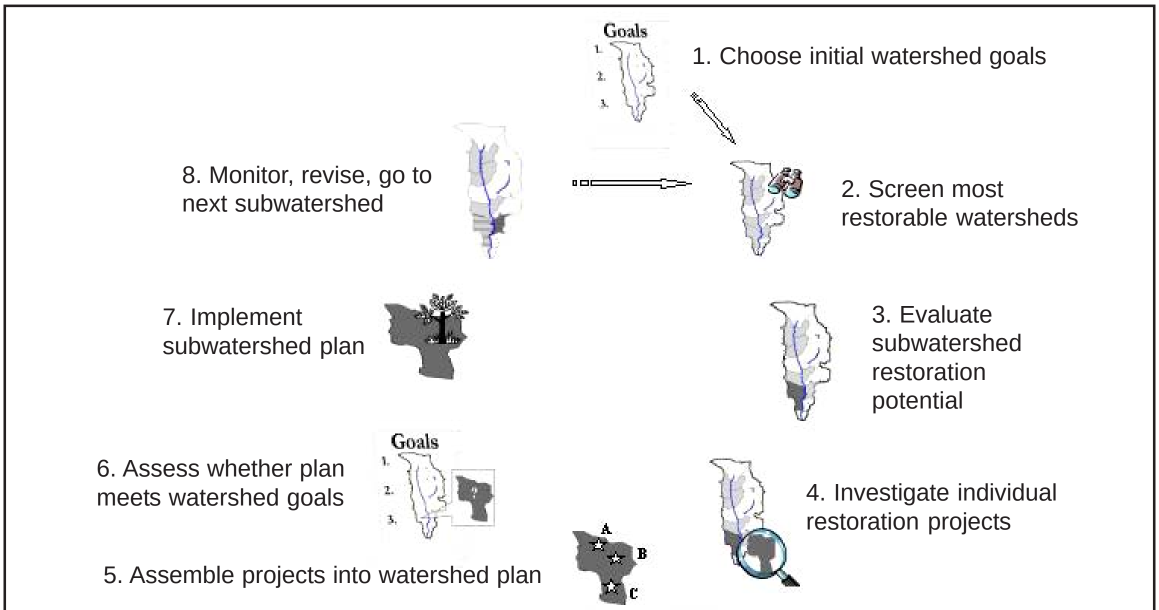


Figure 38: Overview of the Eight-Step Framework to Restore Urban Watersheds

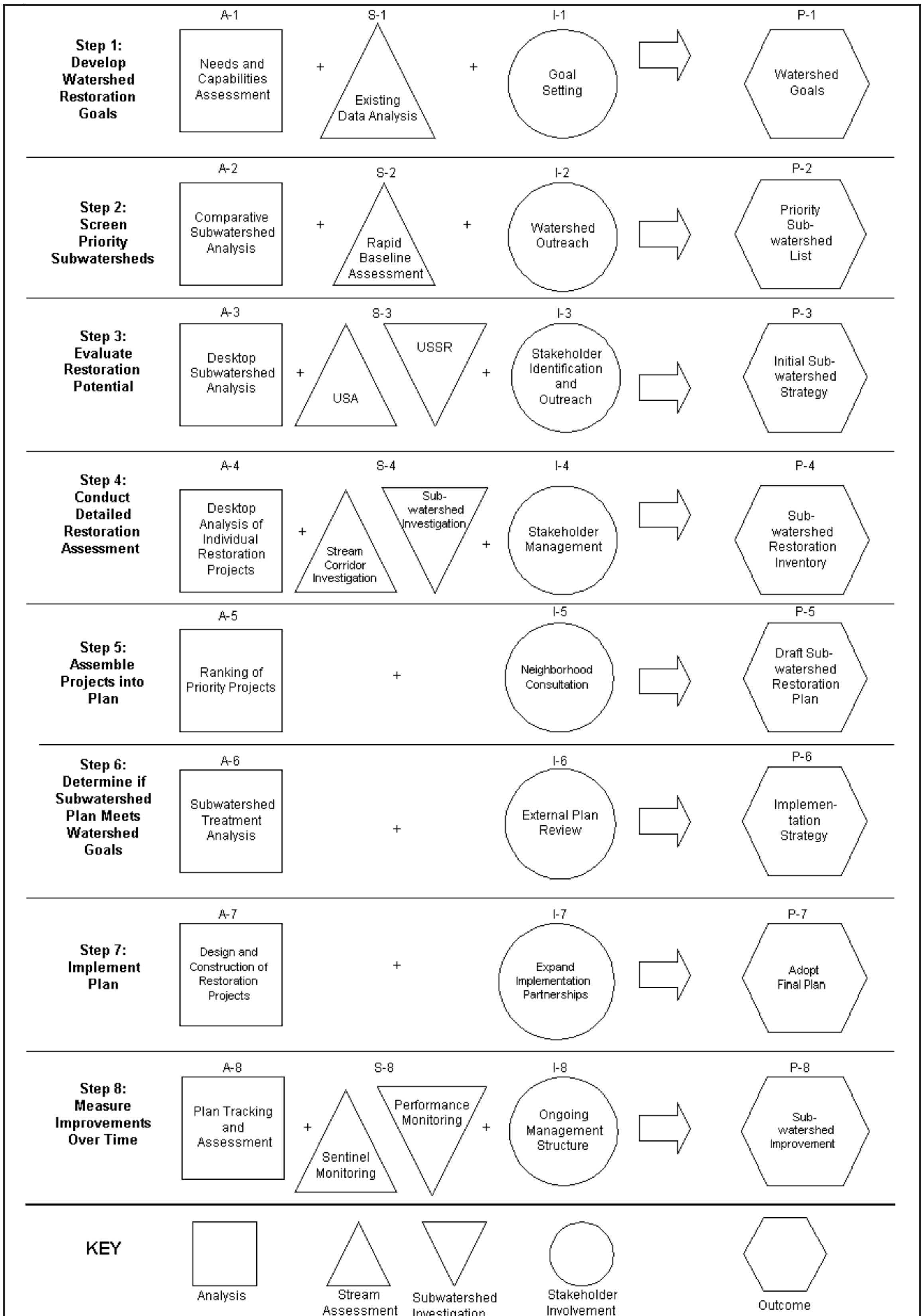
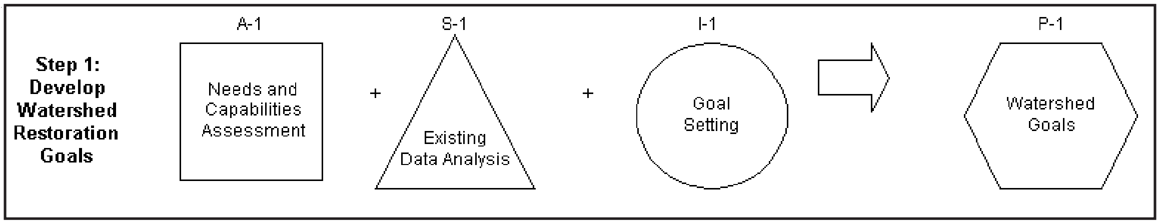


Figure 39: Detailed Steps and Tasks Involved in the Restoration Planning Process

Each step in the planning process usually has its own associated desktop analysis, field assessment, stakeholder involvement, or management product.



Step 1: Develop Watershed Restoration Goals

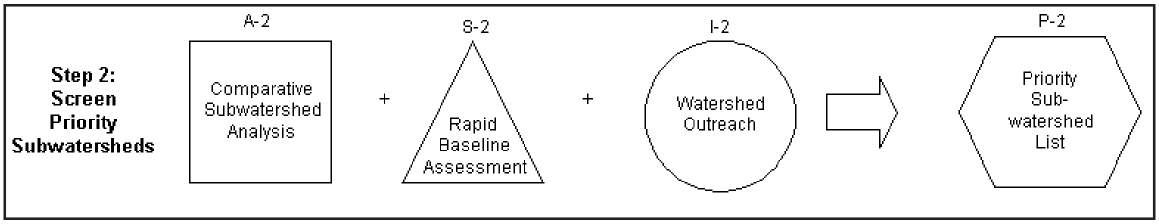
It is surprising how many watershed restoration efforts have started with neither clear agreement on the specific goals and objectives they are expected to accomplish, nor a thorough understanding of available planning resources. Therefore, this issue should be addressed as early as possible to set clear expectations for watershed restoration.

A-1 Needs and Capabilities Assessment (NCA) This desktop analysis helps evaluate the factors driving local restoration and find available resources to make it happen. A needs and capabilities assessment (NCA) examines two areas. The first part comprehensively analyzes federal and state “regulatory drivers” that influence watershed restoration, including the alphabet soup of TMDLs, MS4 NPDES Permits, CSO, SSO, SWDA, ESA, FEMA, among others. The second part analyzes existing municipal capabilities and resources for watershed restoration. This usually entails an agency-by-agency review of existing staff, programs, funding and mapping resources that can potentially be applied to watershed restoration. Both assessments are best conducted on a watershed-wide or municipal scale, in cooperation with regional stakeholders.

S-1 Existing Data Analysis This task answers the question: “What is already known about the watershed?” In many cases, a wealth of watershed monitoring and mapping data has been produced over the years, which can help define critical water resource problems. Consequently, this task involves an extensive analysis of historical water quality and biological monitoring data within the watershed, as well as a search for any available mapping and GIS resources. While good watershed information usually exists, the challenge is to locate it and critically evaluate its quality. The data analysis usually requires an intensive search of academic institutions, federal databases, regional GIS centers, state and local agencies, and non-governmental organizations. If sound data is not available, then additional monitoring or research may be needed to establish goals. The end product is a baseline assessment that describes water quality and habitat problems across the watershed or municipality.

I-1 Achieving Consensus on Goals Goal-setting requires extensive stakeholder input to identify important community interests and issues that will drive the watershed restoration effort. Under this task, forums are created to find out what the public thinks about urban watersheds and what issues they want incorporated in the restoration plan. Recurring issues include recreation, greenways, flooding, waterfront and neighborhood revitalization, enforcement, and cleanups, in addition to water quality and habitat. By listening to all four groups of stakeholders, it is possible to gain broad agreement on the overall goals that will drive local watershed restoration efforts.

