# A Science Framework for Ecological Health in Seattle's Streams

*Prepared by*


Seattle Public Utilities
700 Fifth Avenue, Suite 4900
P.O. Box 34018
Seattle, WA 98124-4018

Stillwater Sciences
1314 NE 43rd Street, Suite 210
Seattle, WA 98105


Seattle Public Utilities

Stillwater Sciences

April 2007

**Suggested citation:**
Seattle Public Utilities and Stillwater Sciences. 2007. A science framework for ecological health in Seattle's streams. Final report. Seattle, Washington.

# Acknowledgements

The development of this report relied on interaction with and contributions from Seattle Public Utilities, government regulatory agencies, and industry representatives who were involved in the initial development process, attended the Science Framework workshops, and provided technical review of the draft Science Framework document. The input from the following contributors is acknowledged and appreciated:

| Affiliation | Contributors | |
|---|---|---|
| *Primary Authors* | | |
| Seattle Public Utilities | Julie Hall | |
| Stillwater Sciences | Stephen Ralph<br>Jennifer Aspittle | Sheri Woo |
| *Report Graphics Assistance* | | |
| Herrera Environmental Consultants | Craig Doberstein<br>Rhoda Bolton | Bret Magdasy |
| *Document Development and Workshops* | | |
| Seattle Public Utilities | Nancy Ahern<br>Clayton Antieau<br>Shelly Basketfield<br>Bruce Bachen<br>Cara Berman<br>Todd Bohle<br>Karl Burton<br>Mike Cooksey<br>Linda DeBoldt<br>Jim Erckmann<br>Adrienne Greve<br>Deborah Heiden<br>Michael Hinson<br>Darla Inglis | Louise Kulzer<br>Keith Kurko<br>Katherine Lynch<br>Brent Lackey<br>Judith Noble<br>Laura Reed<br>Pete Rude<br>Beth Schmoyer<br>Joe Starstead<br>Tracy Tackett<br>Ray Timm<br>Ingrid Wertz<br>Jean White<br>Laura Wishik |
| Northwest Hydraulic Consultants | David Hartley | |
| Parametrix, Inc. | Jan Cassin | |
| University of Washington | Derek Booth | |
| NOAA Fisheries | Sarah Morley | |
| USFWS | Paul Bakke | Roger Peters |
| *Reviewers of Draft Science Framework* | | |
| Brown and Caldwell | Scott Tobiason | |
| NOAA Fisheries | George Pess | |
| Seattle University | Jean Jacoby | |
| TetraTech | Rob Plotnikoff | |
| University of Washington | Derek Booth | |

# Executive Summary

### Introduction

This *Science Framework for Ecological Health in Seattle's Streams* ("Science Framework") serves as a roadmap for thinking about and making decisions to improve ecological health in Seattle's aquatic areas. This document does not provide a "destination" for Seattle's streams, but instead identifies preferred routes, ways to measure progress, and potential challenges. By promoting constructive conversations about sound ecological investments, environmental impacts, desired future stream conditions, and policy choices, the Science Framework provides a scientific foundation for choosing and moving towards a destination for streams, while balancing human uses of Seattle's watersheds.

The primary purpose of this document is to inform ongoing discussions about the future of Seattle streams, and to guide the activities of the City of Seattle's departments, citizens, and businesses that affect progress towards those future stream conditions. A secondary purpose of this document is to contribute to the development of an adaptive management program for the City's streams. Within an adaptive management program, the first tasks would be to define realistic goals and corresponding objectives for each stream, to identify the improvement actions and programs that will allow us to reach those goals and objectives, and to determine the actions' and programs' effectiveness through monitoring. In this document, we identify and define two categories of monitoring: (1) a "status-and-trends" monitoring program, and (2) effectiveness monitoring; both are used to guide the near-term and ultimate success of restoration programs for Seattle's streams.

Although useful information is presented throughout this document, three sections are of particular note. These three sections include: (1) listings of primary and secondary indicators, useful for gauging the current status of Seattle's streams (Section 2.3), (2) an outline and example of an adaptive management process that is recommended so that realistic goals can be identified (Sections 3.2 and 3.5), and (3) specific stream improvement recommendations for Seattle's five primary streams (Appendix G).

### What are indicators of ecologically healthy streams?

While we do not explicitly declare the goals and destinations for each of Seattle's streams (that will be the task of stakeholders, scientists, and decision makers working collectively), we do assume that improving stream ecological health is a shared desire. We define ecologically healthy streams as those that exhibit ecological functions and features that support diverse, native, and self-sustaining aquatic, benthic and riparian communities. Specific ecological functions include those that support successful spawning, incubation, and rearing habitat for native fish, such as salmon and trout; and a productive benthic invertebrate community.

Although indicators of ecological health are many and varied, some are more useful than others. In the draft version of the Science Framework report, over 30 indicators were proposed in response to suggestions from workshop participants (Appendix E). After technical review by the peer reviewers, the number of proposed indicators decreased to 9 in a primary or "core" group of indicators, and 4 in a secondary group of indicators (Table A).

**Table A.** Proposed indicators of ecological health include the following primary and secondary metrics.

| Stream attribute | Primary indicators | Secondary indicators |
|---|---|---|
| Hydrology | $T_{Q\ mean}$ (flow flashiness) | |
| Water quality | Maximum temperature<br>Dissolved oxygen | Turbidity/suspended solids/or other<br>Toxicity |
| Instream habitat | Bank armoring<br>Woody debris<br>Pool spacing<br>Shading<br>Artificial fish barriers | Bed surface particle size distribution<br>Floodplain connectivity |
| Biological communities | Benthic Index of Biological Integrity<br>Fish Biomass | |

**How should we approach making improvements?**

To improve Seattle's watershed and stream ecological health, many types of improvement actions have already been implemented, such as natural drainage systems, riparian plantings, and pollution prevention plans. However, documentation of their effectiveness in improving overall stream health is very limited, either due to limited project opportunities or due to limited monitoring funds. This lack of documentation leaves resource managers unable to assess biological and ecological benefits associated with these actions. Without such information, managers and decision makers are unable to determine whether to continue implementing certain types of projects, or to identify realistic stream goals.

The adaptive management process would attempt to fill this information void. In an adaptive management process, stakeholders, resource managers, and scientists try to incorporate new and on-going improvement actions into studies that test science-based hypotheses. Based on results, improvement actions can be adjusted as necessary. Because land use activities and management decisions that affect urban streams will continue even without full knowledge of their effects, employing the adaptive management process is a way to continue land and resource management while acknowledging the uncertainty, but doing so in a way that allows one to learn and make adjustments in future actions.

A basic and general adaptive management process would include the following actions. First, for each stream, management goals and associated objectives would be identified. Based on those goals, improvement actions and programs can be defined and implemented. Effectiveness monitoring of individual improvement actions and programs would be tied to testing hypotheses upon which the improvement actions are based. The status-and-trends monitoring would document the improvement actions' cumulative effects, accrued over many years and many locations. The monitoring data are then used to analyze and re-visit the improvement actions and overall management goals. We can then assess whether management goals are realistic, whether improvement actions met expectations or need to be modified, and ultimately after many iterations, whether ecological health has improved.

Some considerations about managing Seattle's streams include:

- Expectations should be set based on what can realistically be achieved, given the ongoing human actions that impact ecological health;
- Future improvement actions should be based on clear objectives and hypotheses about cause and effect relationships, and should be undertaking only with an accompanying commitment to effectiveness monitoring;
- Future improvement actions should consider the scale and locations of impacts, acknowledge unique stream conditions, and be implemented in the proper sequence.

**Who has a role in making improvements?**
Many entities affect stream conditions; achieving stream improvements will rely on the efforts from many members of the community, including:

- Watershed residents and businesses
- Shoreline and stream-side property owners
- The City of Seattle
- Land developers
- State and Federal government

To achieve stream health improvement, we need to tie together all actions, from potentially harmful to improvement, undertaken by various groups and agencies. Each group and agency can benefit from seeing their piece as a part of the whole; any additional and ongoing actions can be specifically planned to "fit in" with the stream-specific goals and objectives. Because the current state of Seattle's urban streams is a result of many management actions by many entities, a return to improved ecological states will similarly require a substantial number of actions that cumulatively create a benefit.