P-1 Watershed Goals and Objectives The management product of this task is the definition of clear, measurable goals that command broad public support to guide the watershed restoration process. Assuming that consensus on these goals can be reached, it is helpful to produce a watershed agreement, a memorandum of understanding or similar directive that establishes interim goals for watershed restoration that can be executed by elected officials, key stakeholders and/or senior agency leaders. These agreements can raise the profile of watershed restoration and ensure greater inter-agency coordination later in the process.



Step 2: Screen for Priority Subwatersheds

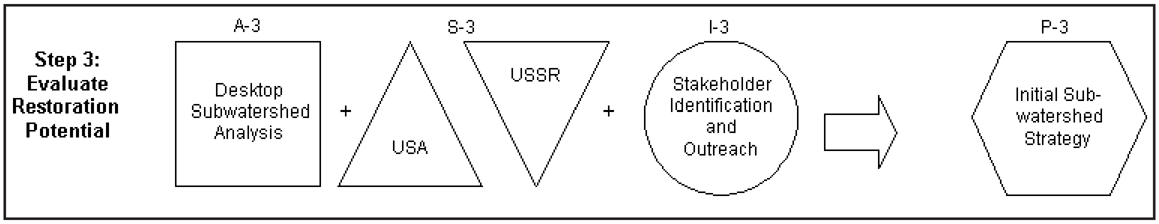
The second step of the framework selects priority subwatersheds within the watershed that show the most promise for effective restoration. This step can be skipped if the subwatershed(s) have already been selected.

A-2 Comparative Subwatershed Analysis It is relatively easy to quickly screen the most promising subwatersheds from a desktop, assuming that basic GIS layers are available. The first step is to subdivide the watershed to delineate subwatersheds that are typically about one to five square miles in area. In the second step, important stream corridor and subwatershed metrics are derived from GIS data to "discriminate" among subwatersheds. At the stream corridor level, key metrics include channel density, stream corridor area, and stream assessment data. For upland areas, key variables include the subwatershed impervious cover, public land, detached residential housing, industrial lands, natural area remnants, and the presence or absence of storm water practices. Each of these factors can be weighted and analyzed in a simple spreadsheet model to rank the comparative restoration potential for each subwatershed.

S-2 Rapid Baseline Assessment Some communities may want to collect more monitoring data to characterize water quality, habitat or biological conditions across its subwatersheds, although this can be both expensive and time-consuming. The basic approach is to establish a network of fixed stations where stream parameters are rapidly measured to indicate current aquatic health within all subwatersheds. These subwatershed "indicators" can be used to track how a stream may respond to future subwatershed restoration efforts. Examples include the Rapid Stream Assessment Technique (RSAT), Rapid Bioassessment Protocol (RBP), dry or wet weather water quality sampling, and fish shocking. The basic objective of a baseline assessment is to get data within a few months that can be incorporated into the comparative subwatershed analysis.

I-2 Watershed Outreach Once again, it is important to involve key stakeholders in the process of choosing priority subwatersheds, since strong public support is often instrumental in successful restoration (particularly when organized community or watershed groups exist). Effective watershed outreach efforts at this stage include workshops, community meetings, field trips, and watershed maps. Efforts should be made to condense watershed issues into an accessible and understandable format. Watershed outreach efforts can increase public understanding about local watershed problems, set realistic expectations and may even recruit new stakeholders to the cause. Stakeholders can also play a role in devising the weighting factors for subwatershed ranking to maximize overall support.

P-2 Subwatershed Priority List The management product associated with this step is simple: a decision on which subwatersheds to work on first. It is often helpful to produce a technical memo documenting the ranking system used to derive the priority subwatershed list to justify why restoration efforts are being deferred in other subwatersheds.



Step 3: Evaluate Restoration Potential

The third step is a systematic assessment of potential restoration opportunities within the stream corridor and subwatershed, and involves five important tasks.

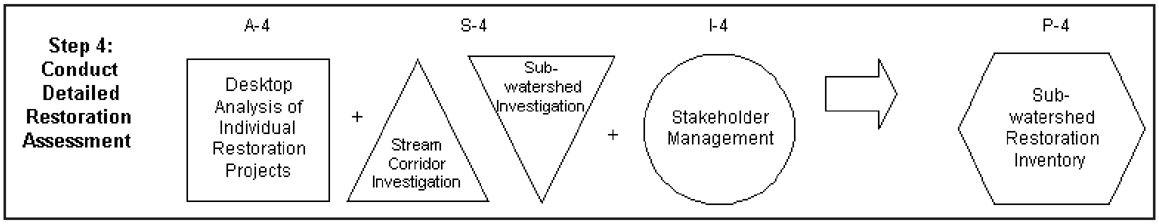
A-3 Desktop Subwatershed Assessment It is important to compile basic subwatershed information and generate base maps for stream corridor and subwatershed assessments prior to going out in the field. This first phase of desktop analysis characterizes current subwatershed characteristics, plans routes and establishes stream survey reaches. Extra time spent in the office can save a lot of time out in the field. The second phase of desktop analysis occurs after the field assessments and stakeholder involvement tasks are completed. This phase assembles, implements and analyzes subwatershed data to devise an initial restoration strategy.

S-3a Unified Stream Assessment (USA) The USA is a rapid assessment of all surface drainage in a subwatershed to identify problems and restoration opportunities within the stream corridor. The USA evaluates eight stream impacts or conditions, including storm water outfalls, severe erosion, impacted buffers, utility crossings, trash and debris, stream crossings, channel modifications, and miscellaneous features. The running survey relies on GPS mapping, digital photos and reach analysis to identify potential sites for individual retrofit, stream restoration, discharge prevention or riparian management projects. The data compiled from USA surveys is then analyzed to evaluate the restoration potential of the stream corridor (see Manual 10).

S-3b Unified Subwatershed and Site Reconnaissance (USSR) The USSR is a companion survey that explores pollution sources and restoration opportunities in the upland areas of a subwatershed. During a USSR survey, a team drives all roads in the subwatershed, evaluates neighborhood conditions, and assesses all open spaces larger than two acres. The USSR profiles current practices in residential neighborhoods, the condition of streets and storm drains, and the potential for on-site retrofits. It is also used to confirm the location and severity of storm water hotspots. Finally, the USSR creates an inventory of upland sites for potential reforestation or natural area restoration. Data collected from the USSR is then analyzed to evaluate strategies such as improved retrofits, source control, pervious area management and municipal practice in the subwatershed.

I-3 Stakeholder Identification and Outreach In this task, all of the potential stakeholders that live or work in the subwatershed are identified, a group that may include individuals from civic groups, churches, neighborhood associations, schools, institutional landowners, businesses, and other organizations. These individuals should be actively recruited to participate in future stakeholder meetings. Some stakeholders can be identified during the USSR, but additional networking is usually needed to get the right people to the table.

P-3 Initial Subwatershed Restoration Strategy This step produces a great deal of initial data on restoration options and opportunities in the subwatershed. The management product for this step is a quick analysis of subwatershed data to devise an initial restoration strategy. This initial strategy is often accompanied by a scope of work outlining detailed restoration investigations to pursue in subsequent steps.



Step 4: Conduct Detailed Restoration Assessment

The fourth step of the framework involves assessing the feasibility of individual restoration projects in the subwatershed or stream corridor.

A-4 Desktop Analysis of Projects This desktop task develops detailed concept designs for individual restoration projects identified during the initial subwatershed restoration strategy. Project data from detailed site investigations is then used to work up concept designs for the most feasible and effective restoration projects in the subwatershed. Some upland restoration practices, such as source control and municipal practices, are developed and refined at the desktop level. Each candidate project is then evaluated with regard to feasibility, design constraints, estimated cost and potential restoration benefits. Planning and design information for individual restoration projects are then organized into spreadsheets and/or GIS for subsequent analysis in the next step.

S-4a Stream Corridor Project Investigations This task gathers the field and/or engineering data needed to develop workable concept designs for individual restoration projects in the stream corridor. Depending on the initial restoration strategy, this may entail one or more of the following:

· Retrofit Reconnaissance Inventory
· Stream Restoration Investigation
· Riparian Management Investigation
· Discharge Prevention Investigation

The goal of each investigation is to acquire enough data to develop a basic concept design for each restoration project.

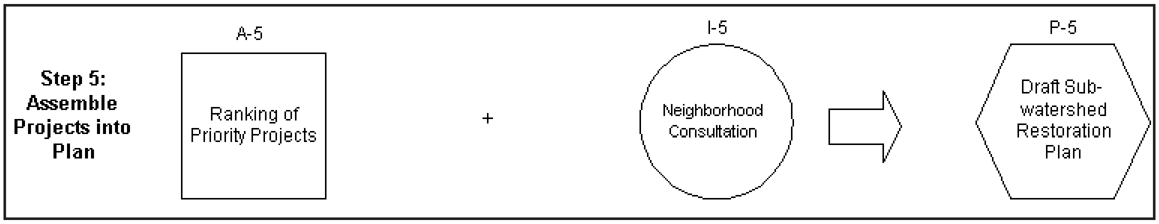
S-4b Upland Project Investigations This task involves a series of detailed site assessments to develop workable plans or programs to control upland pollutant sources and/or restore pervious areas in the subwatershed. Depending on the initial restoration strategy, this may entail one or more of the following investigations:

· Hotspot Compliance Inspections
· Natural Area Remnant Studies
· Pervious Area Management Inventory

These rapid investigations are used to either develop a basic concept design for each project or determine effective program delivery.

I-4 Managing Stakeholder Input The first community stakeholder meeting should report on the early results of subwatershed analyses and get initial feedback from the “nighttime” stakeholders that live and work in the subwatershed. While evening meetings are a common way of soliciting involvement, other methods such as Saturday subwatershed tours, websites, mailings, or stream walks can also be used to solicit involvement. All of these involvement methods can help elicit the issues and concerns stakeholders want to incorporate into the subwatershed plan.