**What are next steps to move forward?**
To take action with this Science Framework, the next critical step is making this information available to and engaging other City departments; other local, state and federal agencies; and businesses, citizens, and community groups with a stake in the future of Seattle's streams. To clearly articulate the information, having a common language and vocabulary about monitoring, stream processes, ecological health, and goals, is critical. Status-and-trend monitoring will be important for tracking the cumulative progress of future and ongoing improvement actions and programs; effectiveness monitoring will help us understand whether our improvement actions "work." Identifying goals for each of Seattle's primary streams, and developing status-and-trends and effectiveness monitoring programs, are central to adaptively managing our watersheds and truly making progress in improving aquatic ecosystems.

# Table of Contents

**1 INTRODUCTION ..... 1**

1.1 Science Framework Components ..... 1
1.2 Science Framework Development ..... 2
1.3 Science Framework Use ..... 2
1.4 Recognized Assumptions ..... 5

**2 WHAT ARE INDICATORS OF ECOLOGICALLY HEALTHY STREAMS? ..... 6**

2.1 Definition of Ecological Health ..... 6
2.2 Stream Ecosystem Processes and Effects of Urbanization ..... 6
2.2.1 Urbanization of Seattle's creeks ..... 7
2.3 Metrics and Indicators of Ecological Health ..... 9
2.3.1 Primary indicators ..... 9
2.3.2 Secondary indicators ..... 13

**3 HOW SHOULD WE APPROACH MAKING IMPROVEMENTS? ..... 15**

3.1 Adaptive Management in Seattle Stream Watersheds ..... 15
3.2 Setting Realistic Goals ..... 22
3.2.1 Acknowledging challenges ..... 22
3.3 Strategies for Making Improvements ..... 26
3.4 Strategic Planning of Improvement Actions ..... 35
3.5 An Example Conceptual AM Plan ..... 36
3.5.1 Using AM studies to inform realistic expectations ..... 41

**4 WHO HAS A ROLE IN MAKING IMPROVEMENTS? ..... 43**

**5 WHAT ARE NEXT STEPS TO MOVE FORWARD? ..... 45**

**6 LITERATURE CITED ..... 48**

## List of Tables

Table 2-1. Proposed primary indicators for tracking ecological health in Seattle's creeks ..... 11
Table 2-2. Proposed secondary indicators for tracking ecological health in Seattle's creeks ..... 13
Table 3-1. Parties involved in an adaptive management program ..... 19
Table 3-2. Examples of human activities that continue to impact and limit the ecological health of Seattle's waterbodies. ..... 24
Table 3-3. Improvement actions, their associated hypotheses, their intended effects and benefits, and possible indicators once the AM process has been implemented for many years. ..... 28

## List of Figures

Figure 1-1. Vicinity map. ..... 3
Figure 3-1. Simplified adaptive management process ..... 17
Figure 3-2. The Evaluation Cycle and its relationships to Seattle's current and ongoing watershed and stream restoration planning, which are annotated in *italics*. ..... 20
Figure 3-3. A continuum of watershed and related stream conditions in urbanized areas. ..... 23

Figure 3-4. Relationships between individual improvement actions, effectiveness monitoring, and status and trend monitoring. ..... 34
Figure 3-5. General stream improvements based on stream types, considering location and scale of impairment causes and effects and potential remedial actions. ..... 37
Figure 3-6. The graphs represent adaptive management studies needed to determine if culvert replacement would increase fish. ..... 42
Figure 5-1. Schematic of City of Seattle efforts and activities that could be informed by or are proposed in the Science Framework.. ..... 47

## List of Appendices

A. Glossary.
B. Memo: Similar "Framework" programs in other cities.
C. Descriptions of Seattle's Five Primary Streams.
D. Conceptual Stream Model and Descriptions and Stream Habitat and Channel Types.
E. Initial List of 30 Indicators.
F. Bibliography.
G. Stream-specific improvement recommendations:
- Fauntleroy Creek
- Longfellow Creek
- Pipers Creek
- Taylor Creek
- Thornton Creek

H. Indicators, Likely Methods, and Cost Considerations.

# Definitions of Abbreviations, Acronyms, and Initialisms

See the Glossary, Appendix A, for further definitions.

| Term | Definition |
|---|---|
| AM | Adaptive management |
| B-IBI | Benthic Index of Biological Integrity |
| °C | Degrees Celsius or centigrade |
| City | City of Seattle |
| CWA | Clean Water Act |
| $D_{50}$ | Median particle size diameter |
| $D_{84}$ | Particle size diameter that equals or exceeds 84 percent of the streambed particles |
| DO | Dissolved oxygen |
| DPD | Seattle Department of Planning and Development |
| e.g. | *exempli gratia,* for example |
| EPA | United States Environmental Protection Agency |
| ESA | Federal Endangered Species Act |
| °F | Degrees Fahrenheit |
| Framework | Science Framework for Ecological Health in Seattle's Streams |
| ft | Foot or feet |
| i.e. | *id est*, that is |
| L | Liter |
| m | Meter |
| LWD | Large woody debris |
| mg | Milligram |
| NTU | Nephelometric turbidity unit |
| Parks | Seattle Department of Parks and Recreation |
| PCB | Polychlorinated biphenyl |
| pH | Potential of hydrogen |
| PSM | Pre-spawning mortality |
| Q | Discharge |
| RIVPACS | River Invertebrate Prediction and Classification System |
| ROW | Restore our Waters [initiative] |
| SOTW | State of the Waters [report] |
| SPU | Seattle Public Utilities |
| $T_{Q\ mean}$ | The fraction of the year in which the mean annual discharge is exceeded |
| W/d | Width-to-depth [ratio] |

This page intentionally left blank.

# 1 INTRODUCTION

This *Science Framework for Ecological Health in Seattle's Streams* ("Science Framework") is a roadmap for thinking about and making decisions to improve ecological health in Seattle's aquatic areas. This document does not provide a "destination" for Seattle's streams, but instead identifies preferred routes, ways to measure progress, and potential challenges. By promoting constructive conversations about sound ecological investments, environmental impacts, desired future stream conditions, and policy choices, the Science Framework provides a scientific foundation for choosing and moving towards a destination for streams, while balancing human uses of Seattle's watersheds.

The primary purpose of this document is to inform ongoing discussions about the future of Seattle streams, and to guide the activities of the City of Seattle's departments, citizens, and businesses that affect progress towards those future stream conditions. A secondary purpose of this document is to contribute to the development of an adaptive management program for the City's streams. Within an adaptive management program, the first tasks would be to define realistic goals and corresponding objectives for each stream[1], to identify the improvement actions and programs that will allow us to reach those goals and objectives, and to determine the actions' and programs' effectiveness through monitoring. In this document, we identify and define two categories of monitoring: (1) a "status-and-trends" monitoring program, and (2) effectiveness monitoring[2]; both are used to guide the near-term and ultimate success of restoration programs for Seattle's streams.

## 1.1 Science Framework Components

This Science Framework report contains the following sections:

1. The "Introduction" discusses what the Science Framework is, how it was developed, and how it is intended to be used.
2. "What are indicators of ecologically healthy streams?" defines "ecological health", briefly provides an overview of stream functions, and proposes indicators that will indicate stream health through time.
3. "How should we approach making improvements?" recommends an adaptive management process for improving stream conditions and discusses setting goals and improvement strategies in additional detail. This section also contains a conceptual adaptive management plan example.
4. "Who has a role in making improvements?" identifies who has opportunities for managing and improving stream ecological health.
5. "What are next steps to move forward?" illustrates the number of efforts that can take guidance from this document to implement projects and programs that will improve ecological health in Seattle's streams.

[1] Goals are broad statements of the ultimate desired state; objectives serve to separate the necessary actions and milestones to incrementally achieve the goal.

[2] A "status-and-trends" monitoring program that examines relevant indicators through time is critical for identifying overall stream health changes and the cumulative effects of all watershed and stream activities. "Cause-and-effect" monitoring (or effectiveness monitoring) examines project outcomes and is critical for understanding if our actions are effective and worth repeating or if they need to be changed.

In an effort to keep this Science Framework document concise, much of the supporting information is in the appendices. A glossary of terms in also included in Appendix A.

This Science Framework focuses on Seattle streams, with particular emphasis on the five major streams within the City's boundaries (Fauntleroy, Longfellow, Piper's, Taylor, and Thornton creeks; Figure 1-1). This document relies heavily on the "State of the Waters" (SOTW) report (Seattle Public Utilities [SPU] 2007, in prep.), in which existing information for the five major streams is compiled. A similar science framework should be developed for the other waters within Seattle, including the shoreline of Puget Sound, Lake Washington, the Ship Canal and Lake Union, and the Duwamish River.

## 1.2 Science Framework Development

Developing the Science Framework consisted of:

- Review and analysis of similar programs occurring in other municipalities or counties (Appendix B);
- Review and analysis of pre-development stream conditions through a literature search (Appendix C);
- Formulation of a conceptual creek model, representing pre-development and existing urban conditions (Appendix D);
- Identification of an initial set of ecological health indicators (Appendix E);
- Workshops during which attendees discussed the Science Framework approach in general, and the selected indicators specifically;
- Circulation of a draft Science Framework document, which was subject to technical review by representatives of resource agencies and academia;
- Substantial revision of the draft Science Framework document, to address comments made during the technical review.
- Generation of a bibliography that lists sources that were consulted but not formally cited (Appendix F);
- Generation of improvement recommendations for Seattle's five primary streams (Appendix G); and
- Review of likely methods and cost considerations for the selected indicators (Appendix H).

This document serves as a technical foundation for understanding the essential components of healthy stream ecosystems, based upon our current scientific understanding and acknowledgement that our understanding of ecological systems is incomplete and sometimes uncertain. The framework is also based upon the premise that improvements should lead to stream systems that maintain themselves, which should lead to fewer conflicts between stream systems and urban land uses (such as flooding), and less ongoing maintenance.

## 1.3 Science Framework Use

Within Seattle Public Utilities' (SPU's) jurisdiction and the City of Seattle, many planned and on-the-ground activities are occurring that affect Seattle's water bodies. We envision this document being used in a number of efforts:

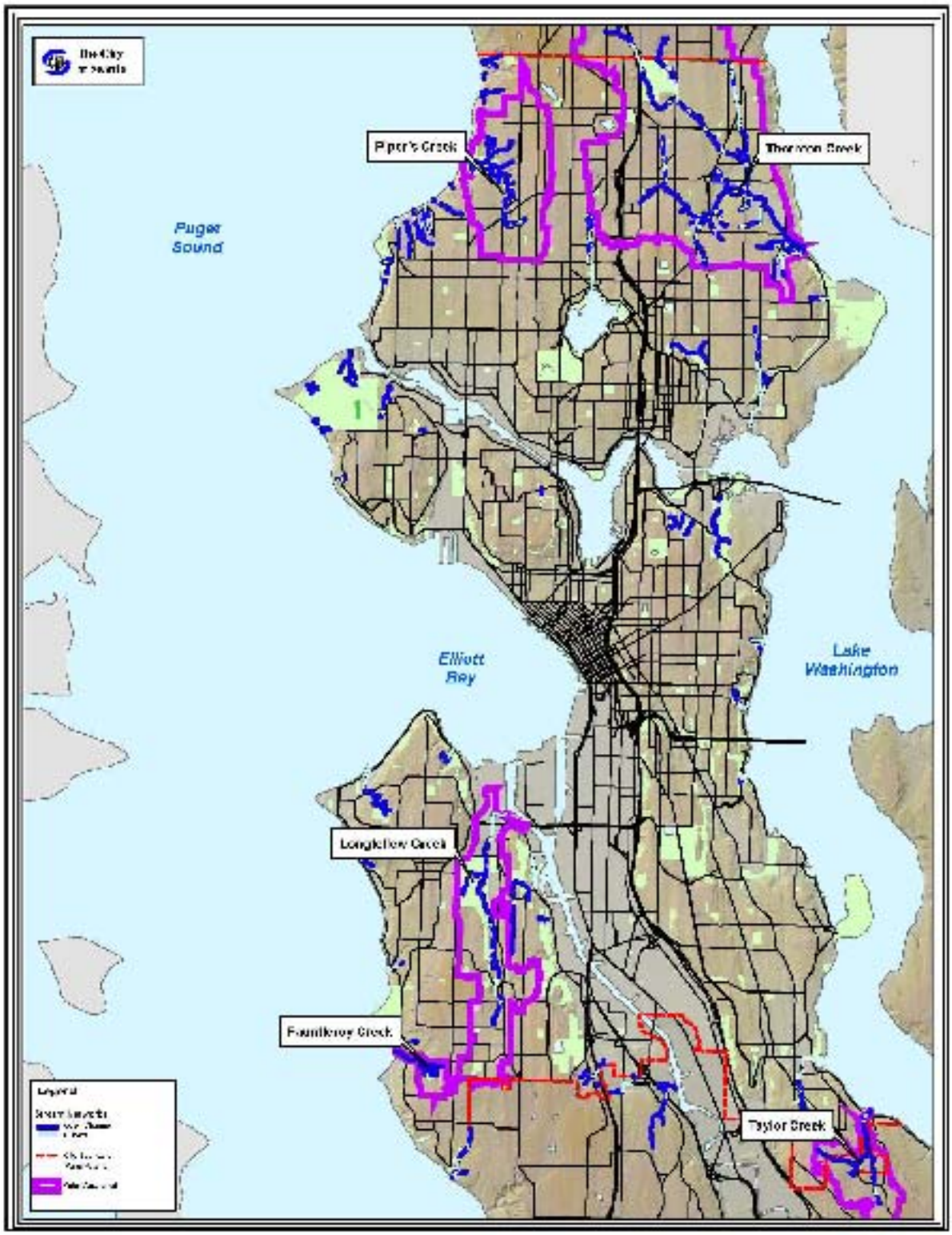


**Figure 1-1. Vicinity map.**

This page intentionally left blank.

- Setting realistic and measurable ecosystem health goals and creek-specific objectives under the *Restore our Waters* (ROW) initiative;
- Also under the ROW initiative, developing restoration plans and identifying how each City department can contribute to reaching those ecosystem health goals (e.g., SPU stormwater management, Department of Planning and Development (DPD) planning, regulations, and permitting, Seattle Department of Transportation road improvements);
- Supporting development of SPU surface water service levels;
- Supporting development of an integrated water quality and habitat monitoring program, including both status and trends and effectiveness monitoring efforts;
- Guiding the City of Seattle's habitat matching grant program;
- Guiding effective and strategic mitigation actions that are proposed in response to regulatory requirements;
- Monitoring and analyzing effects on aquatic resources from projects that are proposed by the City, businesses, or private citizens;
- Guiding an adaptive management process, allowing resource managers to prioritize improvement projects;
- Guiding applied research to test our assumptions about the restoration of urban streams.

## 1.4 Recognized Assumptions

To develop the Science Framework, a number of assumptions were used:

Assumption 1: A healthy stream exhibits the necessary ecological functions and features that support diverse, native, self-sustaining aquatic and riparian communities;

Assumption 2: Relative to their pre-development condition, Seattle's streams are not "ecologically healthy" and many citizens want them to be improved;

Assumption 3: The City has certain legal obligations regarding streams (e.g., Growth Management Act, Clean Water Act, Endangered Species Act), but there are also legal constraints on the City's ability to require or provide protection or restoration of streams (private property rights, limited municipal authority, preemption by state and federal law, etc.). Further, the sources of pollution and causes of deteriorating stream health are not all under the City's control (e.g., atmospheric deposition and discharges permitted by other governmental agencies);

Assumption 4: Collectively, the government of the City of Seattle, Seattle citizens, Seattle businesses, and others, perform or are responsible for a number of activities that affect the health of Seattle's streams; and

Assumption 5: Indicators of stream health can be identified and tracked over time to document areas needing improvement, and when associated with specific hypotheses of management actions, they can help to evaluate the outcomes of restoration "success."

# 2 WHAT ARE INDICATORS OF ECOLOGICALLY HEALTHY STREAMS?

To lay a basic foundation for all users of this Science Framework, this section includes a definition of "ecological health", briefly describes undisturbed stream processes, characterizes the effects of urbanization on Seattle's streams, and proposes indicators that can be used to track stream health through time.

## 2.1 Definition of Ecological Health

The Government of British Columbia (2001) defines "ecological health" as "the occurrence of certain attributes that are deemed to be present in a healthy, sustainable resource, and the absence of conditions that result from known stresses or problems affecting the resource." For purposes of these initial efforts, we define ecologically healthy streams as those that exhibit ecological functions and features that support diverse, native, and self-sustaining aquatic, benthic and riparian communities. Specific ecological functions include those that support successful spawning, incubation, and rearing habitat for native fish, such as salmon and trout; and a productive benthic invertebrate community.