P-4 Subwatershed Restoration Inventory The management product associated with this step is an inventory of feasible restoration projects for the subwatershed that addresses restoration goals and objectives set at the watershed level.



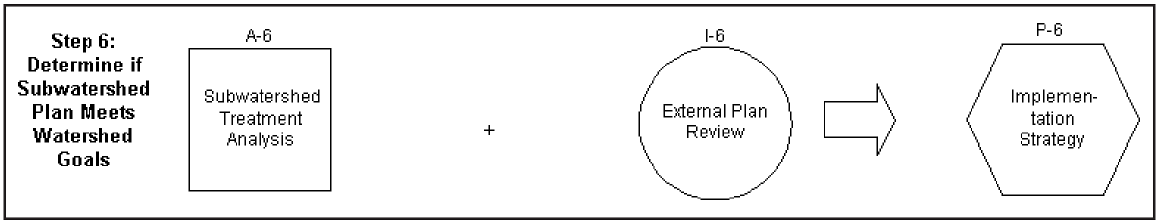
Step 5: Assemble Projects into Plan

The fifth step transforms the restoration inventory into a draft subwatershed plan that recommends the most cost-effective combination of restoration projects and programs to meet subwatershed goals. Key tasks of this step include project ranking, neighborhood consultation and plan writing.

A-5 Project Evaluation and Ranking This task involves a detailed evaluation and ranking of the whole range of projects and programs in the restoration inventory. Each project or group of projects is ranked according to subwatershed area treated, cost, feasibility, environmental benefits, public acceptance and other key implementation factors. The exact ranking factors and their corresponding weights are unique to each subwatershed and should reflect overall restoration goals and stakeholder input. The ranking is typically done through spreadsheet analysis, and the results are used to select the package of projects to recommend for final design. In some cases, additional field survey or subwatershed data may be needed to support project evaluation.

I-5 Neighborhood Consultation Storm water retrofits and other restoration products can significantly alter a local landscape that has been around for years. Residents often have legitimate concerns about access, safety, mosquitoes, weeds, vermin, tree loss and other issues related to a particular restoration project. Consequently, it is wise to get input from adjacent stakeholders and respond to their concerns early in the design process. Forums and field trips to notify adjacent residents about proposed projects are always a good investment.

P-5 Draft Subwatershed Restoration Plan The management outcome of this task is a concise subwatershed plan with specific recommendations for implementing restoration projects and programs, along with a subwatershed management map. A good subwatershed plan need not be long or complex. Instead, it should be written with the punch of a newspaper article, and clearly specify the “what,” “why,” “when,” “where,” and “how much” of the recommended combination of restoration projects.



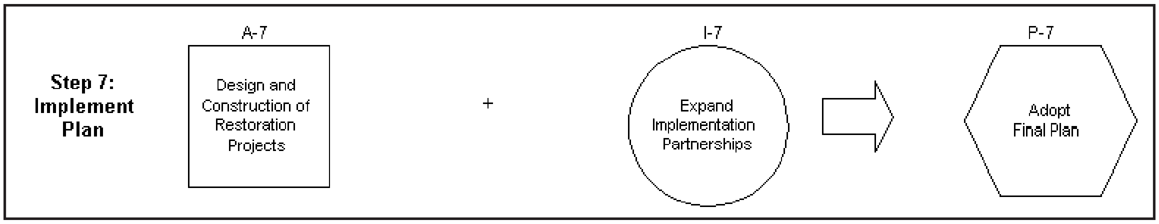
Step 6: Determine Whether Subwatershed Plan Meets Watershed Goals

This is perhaps the most frequently overlooked step in watershed restoration: determining whether or not the subwatershed plan can meet watershed goals. In some cases, models and predictive tools to make this determination may not exist. In these cases, plan success can only be measured by future monitoring in the subwatershed, and the subwatershed restoration plan becomes its own experiment. In other cases, however, predictive models can be used to determine whether the plan will meet restoration goals. Some communities may elect to pursue this step concurrently with the development of the draft subwatershed plan.

A-6 Subwatershed Treatment Analysis If watershed restoration goals are oriented toward hydrology or water quality, there are several good desktop models for estimating the plan's watershed treatment and associated pollutant reduction. Manual 2 describes how to apply the Watershed Treatment Model (WTM) to quantify the pollutant reduction achieved by the subwatershed restoration plan, and provides references for other subwatershed assessment tools. Fewer predictive models exist to evaluate restoration goals geared to improving habitat or aquatic biodiversity.

I-6 External Plan Review An important element of plan evaluation is review and input from the subwatershed stakeholders, who help ensure the plan meets the unique needs of both the subwatershed and the community. Generally, review of the draft plan involves at least one additional stakeholder meeting.

P-6 Implementation Strategy It is extremely useful during this step to begin thinking about what it will take to get the plan adopted and how it might be funded over time. Since watershed plans compete against many other municipal expenditures, it is helpful to develop an implementation strategy for navigating the plan through the political and bureaucratic system. Two management tasks are associated with this step. The first is to make a persuasive case that the subwatershed plan is worth the community investment, and the second is to create an organized campaign for presenting that case to the influential members of the community. This campaign should target elected officials, regulators, local media, state and federal funders, and the activist public.



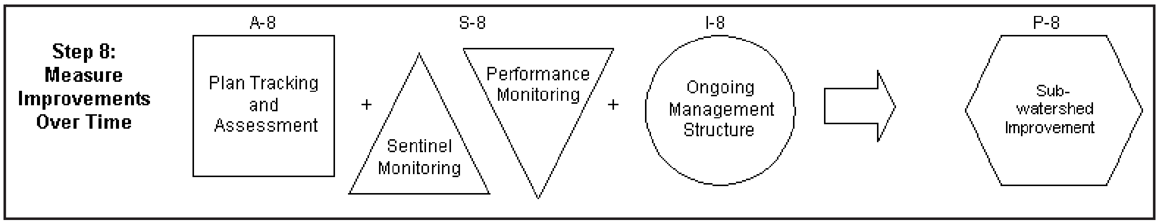
Step 7: Implement Plan

This step deals with the many complex tasks involved in the final design, public review and adoption of the plan.

A-7 Design of Restoration Projects Much of the time and expense in the subwatershed planning process is expended for the final design, engineering and permitting of individual restoration projects. Since many different projects and programs will be implemented in the subwatershed plan, you will need to anticipate how to "deliver" restoration projects (i.e., how to sequence design, construction, inspection, maintenance and monitoring within budget constraints). Particular emphasis should be placed on getting the most accurate project cost estimates possible, so that the total cost of the plan can be established and phased over time. [*Note: In some cases, additional field or subwatershed data may be needed to support final design, such as geotechnical surveys. In other cases, a community may wish to adopt the final subwatershed plan before commencing with final design of restoration projects (A-7).*]

I-7 Expanding Implementation Partnerships While it may seem redundant to have another round of stakeholder involvement, it is important to get formal support and endorsement of the final plan. The goal is to transform stakeholders into partners, and create a broad community coalition to attract the political support needed to get reliable funding for plan implementation.

P-7 Adopt Final Plan There is no universal method for final plan adoption, given that the political process, partnership structure, and budgetary system are unique in every community. The basic management product in this step is to work through the existing process to adopt the plan, and define a short- and long-term funding strategy to implement it. It is important to keep in mind that many communities cannot obligate operating funds beyond the current budget year (although they may be able to sequence capital projects over a longer time frame).



Step 8: Measure Improvements Over Time

Urban restoration is such a new field that each restoration plan is basically its own experiment. As a result, it is important to institute tracking and monitoring systems to measure improvements in subwatershed indicators over time. These systems can include internally tracking the delivery of restoration projects in a subwatershed, as well as monitoring stream indicators at sentinel monitoring stations. Performance monitoring of individual restoration projects can be tracked to improve the design of future restoration practices. Information gathered from each of these tracking systems is used to revise or improve the restoration plan over a five- to seven-year cycle.

A-8 Tracking and Plan Implementation Few people fully comprehend the complexity of delivering a large group of restoration projects within a small subwatershed. It is a good idea to use a spreadsheet or GIS system to track project implementation data such as project construction, inspection, maintenance and performance. Project tracking data chronicles progress made in subwatershed implementation, and can isolate management problems to improve the delivery of future restoration projects.

S-8A Sentinel Monitoring Stations In this task, fixed, long-term sentinel stations are established to measure trends in selected aquatic indicators over many years (preferably at the same locations monitored during the initial baseline assessment). Sentinel monitoring is perhaps the best way to determine how streams are actually responding to subwatershed restoration. Few communities have the resources to continuously maintain a long-term monitoring program, but the existence of sentinel stations ensures that the right indicators are measured at the same places when money is available for monitoring.

S-8B Project Monitoring Restoration practices are often experimental, and it is important to measure whether restoration projects are really working as they were designed to. As a result, communities may want to invest in performance monitoring of individual restoration projects to improve future designs. Such monitoring can be relatively simple (observing the success of a reforestation project) or extremely complex and expensive (measuring the pollutant reduction of a storm water retrofit or the biological response to a comprehensive stream restoration project).

I-8 Ongoing Management Structure Full implementation of subwatershed restoration plans usually takes a minimum of three years, and often as many as 10. Therefore, it is critical to find a way to sustain momentum for subwatershed restoration over such an extended period. The preferred method is to create a small watershed organization or interagency committee to advocate for the plan and handle ongoing education, outreach and public involvement tasks. Ideally, such a group should be created much earlier in the process (or may have already existed). The key point is that the watershed advocacy function must be sustained and supported throughout the implementation stage, and often well beyond.

P-8 Subwatershed Improvement The management outcome of this step is fairly simple: a measurable improvement in the indicators used to define subwatershed quality. If expected improvements have not occurred, a re-assessment of either the subwatershed restoration plan or expectations for meeting watershed goals may be required.

Summary

This chapter presents an ideal framework to guide and organize the small watershed restoration planning process. In reality, every community will end up with its own peculiar planning process reflective of its diverse watersheds, unique goals, funding sources, partners and prior experience. The key point is that each community should develop a clear and understandable process to translate plans into action. The next manual, *Methods to Develop Restoration Plans for Small Urban Watersheds*, presents different options to help create an effective planning process.