## 2.2 Stream Ecosystem Processes and Effects of Urbanization

Stream ecosystems are shaped by a number of physical, chemical, and biological processes (Naiman et al. 1995; Spence et al. 1996). These processes operate over short and long time frames, and over small and large areas. In the past millions of years, long-term and large-scale glaciers, earthquakes, and other tectonic activity (i.e., volcanic eruptions) in the Pacific Northwest have created the physical template upon which Pacific Northwest aquatic systems are based. These processes and events shape watershed characteristics such as topography, geology, and climate, which in turn shape vegetative cover and watershed soils. Collectively, these processes influence how water, sediment, wood, and nutrients are moved from land to streams or other watercourses (Appendix C) (Spence et al. 1996). The riparian corridor serves as the interface between the upland, terrestrial system and that of the aquatic environment (Gregory et al. 1991).

Using water, sediment, wood and nutrient inputs from the watershed, a stream is subject to processes that occur in the stream and in the surrounding riparian corridor that shape its habitat (Naiman et al. 1995). Precipitation, soil structure, and land cover largely define the rate at which water reaches the stream. Dissolved minerals and organic compounds determine the stream's water quality. The riparian zone has many roles within the stream: supplying shade to moderate water temperatures, providing bank stability from plant roots, controlling sediment inputs to streams by trapping sediment and filtering surface runoff, contributing organic litter and large woody debris from vegetation, and mediating the flow of nutrients (Spence et al. 1996). Instream and riparian processes interact with one another, determining the flow regime, water quality, riparian habitat, and instream habitat. These stream and riparian characteristics collectively influence instream and riparian biological communities, including benthic invertebrates, fish, and wildlife. Biological processes such as organic decay, respiration, and feeding also affect physical and chemical processes and characteristics in the stream, such as water temperature or nutrient cycling.

The processes described above are most readily observed in forested environments that were prevalent in Seattle's past, but are now quite limited. A description of watershed and stream processes specific to the Puget Lowland area is given as a report appendix (Appendix D), with more detail presented elsewhere (SPU 2007, in prep.). A broader description of stream processes can also be found in Spence et al. (1996).

### 2.2.1 Urbanization of Seattle's creeks

Over the past 150 years, Seattle has experienced progressive and significant urban development that has drastically altered the features of the City's watersheds. Most forest and wetland areas have been paved and converted to industrial, commercial, residential, and open space land uses. In the course of this development, Seattle's watersheds have largely become impervious surfaces, covered by roads, parking lots, roofs, and sidewalks. While development has created a highly livable environment for humans, these changes have greatly altered the fundamental processes and ecological health of Seattle's streams (see SPU 2007, in prep.).

#### 2.2.1.1 Urbanization effects on hydrology and water quality

All of Seattle's creeks experience high peak flows and "flashiness" when stormwater rapidly runs off impervious surfaces (roads, buildings, parking lots) and enters drainage systems for fast delivery to streams and eventually Puget Sound. Although the flow record is less than 10 years and represents limited locations, the 2-year flow event has increased to approximately four or five times that expected under forested watershed conditions in most streams. Stream flow is a major factor driving instream channel processes, such as sediment recruitment and transport, bank and streambed erosion, and ultimately the formation and maintenance of instream habitat. Seattle streams' flow conditions are damaging stream habitat, and this damage is exacerbated by bank armoring and encroachment by buildings and other structures, which minimize or eliminate connections between streams and their floodplains. In urban streams, high flows and their associated habitat degradation restrict the types and abundances of stream biota.

Water quality also deteriorates with urbanization. Stormwater washes a variety of pollutants off of roads, lawns, and industrial areas into streams. For most of Seattle's streams, Washington State water quality criteria for the protection of aquatic life are exceeded infrequently, but do occur. The exceedances that do occur are most frequently for fecal coliform bacteria, dissolved oxygen, and water temperature. Other parameters that generally meet state water quality criteria or benchmarks include suspended solids and turbidity.

Fecal coliform bacteria levels are high and frequently exceed the state water quality criteria in the four urban streams that have been tested (Thornton, Piper's, Longfellow, and Fauntleroy creeks). Bacteria levels are typically higher in storm runoff samples than in non-storm samples due to the impacts of nonpoint source pollution on urban storm water runoff. Limited testing of fecal coliform sources in Thornton and Piper's creeks indicates that birds and urban wildlife (e.g., rodents) are the largest sources of bacteria, while human sources are very low (Herrera 2006).

Stream dissolved oxygen (DO) and temperature exhibit distinct seasonal patterns, with water temperature generally higher in the summer and lower in the winter. In Longfellow and Thornton creeks, dissolved oxygen and temperature occasionally fail to meet state water quality criteria in the summer. During the summer, the loss of canopy cover, warm stormwater runoff from paved surfaces, and changes in tributary and groundwater flow likely account for lower dissolved oxygen and higher temperatures.

There are no state water quality criteria for nutrients, and the available criteria for total nitrogen and total phosphorous were developed by the Environmental Protection Agency to characterize streams that are minimally impacted by human activities. These criteria are frequently exceeded in Seattle's urban streams. Phosphorous exceedances occur more frequently during storm flow events.

Metal and organic pollutant data are very limited and mostly were collected during non-storm events. Based on that limited sampling, metal concentrations in urban streams occasionally exceed state water quality criteria. Similar to fecal coliform bacteria patterns, most metal concentrations are higher in storm event samples than in non-storm samples. An exception is zinc, which exhibits comparable concentrations during both storm and non-storm events.

#### 2.2.1.2 Urbanization effects on habitat conditions

Instream habitat quality varies widely within and among Seattle's streams. In general, habitat quality is degraded by high and flashy flows, the lack of floodplain connections to relieve habitat damage caused by high flows, and little large instream wood to create diverse habitat and scour pools. These factors lead to simple, uniform stream conditions where pools are sparse and gravel and cobble sediments that support instream biota are scarce. In addition, many tributary and intermittent streams have been piped or channelized, affecting the nutrients and water that feed mainstem streams and reducing habitat for many aquatic species that use tributaries and intermittent streams for refuge and rearing.

Surrounding land uses appear to have a large effect upon instream and riparian conditions. High quality instream habitat tends to be limited to reaches in public parks or open spaces, such as in Carkeek Park in the Piper's Creek watershed, and in Lakeridge Park in the Taylor Creek watershed. Most park areas have limited bank armoring, and buildings and roads are located away from the streams, promoting stream and riparian processes that maintain habitat. However, even areas with higher quality habitat tend to lack the number and quality of pools and woody debris that would be expected in less intensively-used watersheds. Lower quality instream habitats suffer from bank armoring, nearby encroachment, and degraded riparian areas, which often coincide with adjacent residential and commercial land uses. Both Longfellow and Thornton creeks, where development occurs along most of the stream, contain large percentages of lower quality habitat and rather small percentages of high quality instream habitat. In contrast, the riparian zones along Piper's and Taylor creeks are dominated by high quality habitat (over 65% of the stream), that occurs almost exclusively within park areas. However, these riparian areas face challenges from invasive species like English ivy (*Hedera helix*) and Himalayan blackberry (*Rubus armeniacus*), which can out-compete native plant species and degrade riparian communities.

Low-quality riparian areas are dominated by grass, landscaping, invasive species, and the absence of trees that provide shade and bank stability. These low-quality areas tend to occur in residential and commercial areas where invasive plants are either allowed to take over or where land owners replace native plants with ornamentals. For example, Thornton Creek, which has the highest percentage of watershed in residential and transportation uses, also has less than 10% of its riparian zone in "good" condition. Low-quality riparian areas allow sunlight to heat the stream, contribute little to instream production, and disrupt the connections between riparian and instream processes and habitats. Often, the stream banks of these areas are unstable.

## 2.3 Metrics and Indicators of Ecological Health

Status and trend monitoring programs are designed to establish baseline conditions, to track changes over many years, and to assess the cumulative net result of multiple, watershed-wide management actions. Such monitoring is accomplished through tracking key ecological indicators through time at key locations. Status and trend monitoring will allow us to understand present conditions in Seattle's waters (status), to compare information over a broader geographic area and time frame (trends), and to compare results with those from similar basins located outside of the City boundary. Status and trend monitoring incorporates scales of time and space that are larger than the scales of site specific monitoring.