Appendix A: Derivation of Predictions for the Impervious Cover Model

The third chapter of this manual presents quantitative predictions as to how 22 specific stream corridor indicators behave in the context of the Impervious Cover Model (ICM). These general predictions are intended to diagnose the severity of stream impacts, set realistic goals for restoration, and plan and design restoration practices in the stream corridor.

This Appendix outlines the current research supporting the ICM, with particular reference to the impacted (*I*), non-supporting (*NS*) and urban drainage (*UD*) stream categories. It begins with a general discussion about the limitations and caveats of the ICM, and then explores how specific quantitative or narrative predictions were derived for each of the 22 stream corridor indicators. The section describes how each indicator was defined, measured or computed, and the baseline condition against which it is compared. Next, the research, models, and other evidence used to support predictions are described. Remarks are also made about the utility of each indicator in urban subwatershed restoration planning and design.

Lastly, we comment on our confidence in the accuracy and reliability of the individual indicator predictions of the ICM. In some cases, the predictions are merely untested hypotheses, while others are solidly grounded in science and engineering. Where possible, we recommend ways these predictions could be improved or narrowed through further urban subwatershed research.

This appendix is organized into seven sections:

A. Summary of the ICM and its Use in Subwatershed Restoration Planning
B. Derivation of Hydrologic Predictions for the ICM
C. Derivation of ICM Predictions for Physical Alteration of the Urban Stream Corridor
D. Derivation of Urban Stream Habitat Predictions for the ICM
E. Derivation of Urban Water Quality Predictions for the ICM
F. Derivation of Aquatic Diversity Predictions for the ICM
G. Summary

A: Summary of the ICM and its Use in Subwatershed Restoration Planning

The ICM organizes a series of testable hypotheses about how stream corridor indicators respond to greater subwatershed impervious cover (IC). It is used to classify three types of urban streams based on subwatershed IC: impacted, non-supporting and urban drainage. We have not included any predictions for *sensitive streams* (that have less than 10% IC), because they do not meet our definition of urban subwatershed, and are often predicted better by other subwatershed metrics (CWP, 2003).

The ICM applies to small streams, from first to fourth order, with a contributing subwatershed area of less than 10 square miles. ICM predictions are general, and may not apply to every stream within the proposed classifications. Urban streams are notoriously variable, and factors such as gradient, stream order, stream type, age of subwatershed development, and past land use can and will make some streams depart from these predictions. Indeed, these “outlier” streams are extremely interesting from the standpoint of restoration. In general, subwatershed IC causes a continuous but variable decline in most stream corridor indicators. Consequently, the severity of individual indicator impacts tends to be greater at the upper end of the IC range for each stream category.

The ICM does not explicitly address the influence of past subwatershed treatment or the effect of future subwatershed restoration practices. This is not currently much of a limitation since few urban subwatersheds have been comprehensively treated and/or restored to date. Indeed, Manual 2 presents a sequence of monitoring and modeling methods to measure how individual stream indicators might respond to subwatershed treatment.

It should also be noted that limited evidence exists to define indicator behavior in the upper range of NS stream category and the entire UD category. More systematic research is needed on these highly urban streams, which have received scant attention despite the fact they are the most polluted, impaired and degraded of any stream category.

For comparative purposes, a baseline condition is provided to give a general sense of the maximum possible improvement in the indicator that might be achieved by subwatershed restoration (although this degree of improvement cannot be attained in all urban subwatersheds). The baseline condition helps assess and quantify realistic goals and objectives for subwatershed restoration. In general, the baseline condition is defined as a stream located in a rural subwatershed in good condition. Rural land use is considered to be a subwatershed that contains a mix of forest, pasture, and crops; has not experienced extensive channel modification; has an intact riparian forest buffer; and lacks major point sources of pollution.

Lastly, while the ICM is quite useful, it is obviously not the only factor to consider in urban subwatershed restoration planning. Other subwatershed metrics, such as turf or pervious cover, stream corridor condition, age and condition of sewer system, stream interruption, hotspot density, and age of development are all extremely useful to define opportunities and constraints for subwatershed restoration.

B: Derivation of Hydrologic Predictions for the ICM

1. Influence of Storm Water Runoff

<u>Definition and measurement of indicator</u> This indicator is defined by the subwatershed runoff coefficient or Rv, which measures the fraction of annual rainfall volume that is converted into storm water runoff. It is measured by simultaneously sampling the volume of rainfall and storm water runoff produced at a single catchment over multiple (20+) storm events.

<u>Baseline condition</u> The annual volume of storm water runoff produced by an undeveloped rural subwatershed. Prior research has established that the Rv ranges from 0.02 to 0.07, depending on soils, slope and geology of the rural subwatershed monitored.

<u>Reference used to derive</u> The Rv vs. IC relationship is presented in Figure 1.2 in Schueler (1987), which examined 44 urban catchments monitored in the U.S. during the EPA NURP program.

<u>Utility in restoration planning and design</u> The Rv is a fundamental indicator of the degree of hydrologic alteration within a subwatershed, and is also used to estimate pollutant loadings (which are a direct function of subwatershed IC). The Rv relationship is also used in retrofit design to estimate the size and storage volume required for these practices.

<u>Comments</u> The Rv vs. IC relationship is well documented, and has been directly incorporated into many widely-used engineering hydrology models.

2. Flood Plain Expansion

<u>Definition and computation of indicator</u> This indicator is defined as the ratio of the current peak discharge rate to the pre-development

peak discharge rate produced during a 100-year rainfall event at a specific point of interest within the subwatershed (expressed in units of cubic feet per second, or cfs). This ratio is a useful index of the probable expansion of the flood plain within the existing stream corridor. In practice, the ratio is computed by applying detailed hydrology models to estimate the peak discharge rates for current conditions, which are a function of current subwatershed IC, soil types, and hydraulic conditions in the stream channel and flood plain. The models are then run again to simulate pre-development conditions in the subwatershed, and the ratio of the two current and pre-development peak discharge rates is then computed.

Baseline condition compared to The 100-year peak discharge rate for pre-development conditions is usually modeled assuming the subwatershed has a rural land use mix (e.g., forest, pasture and crops) and does not have a storm drain collection system. For comparison purposes, the index or ratio for an undeveloped rural subwatershed is one.

References used to derive Sauer *et al.* (1983) and Hollis (1975) established the initial relationship. The basic modeling tools to predict 100-year peak discharge rates for pre-development and current development conditions have advanced considerably since then, but the newer hydrologic models still give the same basic results in most urban subwatersheds (USGS, 1996).

Utility in restoration planning and design The index helps define the degree of flood plain expansion in the stream corridor. High index values indicate that flooding problems may be severe in the stream corridor, and could suggest that older stream crossings may lack sufficient capacity to handle increased flood waters. The peak discharge ratio also helps estimate the maximum stress and current velocities that stream repair practices will be exposed to.

Comments The relationship between IC and 100-year peak discharge rate ratios are reasonably well established, but several other subwatershed factors can also strongly influence this indicator. These factors include the type and age of storm drains, the age of subwatershed development, and the existing hydraulic capacity of both the stream channel and its flood plain.

3. Bankfull Flooding Frequency

Definition and computation of indicator This indicator is defined as the number of flow events that completely fill the cross-sectional area of the pre-development channel in an average year of rainfall. Continuous hydrologic simulation models are often used to derive this statistic, by comparing bankfull flood frequency based on current subwatershed conditions against the frequency computed for assumed rural, pre-development conditions.

Baseline condition compared to In rural watersheds, the bankfull flood frequency is about 0.5 events per year, or roughly one bankfull flood event every two years.

References used to derive The basic relationship was developed by Leopold (1968, 1994) and a simple model to relate bankfull flooding frequency to subwatershed IC was advanced in Figure B-3, Appendix B "Bankfull Flooding Frequency Analysis" by Schueler (1987). Data from Konrad and Booth (2002) and Nehrke and Roesner (2002) were also helpful in characterizing the relationship.

Utility in restoration planning and design This indicator helps assess the potential severity of stream bank erosion and habitat degradation within an urban subwatershed. Bankfull flooding frequency can also be reduced when upstream storage retrofits are constructed within a subwatershed, so it is often used to plan the location and required storage of upstream storm water retrofit practices to protect the channel. In addition, bankfull flooding frequency has considerable value in stream repair design.

Comments The actual bankfull discharge can change over time in an urban subwatershed, as the cross-sectional area of the stream channel gradually enlarges to accommodate increased storm water flows (see indicator # 7). Therefore, this indicator will be less accurate in older subwatersheds where channel incision and enlargement have already increased the capacity of the channel to accommodate pre-development bankfull flood discharge rates. Stream order may also be important in defining bankfull flooding frequency in urban streams. Palmer *et al.* (2003) observed the greatest increase in bankfull flooding frequency occurred in first and second streams, and was attenuated to some degree in third and fourth order streams.

C: Derivation of ICM Predictions for Physical Alteration of the Urban Stream Corridor

4. Stream Enclosure/Modification

Definition and measurement of indicator This indicator is defined as the fraction of the pre-development stream network that remains intact, expressed in terms of total length (miles) or stream density (miles/square mile). This indicator is derived by comparing the length of the historical stream network (derived from historical maps or photos) to its current stream length (determined from GIS analysis or field assessment).

Baseline condition compared to Rural streams that have 90 to 100% of the original stream network remaining, although some may have experienced greater modification because of past agricultural drainage, flood control or channelization "improvements."

References used to derive The predictions are primarily based on anecdotal evidence, although several studies have documented that individual urban subwatersheds lose considerable stream density at high levels of development (Dunne and Leopold, 1978 and NVRC, 2001). As a practical consideration, very few biological or habitat indicators are reported above 50 to 60% subwatershed IC, which indirectly suggests that this level of IC may be the breakpoint where natural stream channels are enclosed or channelized.

Utility in restoration planning and design This indicator can help define general opportunities to daylight streams, and is also a good measure of the loss of headwater streams that are important in stream ecology.

Comments The age and intensity of development in a subwatershed can also be very important in defining this stream corridor indicator. For example, recently developed subwatersheds could potentially be subject to less stream enclosure/modification because of wetland permitting and/or stream buffer requirements.

5. Riparian Forest Continuity

Definition and measurement of indicator This indicator is defined as the fraction of the existing perennial stream network that possesses an intact forest buffer of an appropriate width (e.g., 50 feet on either side of channel). Riparian forest continuity, or RFC can be directly measured by the Unified Stream Assessment (Manual 2) or through a GIS analysis of aerial photographs of a subwatershed.

Baseline condition compared to Rural streams typically have an intact riparian forest buffer along about 80 to 100% of their stream corridor, according to regional surveys by Jones *et al.* (1997). Riparian forest continuity, however, can be quite variable in some rural subwatersheds, depending on the prevailing riparian management practices used by adjacent farmers and ranchers.

References used to derive Only one study has defined the behavior of RFC over a broad range of subwatershed IC (Horner *et al.*, 1997), but the Center has consistently seen the sharp decline in RFC during field work in highly urban subwatersheds.

Utility in restoration planning and design Riparian forest continuity is an extremely important indicator of subwatershed with high potential to reforest or improve management of the stream corridor. RFC is also a good indicator to measure progress made in riparian reforestation at the subwatershed level.

Comments Historical stream corridor management actions can also be extremely important to explain RFC behavior within individual subwatersheds. For example, past decisions to locate stream valley parks, regulate the flood plain or require stream buffers during development can all strongly influence RFC.

6. Stream Interruption

Definition and measurement of indicator This indicator is defined as the average number of stream crossings per stream mile in a subwatershed, and can be measured during the Unified Stream Assessment (Manual 2) or through careful GIS analysis of subwatershed aerial photos.

Baseline condition compared to Rural streams usually have less than one crossing per stream mile, according to an extensive national GIS watershed analysis by Jones *et al.* (1997).

References used to derive Only one study has explored the relationship between IC and the number of stream crossings in urban subwatersheds (May *et al.*, 1997), although our field experience, drawn from many urban watershed assessments, suggests that it is a robust relationship.

Utility in restoration planning and design The number of stream crossings can be used to determine urban fishery resource potential, with an emphasis on the potential severity of barriers to fish migration in a subwatershed. In addition, the number of hard crossings can be useful to locate potential storage retrofit sites in the stream corridor, and to identify existing grade controls that may locally moderate stream bank erosion in the stream network.

Comments While that this indicator relationship seems robust, it has not been systematically studied across the full range of IC, particularly in the NS and UD categories. Indeed, stream crossings are probably irrelevant in UD subwatersheds, for the simple reason that there are no streams left to cross.

D: Derivation of Urban Stream Habitat Predictions for the ICM

7. Channel Enlargement Ratio

Definition and measurement of indicator This indicator of expected channel enlargement is defined as the ratio of the ultimate stream channel cross-sectional area compared to the pre-development cross-sectional area, averaged for multiple stream reaches in a subwatershed. Channel enlargement can be measured, if both current and historical cross-sectional data are available for stream channels, and can be modeled if extensive geomorphic data is available.

Baseline condition compared to A rural stream of the same geomorphic type that has stable banks, which is defined as having a ratio of one.

References used to derive The basic relationship has been proposed by Caraco (2001); MacRae and DeAndrea (1999); MacRae (1996); and Hammer (1972). Both Bledsoe (2001) and Booth and Henshaw (2001) observed that the power of IC to predict stream channel enlargement is not particularly great at low to moderate levels of subwatershed development (5 to 15% IC), and argued that many other subwatershed and geomorphic variables complicate the enlargement prediction in these subwatersheds. On the other hand, the Center’s field assessments clearly indicate that progressively greater bank instability and enlargement are common for both the NS and UD stream categories.

Utility in restoration planning and design The channel enlargement indicator is a good index of bank stability along the stream corridor, as well as the likely degree of habitat impairment in the stream. A general understanding of expected channel enlargement is also quite helpful when designing stream repair and restoration practices.

Comments More research is needed to assess the degree of channel enlargement that occurs in the NS and UD stream categories. It is also quite likely the age of development will be an important subwatershed factor, since the channel enlargement process may take decades to fully manifest itself in many urban streams.

8. Sediment Supply to Stream

Definition and measurement of indicator The indicator is defined by the ratio of the annual sediment yield produced from an urban subwatershed compared to a rural one, expressed in terms of mass per unit area per year (e.g., tons/square mile/yr). The sediment yield indicator reflects the delivery of greater urban sediment loads caused by accelerated stream bank and channel erosion. Long-term sediment and flow monitoring are needed to compute the subwatershed sediment yield, which has been done at a few smaller USGS gage sites.

Baseline condition compared to A stable rural stream of the same geomorphic type and subwatershed area.

References used to derive The fact that individual urban subwatersheds have higher unit area sediment yields compared to rural subwatersheds has been established by Barton (2003); Trimble (1997); and Dartiguenave *et al.* (1997). To date, no studies have tracked this indicator over the broad range of impervious cover encompassed by the ICM. In addition, the potential for reduced urban sediment yields because of extensive stream enclosure/ modification has not been investigated, but could be very important in UD subwatersheds.

Utility in restoration planning and design This indicator is important to assess a subwatershed's contribution to downstream sediment loads, as well as predicting internal sediment dynamics within the stream channel. Sediment yield can be used to forecast the future loss of capacity in storage retrofits and stream repair practices due to sediment deposition.

Comments The general prediction is reasonably strong, but is complicated by the evolution process of urban stream channels. More research on the unit area sediment yield data over the range of IC covered by the ICM would be helpful, particularly for channels that are naturally adjusting and those that are channelized/enclosed.

9. Typical Stream Habitat Score

Definition and measurement of indicator This indicator is defined by the average stream habitat score sampled in multiple stream reaches in an urban subwatershed, compared to a rural subwatershed. Stream habitat scores are frequently measured by the EPA rapid habitat assessment protocol (Barbour *et al.*, 1999) or equivalent habitat assessment method.

Baseline condition compared to A rural stream in good condition (i.e., with stable banks and intact riparian zone) typically has "good" or "very good" habitat index scores. As Wang *et al.* (2001) notes, however, habitat scores may be lower in some rural streams with poor riparian management practices.

References used to derive A detailed review of the general relationship between IC and stream habitat is provided in CWP (2003). Most stream researchers have only looked at the relationship between 5 and 25% subwatershed IC (Morse 2001 and Wang *et al.* 2001). Consequently, very little systematic data is available to characterize stream habitat quality within the upper range of the NS streams and the entire UD category. Once again, the Center's field assessments indicate that habitat quality is consistently poor to very poor in these streams.

Utility in restoration planning and design In-stream habitat scores are a useful indicator to assess fishery restoration potential in urban subwatersheds, and can be used to track restoration progress.

Comments More subwatershed research is needed to characterize habitat quality in NS and UD streams in order to refine the predictions.

10. Presence of Large Woody Debris

Definition and measurement of indicator
Large woody debris (LWD) in the stream channel is a good measure of both structural stream habitat and the interaction of the stream with its riparian zone. Large diameter wood in contact with the stream can be measured in the field over several reaches within a subwatershed. The composite score is expressed as the average number of LWD pieces encountered over a unit stream length.

Baseline condition compared to Rural stream, with intact forested riparian zone, averaging five to 15 LWD pieces per 100 feet of stream reach (Fox *et al.*, 2003).

References used to derive Most urban subwatershed LWD data has been gathered for Pacific Northwest streams with subwatershed IC ranging from 0 to 40% (May *et al.* 1997; Fox *et al.*, 2003; Finkebine *et al.*, 2000). No systematic data has been collected for NS streams at the upper end of its IC range, and for the entire UD category, although the Center's field assessments indicate that LWD is scarce or absent in these highly urban streams.

Utility in restoration planning and design
LWD is helpful in assessing fishery resource potential, habitat quality, and the degree of interaction between the stream and riparian zone.

Comments More regional research is needed to assess LWD frequency for both the NS and UD stream categories.

11. Increased Summer Stream Temperatures

Definition and measurement of indicator This indicator is defined as the increase in average maximum summer stream temperature compared to a comparable rural stream draining the same subwatershed area. The warming effect is often referred to as the delta-T and can be monitored using continuous or simultaneous water temperature probes in the stream during the summer months.

Baseline condition compared to Average summer stream temperature for a rural stream that has an intact riparian canopy to provide shade.

References used to derive The primary data on the IC vs. stream temperature relationship was first proposed by Galli (1990). The relationship is also indirectly supported by urban heat island research conducted by Cheung (2002), who found a one degree F increase in summer surface air temperature for each 10% increment in local IC, when the presence of adjacent water and forest cover was controlled. Confounding factors include effect of cold water springs (Kilham and Steffy, 2002), stream canopy, and the presence of storm water ponds in a subwatershed. Still, there is a strong physical basis for the IC/stream temperature relationship up to about 60% subwatershed IC. No stream temperature data could be found for UD subwatersheds, whose extensive below-ground drainage could potentially have a cooling effect on summer stream temperatures.

Utility in restoration planning and design
Stream temperature is an important indicator to determine fishery resource potential (e.g., ability to support trout, salmon or sensitive aquatic insect species).

Comments More research is needed to refine stream temperature predictions for the NS and UD stream categories.

E: Derivation of Urban Water Quality Predictions for the ICM

12. Annual Nutrient Load

Definition and computation of indicator This indicator is defined as the annual unit area mass storm water loading of phosphorus and/or nitrogen produced by an urban subwatershed compared to a rural one. Nutrient loads can be computed for any urban subwatershed using the Simple Method (Schueler, 1987), given a reliable estimate of subwatershed IC and median event mean concentrations for the range of land uses present (Table A-1).