Although trend indicators of ecological health are many and varied, some are more useful than others. In the draft version of the Science Framework report, over 30 indicators were proposed in response to suggestions from workshop participants (Appendix E). After technical review by the peer reviewers, the number of proposed indicators decreased to 9 in a primary or "core" group of indicators, and 4 in a secondary group of indicators.

We anticipate these indicators will be useful while status and trend and effectiveness monitoring plans are being developed (Appendix H); the indicators should be re-evaluated during monitoring plan development. The following indicators will also be useful by providing time-series measurements, which are not currently available for Seattle streams.

### 2.3.1 Primary indicators

While numerous stream conditions can be measured, not all are responsive, relevant, and/or practical. Indicators were selected if they were considered ecologically meaningful and reflective of changes in key watershed and stream processes. Indicators were researched through: (1) examining existing literature and the approaches of other cities that are also improving their respective streams, (2) discussing selections with consulting and academic scientists, and (3) holding workshops to solicit input from others working on these issues. Potential indicators were evaluated for (adapted from Bauer and Ralph 1999):

1. Relevance to biota of interest (salmonids and benthic invertebrates).
2. Responsiveness to management. Can the indicator be used to distinguish between natural disturbance or variability and those changes attributed to specific management actions?
3. Appropriateness and importance to urban watersheds and streams.
4. Ease of quantifying. What are the indicator's data quality issues (for example, is it reliable in terms of accuracy and/or precision)? Can we distinguish a "true" change from natural variability (often called the signal-to-noise ratio)?
5. Feasibility. Can the indicator be measured to an acceptable data quality level given constraints on time and cost of data collection?

The proposed primary indicators are:

- $T_{Q\ mean}$ (time, expressed as the fraction of the year in which the mean annual discharge is exceeded)
- Maximum daily water temperature (7-day moving average of the daily maximum stream temperature between June and September)
- Dissolved oxygen (lowest 1-day minimum, in mg/L, concentration dependent on temperature)

- Bank armoring (% of channel length armored)
- Woody debris
- Pool spacing (pools with residual depths >0.3 m [~1 ft], measured as # pools per 100 m or as # bankfull widths or channel widths per pool)
- Artificial fish barriers (# of barriers caused by culverts, weirs, and man-made gradient changes)
- B-IBI (Benthic Index of Biological Integrity, an index based on aquatic macroinvertebrates, ranging from 10 to 50)
- Fish Biomass (in mass per distance, and broken down by seasonal distribution and relative abundance)

The indicators, their importance, and ranges of anticipated values are summarized in Table 2-1. Possible data collection methods and labor estimates were also reviewed (Appendix H). A number of indicators focus on fish presence and distribution. Fish, and particularly salmon, became a focus species in this report due to their social and cultural importance in the Pacific Northwest, and due to the amount of information that is readily available. However, indicators that focus on other animal communities, such as amphibians, would also be important for accessing overall stream health.

**Table 2-1.** Proposed primary indicators for tracking ecological health in Seattle's creeks.

| Indicator or metric | Popular term for indicator | Importance and range of values |
|---|---|---|
| $T_{Q\ mean}$ | Flashiness | High and flashy stream flows can erode stream banks and beds, damage instream habitat, and cause flooding, particularly when the stream has no accessible floodplain. Larger $T_{Q\ mean}$ values are associated with streams exhibiting sustained storm flow periods and gradual flow recession rates (i.e., more stable stream flows). Smaller $T_{Q\ mean}$ values are associated with brief but high peak flow periods and rapid recession rates (i.e., more flashy stream flows). For selected streams in the Puget Sound basin (Konrad and Booth 2002):<br>• Three urban creeks = range 0.25 to 0.30, coefficient variation ranged from 0.11 to 0.16<br>• Three suburban creeks = range 0.31 to 0.39, coefficient variation ranged from 0.10 to 0.11<br>• Four rural creeks = range 0.27 to 0.35, coefficient variation ranged from 0.09 to 0.21 |
| Maximum daily water temperature (7-day average) | High temperature | High water temperatures during the summer increase fish metabolism and induce stress. High temperatures >22°C can become lethal; slightly lower temperatures but >17 °C can render otherwise suitable habitats unusable. Preferred temperatures for salmonids generally range between 12 and 14°C (Spence et al. 1996). Temperatures between 10 and 17°C are common for acceptable summer habitat use (Poole et al. 2001). Seattle streams are designated for use as either core summer salmonid habitat or salmonid spawning, rearing, and migration. The Washington State water quality criterion for aquatic life (adopted December 2006) in "Core Summer Salmonid Habitat" is 16°C (60.8°F). The criterion for "Salmonid Rearing, Spawning and Migration" designations is 17.5°C (63.5°F). |
| Dissolved oxygen concentration in water column | Dissolved oxygen | DO in mg/L varies with temperature. However, DO concentrations below 6.5 to 7.0 mg/L greatly impair adult salmon performance (regardless of temperature) (Spence et al. 1996). The Washington State water quality criterion for aquatic life (adopted 2006) in "Core Summer Salmonid Habitat" is >9.5 mg/L. The criterion for "Salmonid Rearing, Spawning and Migration" designations is >8.0 mg/L. |
| Bank armoring (%) | Bank hardening | Bank armoring limits sediment recruitment and floodplain connections, and is often associated with fill. There is no identified threshold at which bank armoring becomes more or less problematic, however, less armoring is widely accepted as better. In Portland's urban areas, bank armoring reaches 40 to 60% (Gregory et al. 2002). In Seattle streams, armoring ranges between 6 and 28% (SPU 2007, in prep.). |

| Indicator or metric | Popular term for indicator | Importance and range of values |
|---|---|---|
| Woody debris | Woody debris | Woody debris traps sediment, forms pools, and helps to stabilize stream banks and beds. Piece size should be scaled to channel dimensions, but generally of sufficient size to remain stable under typical 2-year flow events. Guidelines for urban streams are few. From streams witin forested Cascade drainages LWD pieces (greater than 2 m length and 25.4 cm [10 in.] diameter) per 100 m range from 26 (25$^{th}$ quartile), to 29 (median), to 38 (75$^{th}$ quartile) (Fox et al. 2003). |
| Pool spacing | Pool spacing | Pools are important for juvenile salmonid rearing and adult holding. Both spacing and depth are critical factors in determining relative quality of aquatic habitat and are positively correlated with LWD within the channel. Especially in urban streams, pools of sufficient depth must be maintained or enhanced to support a sustainable population of native fishes. Residual pool depths sufficient for migrating adult salmon (>0.7 ft) and rearing juveniles (>2.0 ft) (Bjornn and Reiser 1991, Ralph et al. 1994). For this metric, pools are defined as those with a residual depth >0.3 m.<br><br>The distance between pools is a critical feature that directly affects overall stream productivity (Buffington et al. 2003). Streams with too few pools, spaced too far apart will fail to support many juvenile salmon and trout. Pool spacing is highly dependent on wood frequency and varies based on stream type (e.g., step-pool, pool-riffle, see Appendix D). One study found between 2 and 3 pools per 100 m, with a minimum pool depth of 1 m, for "properly functioning conditions" (Sossa and Booth 2004). In Puget Sound forested lowlands, pool spacing can vary between 3 and 10 pools per 100m (Buffington et al. 2004). |
| Shading | Shading or canopy cover | In riparian corridors, loss of trees can affect stream temperatures, inputs of leaf litter and other organic materials, and other inputs for stream production. Remotely appraising the lineal length of stream that supports trees on the margins (e.g., by aerial photographs or satellite imagery) will indicate the amount of shade or canopy cover. |
| Artificial fish barriers | Culvert barriers | The distribution of fish within a stream can be influenced naturally by the stream size, presence of waterfalls, and steep stream gradients. Artificial physical barriers to upstream migration can also interrupt the passage of fish and other animals throughout a stream channel. Consistent with Washington State law (WAC 220-110-070), there should be no net loss of productive capacity of fish habitat from stream crossings or other structures. |
| B-IBI, Benthic Index of Biological Integrity | Macroinverte-brates (aquatic insects) | B-IBI scores indicate the degree of human impact on streams, calibrated for the Puget Sound Lowland. Scores ranges from 10 to 50 and are categorized as very poor (10–16), poor (18–26), fair (28–36), good (37–44) and excellent (>44). |

| Indicator or metric | Popular term for indicator | Importance and range of values |
|---|---|---|
| Fish biomass | Fish | Measurements of fish biomass indicate stream productivity and the ability to support native fish communities. Year to year estimates of distribution, abundance, and growth for both native and non-native fish will provide evidence of increasing or decreasing trends in overall condition of native salmon and trout, and overall species composition of the stream community. Fish biomass, abundance, and growth can vary widely depending on stream type, location, and size. |

### 2.3.2 Secondary indicators

Secondary indicators passed criteria to be included in the primary group, but were "downgraded" because they are either difficult to measure, expensive to measure reliably, or questionable in terms of being responsive to development (Table 2-2).