Table A-1: National Summary of Pollutant Concentrations in Storm Water Runoff					
	All Data	**Residential**	**Commercial**	**Industrial**	**Freeway**
# of storms sampled	3756	1069	497	524	185
	Median Event Mean Concentrations EMC (mg/l or ppm)				
Suspended Solids	58	48	43	77	99
Dissolved Solids	80	71	77	92	78
BOD_5	8.6	9.0	11.9	9	8
COD	53	55	63	60	100
Fecal coliforms #	5081	7750	4500	2500	1700
Fecal streptococci #	17,000	24,000	10,800	13,000	17,000
Nitrate-N	0.6	0.6	0.6	0.7	0.28
TKN	1.4	1.4	1.6	1.4	2.0
Total Nitrogen	2.00	2.00	2.2	2.1	2.3
Total Phosphorus	0.27	0.3	0.22	.26	0.25
Dissolved P	0.12	0.17	0.11	0.11	0.20
Oil and Grease	4	3.1	4.7	4	8
	Median Event Mean Concentrations EMC (ug/l or ppb)				
Total Cadmium*	1.0	0.5	0.9	2.0	1.0
Total Chromium	7.0	4.6	6.0	15	8.3
Total Copper	16	11.1	17	22	35
Total Cyanide*	5.0	5.0	0.1	5.9	nd
Total Lead	16	11.1	18	25	25
Total Mercury*	0.2	0.2	0.2	0.1	0.2
Total Nickel *	8	5.4	7	16	9
Total Zinc	116	73	150	210	200
Fluoranthrene *	6	3	6	3.8	nd
Phenanthrene *	3.95	1.7	4.1	9	nd
Pyrene *	5.2	2.2	5.0	7.2	nd

Source: Pitt et al. 2003
Notes: Medians are of detected values. An asterisk indicates constituent was undetected in more than half of all storm events. A # indicates bacteria measured in counts per 100 ml.

Baseline condition compared to The annual load of phosphorus or nitrogen produced by a rural subwatershed, which has been defined regionally in the National Water Quality Assessment by the USGS (2001). The term “rural” refers to a mix of forest, pastures and crops; note that subwatersheds with extensive row crop or livestock operations can produce much higher nutrient loads.

References used to derive The general relationship between storm water nitrogen loading rates and subwatershed IC has been proposed by Schueler and Caraco (2001). A similar relationship between storm water phosphorus loading rates and subwatershed IC has been presented by Caraco and Brown (2001, Table 4) and Caraco (2001, Figure 1). The nutrient load indicator does not include any nutrients from wastewater discharges (either permitted or illicit), which are often found in NS and UD subwatersheds and could possibly increase annual nutrient loads.

Utility in restoration planning and design Nutrient loads can be a useful indicator to measure progress toward nutrient reduction efforts in subwatersheds where downstream eutrophication is a management concern. Various modeling tools can be used to estimate the effect of various restoration practices to reduce subwatershed nutrient loading rates. Manual 2 in this series describes how the Watershed Treatment Model can be used for this purpose.

Comments Pitt *et al.* (2003) has published extensive summaries of storm water runoff monitoring data that establish reliable estimates of nutrient event mean concentrations over a wide range of subwatershed IC in many regions of the country. Therefore, our confidence in the accuracy of urban nutrient load predictions is fairly high, although we are less confident in the estimates of rural nutrient loads used as the baseline condition.

13. Exceedance of Bacteria Standards

Definition and measurement of indicator This indicator is defined as the frequency that bacteria standards for water contact recreation are exceeded during wet weather and/or dry weather flow events in urban subwatersheds, as measured either by fecal coliform or E. coli bacteria. Bacteria levels are typically measured during stream sampling at trend or sentinel stations within an urban subwatershed.

Baseline condition compared to Water contact bacteria standards are exceeded in rural streams no more than 10 to 20% of storm events per year, and are rarely exceeded during dry weather (USGS, 2001).

References used to derive The basic conceptual model for dry and wet weather bacteria behavior for urban watersheds has been advanced by Schueler (1999 - Figure 1), based on an extensive analysis of storm water and dry weather monitoring data for urban subwatersheds across the country. Other data sources include Mallin *et al.* (2000, 2001) and Pitt *et al.* (2003).

Utility in restoration planning and design The bacteria indicator can help target discharge prevention and source control restoration practices, and can be used to set realistic and achievable goals for water contact recreation during dry and wet weather.

Comments Extensive runoff monitoring has established reliable estimates of storm water bacteria concentrations over a wide range of IC in many regions of the country (Pitt *et al.*, 2003). Although bacteria levels are highly variable, we are reasonably confident in the broad pattern.

14. Aquatic Life Toxicity

Definition and measurement of indicator This indicator is defined as the potential for ambient metal, pesticide or chloride concentrations in storm water runoff to cause mortality in exposed aquatic organisms in urban streams. The degree to which ambient concentrations of storm water pollutants can cause either chronic or acute toxicity to aquatic life are still widely debated (see review in CWP, 2003).

Baseline condition compared to Ambient metal, chloride or pesticide levels measured during storms in a rural stream. In general, acute toxicity is rarely encountered during storms in rural streams, unless adjacent agricultural or orchard spraying is unusually high.

References used to derive Several researchers have reported either acute or chronic toxicity within individual urban subwatersheds with known impervious cover (Crunkilton *et al.*, 1996; Field and Pitt, 1990; Ellis, 1986; Ireland *et al.* 1996; Connor, 1995; Environment Canada, 2001). Systematic toxicity monitoring across the range of IC included in the ICM, however, has not been performed. Several researchers do report a strong urban land use effect (Rice, 1999 and Callender and Rice, 2000).

Utility in restoration planning and design This indicator is important in defining priorities and specific pollutant reduction targets for hotspot source control, municipal practices, neighborhood stewardship, and storm water retrofitting in the context of a subwatershed restoration plan.

Comments While the urban land use effect is quite strong for this indicator, the actual impact that toxins exert on urban stream life is also quite complex, and probably differs for each class of toxins. In particular, the risk of aquatic life toxicity in NS and UD subwatersheds is problematic for several reasons. First, sensitive aquatic organisms may already be absent in NS and UD subwatersheds as a result of other hydrological, physical, habitat and water quality stressors. Second, evidence exists that pesticides may actually be generated at higher rates in impacted subwatersheds compared to NS and UD subwatersheds, since they have more pervious area where pesticides could be potentially applied (Hopkins and Hippe, 1999). By contrast, NS and UD subwatersheds usually contain a greater density of storm water hotspots that have a higher potential for leaks, spills or illegal discharges of toxic pollutants. We have therefore elected to use a more narrative rather than quantitative prediction to describe this indicator that looks at *potential* rather than *actual* frequency of acute or chronic toxicity.

15. Contaminated Sediments/Fish Advisories

Definition and measurement of indicator This indicator can be defined in one of two ways. The first way is to measure the extent to which sediments are enriched in metals, organochlorine pesticides and/or polycyclic aromatic hydrocarbons (PAH) compared to reference sediments from rural subwatersheds. The second way is to measure whether the same compounds accumulate in fish tissue to levels that prompt an advisory restricting fish consumption.

Baseline condition compared to Both indicators are measured in relation to bottom sediments or fish tissue collected from rural subwatersheds. Rural bottom sediments can be contaminated by mercury (which is a widespread national problem) and some pesticides (from agricultural and orchards), but they lack the distinctive “metal/PAH/organochlorine pesticide” fingerprint that is so diagnostic of urban bottom sediments.

References used to derive Abundant evidence exists to show a strong urban land use effect on sediment contamination. This is evident in urban storm water runoff concentrations (Pitt *et al.*, 2003), urban stream bed sediments (Rice, 1999), urban lake and reservoir sediments (Van Metre *et al.* 2000 and Callender and Rice, 2000) and urban estuarine sediments (Holland *et al.* 2003 and Velinsky and Cummins, 1994). A strong urban land use effect was also reported in patterns of sediment contamination in a national survey of sediment quality (US EPA, 1997). The same basic sediment contamination fingerprint has also been widely observed in the bottom sediments of many storm water ponds (Schueler, 1996).

Much less evidence is available to make the link between subwatershed IC and pollutant accumulation in fish tissues that prompt fish consumption advisories. There does appear to be a strong clustering of fish consumption advisories around highly urban subwatersheds for non-mercury pollutants (EPA, 2003). In addition, the USGS (2001) reports extensive evidence of metal and PAH accumulation in fish tissues in urban streams, but they did not systematically monitor them over the wide range of subwatershed IC encompassed by the ICM.

Utility in restoration planning and design This indicator is important to define priorities and specific pollutant reduction targets for hotspot source control, discharge prevention, municipal practices, neighborhood stewardship, and storm water retrofits in a subwatershed plan.

Comments While there is strong evidence for the relation of urbanization and sediment contamination/fish advisories, we lack systematic monitoring over the full range of subwatershed IC to make quantitative predictions at this time. We have therefore elected to use a narrative rather than quantitative prediction for this indicator.

16. Trash and Debris

Definition and measurement of indicator This indicator is ideally defined as the unit area loading rate of trash and debris, expressed in dry weight measured for an urban subwatershed. At this time, however, there is no universally accepted method to report trash and debris loadings. Researchers have variously measured trash/debris using units of gallons, tons, cubic feet, and number of trash bags filled. There also is no consistency in whether reported loads represent dry mass, wet mass or only floatables. In addition, the actual techniques to measure trash/debris loads are quite different, with researchers using booms to capture trash during runoff events, sampling catch basins, measuring the total volume collected by volunteers along a given length of stream or shoreline, or weighing trash collected by skimmer boats in a harbor.

Baseline condition compared to A rural stream, with minor trash loading.

References used to derive Several debris characterization studies were consulted including CRWQCB (2001), OCW (2000), and Steinberg *et al.* (2002). None of these studies sampled small urban subwatersheds, nor did they evaluate trash/debris loads over the range of subwatershed IC included in the ICM. It should be noted, however, that most trash and debris problems and management efforts do occur in highly urban and ultra-urban subwatersheds (i.e., NS and UD streams).

Utility in restoration planning and design This indicator is useful to target stream cleanups, and define residential and business source control practices in contributing subwatersheds. Severe trash and debris problems may call for enhanced municipal practices such as street sweeping, storm drain cleanouts, storm drain stenciling, or illegal dumping controls.

Comments This is perhaps the most poorly understood ICM indicator, due to uneven and inconsistent data quality to measure trash/debris, and the fact that trash loading rates have not been systematically monitored in subwatersheds over the full range of the IC covered by the ICM model. Virtually no trash loading monitoring has been performed within impacted subwatersheds, so this indicator prediction is merely an educated guess.

17. Other Storm Water Pollutants

Definition and measurement of indicator This indicator is defined as the annual unit area mass load of a storm water pollutant produced by an urban subwatershed compared to a rural subwatershed. It can be computed for any subwatershed using the Simple Method (Schueler, 1987), given a reliable estimate of subwatershed IC and median event mean concentrations for the range of land uses present (see Table A-1). Reliable data are available for various measures of organic carbon (COD, BOD5), metals (Cu, Zn, Pb), and oil and grease.

Baseline condition compared to The annual unit area pollutant load produced by a rural subwatershed, which has been defined regionally in the National Water Quality Assessment by the USGS (2001). The term "rural" refers to a mix of forest, pastures and crops; subwatersheds with extensive agricultural or livestock operations can produce higher loads of organic carbon and other pollutants.

References used to derive Schueler (1987) proposed the general relationship between storm water pollutant loading rates and subwatershed IC, which requires a good estimate of the storm water event mean concentration (EMC). Pitt *et al.* (2003) present EMC data for a range of common land uses, which is shown in Table A-1.

Utility in restoration planning and design This is a useful indicator to measure pollutant load reduction needed to meet subwatershed or watershed water quality, such as the Watershed Treatment Model (see Manual 2).

Comments As noted earlier, Pitt *et al.* (2003) have established reasonably accurate storm event mean concentration data for most conventional pollutants for most regions of the country (with the possible exception of the northern tier of U.S.). It should be noted that much fewer data are available to characterize PAH compounds and chlorides.

F: Derivation of Aquatic Diversity Predictions for the ICM

18. Aquatic Insect Diversity

Definition and measurement of indicator This index is defined as the average subwatershed macro-invertebrate or aquatic insect diversity score, as computed by Benthic Index of Biotic Integrity or B-IBI (Barbour *et al.*, 1999). It is typically measured in multiple stream reaches within a subwatershed.

Baseline condition compared to B-IBI scores for rural streams typically range from "good" to "very good."

References used to derive Our predictions are based on visual inspection of B-IBI vs. IC data plots from the following studies Boward *et al.* (1999); MNCPPC (2000); Horner *et al.* (1997); Black and Veatch (1994); Kennen (1999); Yoder (1991) and Fairfax County (2001). In general, B-IBI scores are only reported up to about 40 to 45% subwatershed IC, so the poor diversity predicted for streams in the upper NS and the entire UD category simply represents an extension of the data trend line.

Utility in restoration planning and design This indicator helps assess the general biological health of an urban stream, and can be used to track improvements in stream health as a result of the implementation of subwatershed restoration practices.

Comments The relationship between IC and declining B-IBI scores is strongly supported by current research, although aquatic insect diversity data for UD streams is generally lacking.

19. EPT Taxa

Definition and measurement of indicator This indicator is defined as the proportion of sensitive stonefly, caddisfly and mayfly species in the stream insect community, expressed as the percent of the total score for a rural "reference" stream. Streams with high EPT scores contain many pollution and/or temperature sensitive species, whereas streams with low scores are deemed pollution tolerant.

Baseline condition compared to EPT scores for a rural stream, which are typically 80 to 100% of the reference stream value.

References used to derive The primary references used to predict this indicator were Maxted and Shaver (1997) and Morse (2001), although this metric is also one of the components of the B-IBI scoring (see # 18).

Utility in restoration planning and design This measure of the pollution tolerance of the aquatic insect community indicates the degree to which pollution, degraded habitat, or other stressors are influencing local stream ecology.

Comments Again, very little research is available to characterize EPT scores for streams with more than 40% subwatershed IC, which makes it somewhat hard to make predictions for NS and UD stream categories. Based on extensions of the trend lines, however, it is doubtful that any highly urban streams contain any pollution or temperature sensitive species.

20. Fish Diversity

Definition and measurement of indicator This indicator is defined as the average fish diversity score for an urban subwatershed compared to a rural one. The fish Index of Biotic Integrity or F-IBI is usually sampled in multiple stream reaches to obtain an average score for an urban subwatershed (Barbour *et al.*, 1999).

Baseline condition compared to Rural streams typically have "good" to "very good" fish-IBI scores, unless there has been a major change in land use or riparian management in the subwatershed (Harding *et al.*, 1998).

References used to derive These predictions are based on visual inspection of F-IBI vs. IC data plots from the following studies Wang *et al.* (2001); MNCPPC (2000); MWCOG (1992); Meyer and Couch (2000); Boward *et al.* (1999); Horner *et al.* (2001) and Couch *et al.* (1997). As with B-IBI scores, reported F-IBI data extend only from five to about 45% subwatershed IC, so the poor diversity predicted for streams in the upper NS and the entire UD category simply represents an extension of the data trend line.

Utility in restoration planning and design Fish diversity scores are an excellent indicator of stream health, from the perspective of both stream researchers and the general public, and scores can be tracked over time to measure progress toward fishery restoration goals.

21. Trout or Salmon

Definition and measurement of indicator This indicator is defined as the ability to maintain a self-reproducing population of trout or salmon within a subwatershed. Where this is not possible, the indicator is alternatively defined as the ability to maintain a put-and-take fishery in the stream. This indicator is easily measured through fishery and spawning surveys in an urban subwatershed.

Baseline condition compared to A rural stream with habitat conditions that can support trout or salmon populations.

References used to derive A number of researchers have examined the effect of IC on trout and salmon and have found that these populations are often absent or extremely stressed above 10% subwatershed IC (Boward *et al.*, 1999; Horner *et al.*, 1999; May *et al.*, 1997; WDFW, 1997; Kilham and Steffy, 2002; Scott *et al.*, 1986; Kemp and Spotila, 1997; Moscript and Montgomery, 1997). It may be possible to support salmon at the lower IC range of impacted subwatersheds, but no records of self-reproducing populations could be found in either NS or UD subwatersheds. Urban fishery biologists have established put-and-take recreational trout fisheries in some larger I and NS streams. In addition, there is some data that hardier cutthroat trout may inhabit I and NS streams for at least part of their life cycles (May *et al.*, 1997).

Utility in restoration planning and design This indicator helps set expectations for the fishery resource potential of an urban subwatershed. If a stream can potentially support a self-reproducing or put-and-take fishery, it greatly affects the selection of which subwatershed restoration practices to apply (e.g., stream repair/restoration techniques, elimination of fish barriers, improved riparian management).

Comments This indicator obviously only applies to eco-regions that can support a cold-water fishery. An alternative "indicator" fish species could be selected for regions that have a warm-water fishery.

22. Riparian Plant Diversity

Definition and measurement of indicator This indicator measures plant diversity and community structure in the remaining flood plain forests and wetland fragments of the stream corridor. The three main elements used to describe this indicator are a) the relative dominance of exotic and native plant species within the fragment, b) fragment patch size and structure and c) overall plant diversity within the fragment compared to a rural stream corridor. Each of these elements can be measured along the stream corridor, but they rarely are.

Baseline condition compared to Each of the three riparian elements should be compared against values obtained from flood plain forest or wetland reference sites located in the rural stream corridor.

References used to derive This narrative prediction is based on research that has shown a strong urban land use effect for each element in urban riparian areas (Brush and Zipperer, 2002; Groffman *et al.* 2003; Findlay and Houlihan, 1997; Taylor *et al.*, 1995), as well as extensive anecdotal evidence from urban stream corridor surveys. Consistent and uniform techniques to measure and compare riparian plant diversity, however, have not systematically been applied over the range of subwatershed IC encompassed by the ICM.

Utility in restoration planning and design This indicator could be quite useful in defining the prospects for effective riparian and natural area restoration in the urban stream corridor, but is not fully developed at this time.

Comments This indicator is expressed as very general narrative criteria, relating to dominance of exotic plants, average fragment size and structure and overall plant diversity within the fragment.

G: Summary

The ICM organizes a combination of published and unpublished research, engineering models, field experience, and hypotheses into a stream classification system for three kinds of urban subwatersheds. The strongest evidence for ICM predictions tends to be concentrated in the 10 to 40% subwatershed IC range; much less is known about the behavior of streams in the upper end of the NS category and the entire UD category. We strongly believe additional research on NS and UD streams will further refine and tighten ICM predictions, and invite researchers to test these hypotheses in future monitoring.

Tables A-2, A-3, and A-4 provide a summary of the ICM predictions for impacted, non-supporting and urban drainage stream classifications, respectively. These tables also include a confidence factor, or CF for each indicator, which qualitatively expresses the relative confidence in each indicator prediction on a scale of one to five (with five being the most confident and one being least confident).

Table A-2: ICM Predictions for Impacted Streams (11 to 25% IC)		
Stream Indicator	**Prediction**	**CF**
Influence of Storm Water Runoff	10 to 30% of rainfall converted to runoff	5
Flood Plain Expansion Index	Peak discharge for 100-yr storm increased by a factor of 1.1 to 1.5	4
Bankfull Flooding Frequency	1.5 to 3 bankfull flood events per year	4
Stream Enclosure/Modification	60 to 90% of stream network intact	3
Riparian Forest Continuity	50 to 70% of riparian forest buffer intact	3
Stream Interruption	1 to 2 crossings per stream mile	2
Channel Enlargement	Cross-sectional area 1.5 to 2.5 times higher	3
Sediment Supply to Stream	2 to 5 times more annual yield	3
Typical Stream Habitat Score	Fair, but variable	3
Presence of Large Woody Debris	2 to 8 pieces per 100 feet of stream	2
Summer Stream Temperature	2 to 4 degrees F warmer	3
Annual Nutrient Load	1 to 2 times higher than rural background	4
Violations of Bacteria Standards	Frequent violations during wet weather	4
Potential Aquatic Life Toxicity	Acute toxicity rare, chronic possible	2
Contaminated Bottom Sediments	Sediments enriched, but not contaminated; fish advisories uncommon	2
Trash and Debris Load	1 to 2 tons per square mile per year	2
Aquatic Insect Diversity	Fair to good B-IBI scores	4
EPT Taxa	40 to 70% of reference	4
Fish Diversity	Fair to good F-IBI scores	4
Capacity to Support Trout or Salmon	Some limited potential	4
Riparian Plant Diversity	Stressed and simplified plant communities	2
CF: Confidence factor based on scale of 1 to 5, with 5 representing the highest level of confidence.		