**Table 2-2.** Proposed secondary indicators for tracking ecological health in Seattle's creeks

| Indicator or metric | Popular term for indicator | Importance, secondary rationale, and range of values |
|---|---|---|
| Bed surface particle size distribution | Spawning gravel quality | Sediment sizes affect spawning success and benthic production. Urban streams are typically characterized by insufficient coarse sediment and too much fine sediment. Wolman pebble counts determine $D_{50}$ and $D_{84}$ particle sizes (average values for the "b-axis" diameter of the 50% and 84% particles) at index spawning areas for each stream.<br><br>Ranges of expected values are a function of both localized geology (source characteristics) and flow frequencies of sufficient magnitude that transport bed particles downstream. Expectations for predominant substrates in Puget Sound lowland streams can be generally characterized as follows:<br>• In low gradient (<1%) headwaters/wetlands – predominantly sand/fines<br>• In low gradient (<2%) floodplain reaches– predominantly gravel<br>• In higher gradient reaches (>2%) – predominantly gravel and cobble<br><br>This indicator's measurement reliability is good and has low variability. It does a poor job of discriminating smaller grain sizes and therefore is not useful for determining percent fines in bedload. However, as a general characterization of gravel deposits at spawning habitat, it is an important descriptor, and changes in bed particle size or relative percent of fines in bed substrate at selected locations is useful for gauging overall habitat suitability. |

| Indicator or metric | Popular term for indicator | Importance, secondary rationale, and range of values |
|---|---|---|
| Turbidity, suspended solids, or other | NA | There are no water quality standards for suspended solids, which if transported in large quantities can deposit in slow water areas and affect benthic organisms and fish spawning areas (Suttle et. al. 2004). Potential pollutants can also attach to suspended solids, leading to accumulation in watercourses. Turbidity, which provides a measure of suspended particulate material present in the water column, particularly the fine-grained material, is sometimes used as a surrogate for suspended solids. State water quality standards stipulate that turbidity shall not exceed 5 NTU above background when the background is 50 NTU or less, or a 10 percent increase in turbidity when the background turbidity is greater than 50 NTU.<br><br>Background conditions are usually evaluated in the vicinity of specific discharges to streams, such as runoff from construction sites or piped outfalls, by measuring turbidity in the stream above and below the discharge of concern. Continuous turbidity monitoring should be considered when developing methods for this metric. Background levels in Seattle urban streams can be difficult to establish, because urban storm drain systems often constitute the headwaters of these streams. |
| Floodplain connectivity | Width-to-depth (W/d) ratio | Floodplain connectivity is important for moderating high flows and providing productive habitat. Based on channel or floodplain morphology, connectivity measurements such as channel width to depth ratios allow for understanding stream bed erosion and resulting channel incision (Pess et al. 2005). Ratios are scaled to localized channel gradient and confinement. No recommended range given because channel measurements must be specifically defined within the context of individual channel characteristics.<br><br>This measurement, when repeated over time at fixed locations, would provide a highly reliable indicator of those changes. It would be performed as part of a long-term monitoring program that includes several fixed-station channel cross sections and a longitudinal profile survey, every few years (Bauer and Ralph 1999). However, urban streams present challenges to documenting changes in W/d ratios because width is often artificially constrained by bank armoring, which affects the stream's "true" bankfill width. |
| Aquatic health toxicity | Toxicity | Toxic pollutants in the water column or stream sediments, such as metals, polychlorinated biphenyls (PCBs), and pesticides, can affect the survival and growth of aquatic animals. Tests can be conducted to evaluate the ability of stream water or sediments to support healthy organisms, before any pollutant-specific water quality testing is conducted (which is expensive and time consuming). Methods to evaluate this could include sediment bioassays with *chironomids* or *Hyallela* exposed to stream sediments or in-situ trout egg incubation boxes to look for normal development and survival to emergence. |

# 3 HOW SHOULD WE APPROACH MAKING IMPROVEMENTS?

Many types of actions have been taken to improve Seattle's stream and watershed ecological health. These improvement actions include adding large woody debris to diversify aquatic habitat, replacing culverts to improve fish passage, and installing natural drainage systems to reduce stormwater runoff and pollutants. However, documentation of their effectiveness in improving overall stream health is very limited, either due to limited project opportunities or due to limited monitoring funds. This lack of monitoring leaves resource managers unable to assess biological and ecological benefits. Without such information, managers and decision makers are unable to determine the usefulness of continuing to implement certain types of projects or identify realistic stream goals.

These assessment needs can be addressed through the adaptive management process. In an adaptive management process, stakeholders, resource managers, and scientists try to incorporate new and on-going improvement actions into testing science-based hypotheses; based on results, improvement actions can be adjusted as necessary. Because actions and activities that will affect urban streams will continue without perfect knowledge of their effects, employing the adaptive management process is highly recommended.

This section discusses a general adaptive management process, with additional details about setting realistic goals and improvement strategies. An example conceptual adaptive management plan is also provided (Section 3.5), which describes how one might determine whether ecological health goals are realistic, given funding and other resource limits.

## 3.1 Adaptive Management in Seattle Stream Watersheds

Because both negative effects of urbanization and positive effects of improvement projects will continue, we recommend employing the adaptive management process. Adaptive management (AM) is a widely embraced concept, which allows one to make management decisions in the light of uncertainty, while tracking the outcomes of those decisions thus ensuring that learning from those actions will aid future decisions (Ralph and Poole 2003). AM can also be defined by what it is not: it is not resource management by trial and error. By recognizing the uncertainty in our understanding of ecological processes, we make systematic plans to address the uncertainty through well designed experiments (management actions) that are based on explicit and testable hypotheses. In urban streams, there is uncertainty around the extent of benefits from improvement projects and uncertainty about how far and how quickly collective improvement actions can take us toward increased ecological health. This uncertainty can be addressed and management decisions changed through the learning process associated with AM.

AM is an iterative process (Figure 3-1). To begin this cyclic process, the first task is to define goals and associated objectives. Defining goals and objectives is a public exercise and should be based on a common vision identified through such efforts as the ROW Initiative. While scientists and engineers convey findings and information to the public and stakeholders, it is the decision makers, acting in the interests of the public, who formally define goals and objectives. While goals may be more descriptive at first, measurable objectives should be ultimately identified.

Once goals and objectives are articulated, improvement actions and programs can be designed and implemented to work towards the identified goals and objectives. Project-specific goals and

objectives should also be identified that are consistent with management goals. After developing project-specific objectives, it is important to identify uncertainties and risks in the management

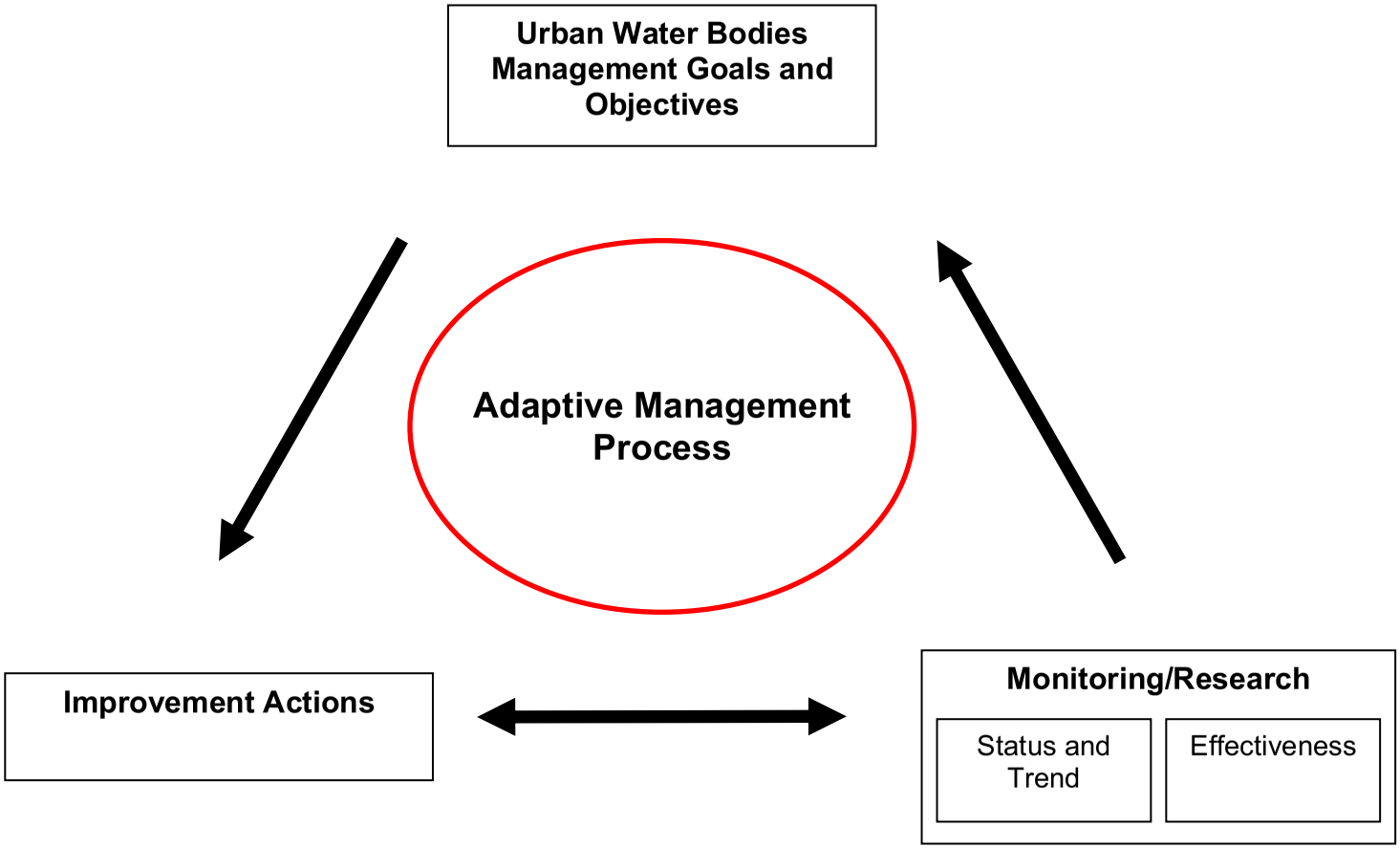


**Figure 3-1. Simplified adaptive management process. For a detailed representation, see Figure 5-1.**

action being taken and then to turn these into evaluation questions, which then would drive the development of specific effectiveness monitoring activities.

Effectiveness monitoring evaluates the outcomes of a deliberate action undertaken to restore physical channel processes, water quality, or the biotic community in terms of meeting expectations. Such monitoring is performed by collecting relevant data before and after project implementation to determine clear changes in project-site conditions. Effectiveness monitoring is usually limited to a given site, but can be aggregated over time to inform any overall trend monitoring that is performed in concert. It is a much better tool to establish insight into cause and effect relationships than is usually provided by longer term status and trend monitoring. Because effectiveness monitoring often covers many sites, results can sometimes be aggregated to allow us to detect response differences inherent in site conditions. Understanding how different locations across the landscape may respond differently to improvement actions is important for determining project effectiveness, as well as examining underlying cause and effect assumptions and understanding site variability. Overall, effectiveness monitoring addresses uncertainty about implementing the right types of projects or programs for resolving problems affecting stream health.

Ultimately, effectiveness monitoring results can be analyzed to determine whether the project is indeed meeting the stated project goals and objectives. Monitoring results can also inform overall management goals and objectives, prompting revisions if new information shows that management goals are clearly infeasible or otherwise unattainable.

Status and trend monitoring plays a role in AM as well. This type of monitoring addresses uncertainty about the "right" ecological health indicators for managing urban streams. Important areas of uncertainty include:

- Whether the selected status and trend indicators will provide a comprehensive assessment of stream health. We have relied on professional judgment to select the indicators based on our current understanding of relationships between indicators and ecological functions. The usefulness of the selected indicators should be matched to the design chosen for monitoring and the indicator list revisited and modified as needed to ensure that changes to stream conditions are adequately represented.
- Whether the selected indicators will change as the result of cumulative watershed actions. Through this AM process, management goals should include numeric indicator objectives which will allow us to test what can be achieved. The selected indicators may not be appropriate for testing our goals, or could indicate that overall management goals need to be revisited for feasibility.

Although the AM concept has been used in the natural resources literature since the 1970s (Holling 1978), the 1990s saw a surge in the popular use of this term. Reviews of the adaptive management process started occurring by the late 1990s (Walters 1997, Levine 2004). More recently, and in connection with the Cedar River Habitat Conservation Plan, Seattle Public Utilities has adapted a general framework for evaluation and adaptive management based on work by the staff of the Ecosystem Management Initiative, Department of Natural Resources and Environment, University of Michigan. That framework could be applied to adaptively manage Seattle streams. The *Evaluation Cycle,* as developed by Dr. Yaffee and his colleagues, entails a series of four steps (Figure 3-2) (Ecosystem Management Initiative 2005).

In Stage A, referred to as "creating a situation map," an organization clarifies what it is trying to achieve, stating explicit goals and objectives and identifying threats and assets related to

achieving these. In Stage B, referred to as "developing an assessment framework," an organization defines success and specifies what is needed to determine if progress towards achieving success, even incremental success, is occurring. In Stage C, referred to as "preparing an informational workplan," the organization identifies what kind of information is needed to answer the evaluation questions. This entails developing a work plan that includes determining what information exists and what is needed, and how that data will be collected and analyzed. In Stage D, referred to as "creating the action plan," the organization determines how the information collected will be used so that people can decide how to change management actions to make them more effective. Planning that has either occurred, or is contained within this Framework document, is annotated in italics on Figure 3-2. Note that both the simplified AM process and the Evaluation Cycle include setting goals and objectives as immediate and important tasks to be done early in the process (Figures 3-1 and 3-2).

Similar to AM, the Evaluation Cycle is an iterative and cyclic process of application, learning, and refinement occurring over many years. In effect, it should become woven into the institutional culture responsible for implementing any program with environmental objectives. A number of parties are involved in developing and implementing an AM program (Table 3-1).

**Table 3-1.** Parties involved in an adaptive management program.

| | **Technical specialists and scientists**[1] | **Stakeholders**[1] | **Decision-makers**[1] | **Program Implementers**[1] |
|---|---|---|---|---|
| **Who** | Hydrologists, engineers, land use planners, and biologists | Members of various business and community-oriented groups that have an interest in the resource | Elected officials, government appointees | Planners, project managers, engineers, biologists, administrators |
| **Example positions** | Staff scientists working for resource management agencies or universities, consulting scientists for stakeholders or resource agencies | Property owners, local business districts, local watershed groups and environmental non-profit groups, other nongovernmental groups, taxpayers | Mayors, executives or council members of local jurisdictions, directors of resource agencies, state and federal elected officials | Staff from resource agencies and stakeholder groups |
| **Role played** | Disseminate scientific information, provide science-based recommendations about program direction, modifications, monitoring, research to test underlying assumptions. | Provide decision-makers with perspectives from a diverse set of parties. Recommend initial program direction, program modifications, and priorities. | Make final decisions about AM program direction and priorities. Could also be responsible for securing funding and staff to make the program operate. | Facilitate communication among the various AM groups, prompting recommendations and decision-making, conducting day-to-day tasks that keep the AM program cycling. |

[1] To keep dissemination of information and decision-making relatively quick and efficient, technical advisory committees and adaptive management oversight committees are often formed with members from these various groups.