Table A-3: ICM Predictions for Non-Supporting Streams (26 to 59% IC)		
Stream Indicator	**Prediction**	**CF**
Influence of Storm Water Runoff	25 to 60% of rainfall converted to runoff	5
Flood plain Expansion	Peak Discharge for 100-year storm increased by a factor of 1.5 to 2	4
Bankfull Flood Frequency	3 to 7 bankfull flood events per year	4
Stream Enclosure/Modification	25 to 60% of stream network intact	3
Riparian Forest Continuity	30 to 60% of riparian forest buffer intact	3
Stream Interruption	2 to 10 stream crossings per mile	2
Channel Enlargement	Cross-sectional area 2.5 to 6 times larger	3
Sediment Supply to Stream	5 to 10 times more sediment yield	2
Typical Stream Habitat Score	Consistently poor	3
Presence of Large Woody Debris	Scarce	2
Summer Stream Temperatures	4 to 8 degrees F warmer	3
Annual Nutrient Load	2 to 4 times higher than rural background	4
Violations of Bacteria Standards	Continuous violations during wet weather; episodic violations during dry weather	4
Potential Aquatic Life Toxicity	Moderate potential for acute toxicity during some storms and spills	3
Contamination of Bottom Sediments	Episodic potential for acute toxicity; fish advisories likely	3
Trash and Debris Loading	2 to 5 tons per square mile per year	2
Aquatic Insect Diversity	Poor B-IBI scores	4
EPT Taxa	20 to 50 of natural reference	3
Fish Diversity	Poor F-IBI scores	4
Capacity to Support Trout or Salmon	Temporary use only (i.e., put-and-take)	3
Riparian Plant Diversity	Simplified and dominated by exotic sp.	2
CF: Confidence factor based on scale of 1 to 5, with 5 representing the highest level of confidence.		

Table A-4: ICM Predictions for Urban Drainage Streams (?60% IC)		
Stream Indicator	**Prediction**	**CF**
Influence of Storm Water Runoff	60 to 90% of rainfall converted to runoff	5
Flood Plain Expansion Index	Peak Discharge for 100-year storm increased by factor of 2 to 3	4
Bankfull Flooding Frequency	7 to 10 bankfull events per year	2
Stream Enclosure/Modification	10 to 30% of stream network intact	2
Riparian Forest Continuity	>30% of riparian forest buffer intact	2
Stream Interruption	No streams left to cross	1
Channel Enlargement	Cross-sectional area 6 to 12 times larger	2
Sediment Supply to Stream	Sediment yield lower	1
Typical Stream Habitat Score	Poor, often absent	2
Presence of Large Woody Debris	Absent	2
Summer Stream Temperatures	More than 8 degrees F warmer	3
Annual Nutrient Load	4 to 6 times higher than rural background	4
Violations of Bacteria Standards	Continuous violations during wet weather, frequent violations during dry weather	4
Potential Aquatic Life Toxicity	High potential for acute toxicity episodes during dry and wet weather	2
Contaminated Bottom Sediments	Sediment contamination and bio-accumulation should be presumed	3
Trash and Debris Loads	5 to 10 tons per square mile	2
Aquatic Insect Diversity	Very poor B-IBI scores	1
EPT Taxa	0 to 20% of reference	2
Fish Diversity	Very poor F-IBI scores	2
Capacity to Support Trout or Salmon	None	2
Riparian Plant Diversity	Isolated remnants; Dominated by exotics	2
CF: Confidence factor based on scale of 1 to 5, with 5 representing the highest level of confidence.		

Appendix B: Organization of Restoration Technique Profile Sheets for the Manual Series

Manual 3: Storm Water Retrofit Practices

Storage Retrofit Techniques
Modify Existing Detention Ponds (SR-1)
Storage Above Roadway Culverts (SR-2)
New Storage Below Outfalls (SR-3)
Storage in the Conveyance System (SR-4)
Storage in Road Right of Ways (SR-5)
Large Surface Parking Lots (SR-6)

On-site Non-Residential Retrofit Techniques
Bioretention (OS-7)
Swales (OS-8)
Infiltration Tench (OS-9)
Storm water Filters (OS-10)
Permeable Pavement (OS-11)
Storm Water Planters (OS-12)
Cisterns (OS-13)
Green Rooftops (OS-14)

On-site Residential Retrofit Techniques
Rain Barrels (OS-15)
Rain Gardens (OS-16)
French Drains and Dry Wells (OS-17)

Manual 4: Stream Repair Practices

Stream Cleanup Techniques
Stream Cleanups (C-1)
Stream Adoption (C-2)

Stream Repair Techniques
Boulder Revetment (R-3)
Rootwad Revetment (R-4)
Imbricated Rip Rap (R-5)
A-Jacks (R-6)
Live Cribwalls (R-7)
Streambank Shaping (R-8)
Coir Fiber Logs (R-9)
Erosion Control Fabrics (R-10)
Soil Lifts (R-11)
Live Stakes (R-12)
Live Fascines (R-13)
Brush Mattress (R-14)
Vegetation Establishment (R-15)
Wing Deflectors (R-16)
Log, Rock and J Vanes (R-17)
Rock Vortex Weir (R-18)
Rock Cross Vane (R-19)
Step Pools (R-20)
V Log Drops (R-21)
Lunkers (R-22)
Large Woody Debris (R-23)
Boulder Clusters (R-24)
Baseflow Channel Creation (R-25)
Parallel Pipes (R-26)
Stream Daylighting (R-27)
Culvert Modification (R-28)
Culvert Replacement and Removal (R-29)
Devices to Pass Fish (R-30)

Comprehensive Restoration Techniques
Combining Stream Repair Practices (S-31)
Channel Redesign (S-32)
De-channelization (S-33)

Manual 5: Riparian Management Practices

Site Preparation Techniques
Removal/Prevention of Dumping (SP-1)
Invasive Species Control (SP-2)
Urban Soil Preparation (SP-3)
Storm Water Management (SP-4)

Revegetation Techniques
Active Reforestation (F-5)
Park/Greenway Plantings (F-6)
Natural Regeneration (F-7)
Riparian Wetland Restoration (F-8)

Manual 6: Discharge Prevention Practices

Techniques to Find Discharges
Outfall Reconnaissance Investigation (D-1)
Chemical Outfall Monitoring (D-2)
In-stream Dry Weather Sampling (D-3)
In-Pipe Investigations (D-4)
Hotlines and Citizen Reporting (D-5)
Dye, Smoke and TV Testing of Suspect Pipes (D-6)
Infrared Aerial Thermography (D-7)
Finding Failing Septic Systems (D-8)

Techniques to Fix Discharges
Municipal Spill Management (D-9)
Structural Repairs (D-10)

Techniques to Prevent Discharges
Public Education/Employee Training (D-11)
Authority to Control Discharges (D-12)

Manual 7: Pervious Area Management Practices

Site Preparation Techniques
Removal/Prevention of Dumping (SP-1)
Invasive Species Control (SP-2)
Urban Soil Preparation (SP-3)
Storm Water Management (SP-4)

Re-vegetation Techniques
Active Reforestation (F-5)
Park/Greenway Plantings (F-6)
Natural Regeneration (F-7)
Riparian Wetland Restoration (F-8)

Manual 8: Pollution Source Control Practices

Neighborhood Stewardship Techniques
Low Input Lawn Care (N-1)
Reduced Pesticide Use (N-2)
Xeriscaping (N-3)
Natural Landscaping (N-4)
Tree Planting (N-5)
Yard Waste Composting (N-6)
Soil Reclamation (N-7)
Erosion Repair (N-8)
Septic System Cleanouts (N-9)
Safe Pool Discharges (N-10)
Safe Car Washing (N-11)
Driveway Sweeping (N-12)
Safe Deicer Use (N-13)
Household Hazardous Waste Collection (N-14)
Car Fluid Recycling (N-15)
Downspout Disconnection (N-16)
Single Lot Controls (N-17)
Pet Waste Pick-up (N-18)
Storm Water Practice Maintenance (N-19)
Bufferscaping (N-20)
Storm Drain Stenciling (N-21)

Hotspot Pollution Prevention Techniques
Vehicle Maintenance and Repair (H-1)
Vehicle Fueling (H-2)
Vehicle Washing (H-3)
Vehicle Storage (H-4)
Outdoor Loading and Unloading (H-5)
Outdoor Storage (H-6)
Spill Prevention and Response (H-7)
Dumpster Management (H-8)
Building Repair and Remodeling (H-9)
Building Maintenance (H-10)
Parking Lot Maintenance (H-11)
Turf Management (H-12)
Landscaping/Grounds Care (H-13)
Swimming Pool Discharges (H-14)
Unique Hotspot Operations (H-15)

Manual 9: Municipal Practices and Programs

Techniques for Streets and Storm Drains

Street and Parking Lot Sweeping (M-1)
Catch Basin Cleaning (M-2)
Road Maintenance (M-3)
Employee Training (M-4)

Best Practices for New Construction

Conduct Site ESA (RP-1)
Protect and Restore Natural Area (RP-2)
Natural Area Maintenance (RP-3)
Efficient Use of IC (RP- 4)
Employ BSD (RP-5)
Maximize Transportation Choices (RP-6)
Manage Rooftop Runoff (RP-7)
Courtyard Plaza Design (RP-8)
Minimize Parking Lot Runoff (RP-9)
Design Streetscapes (RP-10)
Municipal Pollution Prevention (RP-11)

Inspection and Enforcement

Enforcement (E-1)

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