# The Evaluation Cycle

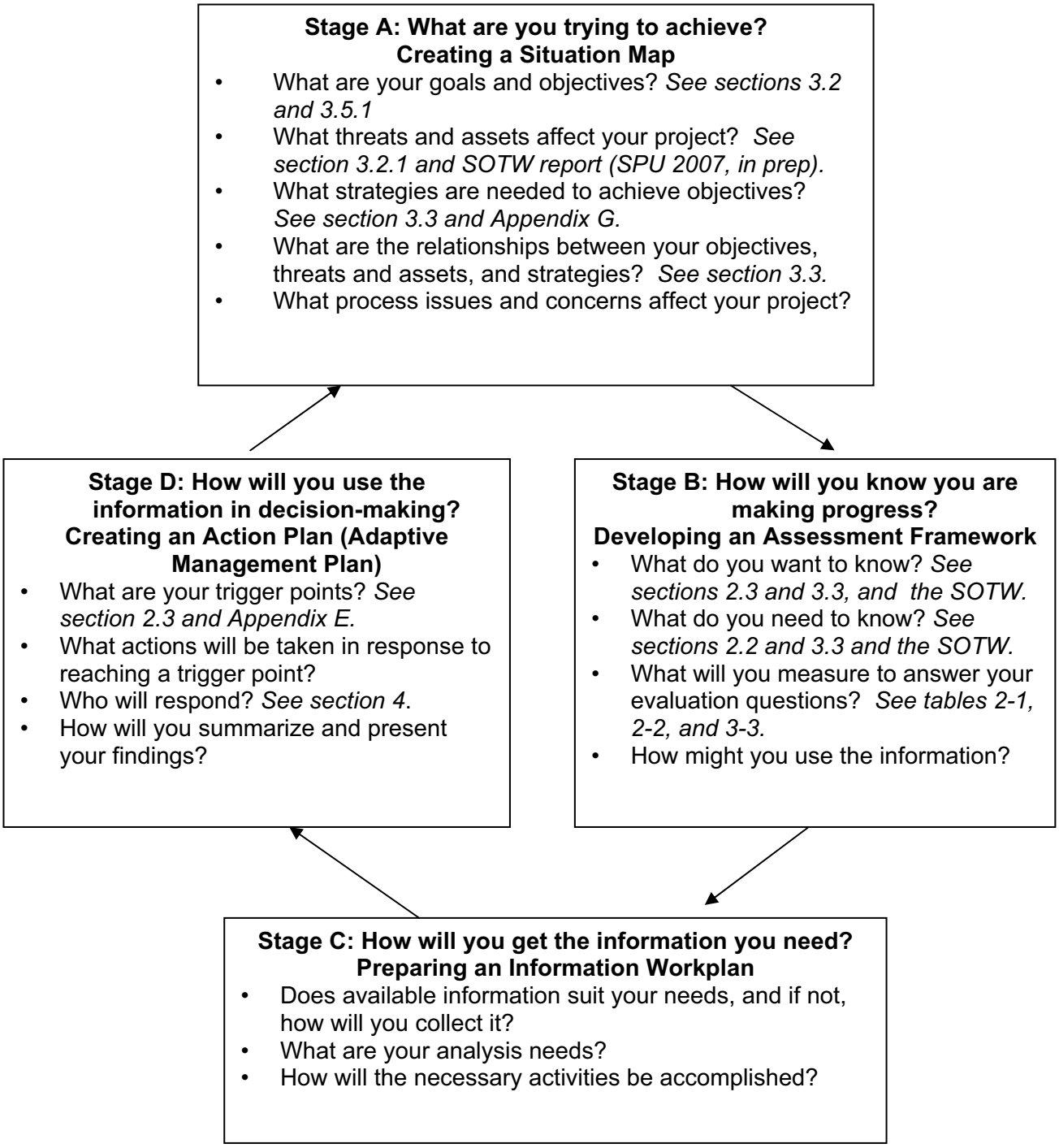


**Figure 3-2. The Evaluation Cycle (Department of Natural Resources, University of Michigan, 2003) and its relationships to Seattle's current and ongoing watershed and stream restoration planning, which are annotated in *italics*.**

As described by the Ecosystem Management Initiative staff, the Evaluation Cycle is heavily weighted towards the social aspects of resource management. Implied but not explicitly stated is a step or stage in which: (1) objectives are linked to hypotheses that guide the development of specific monitoring, and/or (2) applied research and experimentation fill in key gaps in the relationship between actions and outcomes. These steps are components of developing a "cause and effect" or effectiveness monitoring program which is critical for adaptive management. (For a more thorough discussion of the social and scientific intersection of adaptive management, see Ralph and Poole 2003).

While the Evaluation Cycle provides a thorough analysis of the social aspects of resource management, the EPA has outlined an adaptive management process that tends to focus on the applied research aspects (EPA 2003, Ralph and Poole 2003):

- Define problem and establish goals and objectives;
- Develop conceptual models that describe links between existing resource conditions, management actions and objectives;
- Identify key uncertainties and assumptions;
- Develop testable hypotheses;
- Plan and implement specific monitoring and applied research experiments;
- Assess resulting monitoring and research data in light of hypotheses, and integrate new information that changes ineffective management actions, as necessary; and
- Prepare to design additional experiments to answer related and confounding questions.

Similarities between the adaptive management process and this Science Framework are intentional to facilitate development of an adaptive management plan. Distilled to its essence, an adaptive management plan would:

1. Include a comprehensive problem analysis,
2. Identify a suite of remedial actions that (we speculate) could limit or reverse the severity of the problem(s), and
3. Define appropriate monitoring and research that would track outcomes and evaluate the persistence or remediation of the most serious and important factors, through testing of specific hypotheses.

These three steps would provide the context in which we could link identified problems with documented short term and long term changes that we expect to see due to various management actions over time. Further, an adaptive management plan would consider multiple and interacting actions to address both fundamental processes (like changed hydrology and sediment inputs), as well as site by site "fixes" that treat perceived symptoms (like lack of pools or woody debris). The possibility that one type of urban effect (say poor water quality conditions due to elevated temperatures or low dissolved oxygen) is more ecologically important than another (say, limited juvenile rearing habitat) is high. This AM approach allows one to prioritize remedial actions based on explicit statements of the nature and relative significance of the problem, expressed as hypotheses.

An adaptive management plan would need to consider all causes and observed effects; scientists would need to decide which are the most ecologically critical, while policy makers and the general public would need to decide which effects can be realistically addressed, given social and economic considerations (see Section 3.2). The City of Seattle would likely want to adopt those

actions deemed to have the greatest physical and biological benefit within a reasonable cost range.

## 3.2 Setting Realistic Goals

Being able to evaluate success of any program or project depends on clearly stated goals and measurable objectives. As shown in Figures 3-1 and 3-2, identifying goals and objectives is a key element of restoration planning. This section discusses elements that should be included in any process to determine goals and objectives for Seattle's streams.

Streams, intermittent streams, and other waters, can exist is a variety of states (Figure 3-3) and reflect the conditions of their watersheds. Streams in undisturbed areas with minimal watershed development exist in a natural state (far left on figure), with high quality riparian corridors and instream habitat. These streams can support native fish and benthic communities. At the other extreme are streams in watersheds with dense land uses, which exhibit severely degraded stream conditions. These streams have temperature and dissolved oxygen problems, very limited riparian and instream habitat, and contain a simple fish and benthic community composed of highly tolerant plants and animals, often including invasive species (far right on figure). Between the two extremes of the figure, there is a continuum of stream conditions that are possible.

In thinking about goals, there are two important points for each creek: (1) where the creek presently lies on the continuum, and (2) where we wish the creek to be on the continuum. The first continuum point can be determined by monitoring indicators (see Section 2.3 and Appendix E). Determining the second continuum point is important for adaptive management and the adaptive management process can assist in making determinations (see Section 3.5). Currently, Seattle's streams are located in the major impact category (Appendix G), with Fauntleroy, Piper's, and Taylor creeks in relatively better condition than Longfellow and Thornton creeks (SPU 2007, in prep.).

In setting goals for the future conditions of Seattle streams, the degree of impact already experienced by the streams and their watersheds must be considered, because more improvement will require more time and money. The further the goal is to the left on the stream condition continuum (Figure 3-3), the more resources will be needed and the less feasible the goal. However, the status quo condition or further degradation (movement to the right) is likely not acceptable to most Seattle citizens. Setting realistic improvement goals (i.e., determining the distance to move on the continuum) is possible through adaptive management and through strategically selecting among many possible improvement projects (Sections 3.4 and 3.5).

### 3.2.1 Acknowledging challenges

In setting goals for improvement, ongoing human activities need to be considered. Stage A of the Evaluation Cycle includes identifying "threats and assets", in addition to goals (Figure 3-2). Human activities that continue to impact and limit Seattle's urban creeks are numerous and deeply embedded culturally, and some may be very difficult to limit (Table 3-2). Conversations about future goals need to consider which activities can be changed, to what extent, and over what timeframe. Without making changes in human behaviors, even those that are deeply engrained, making noticeable improvements will be extremely difficult, if possible at all.

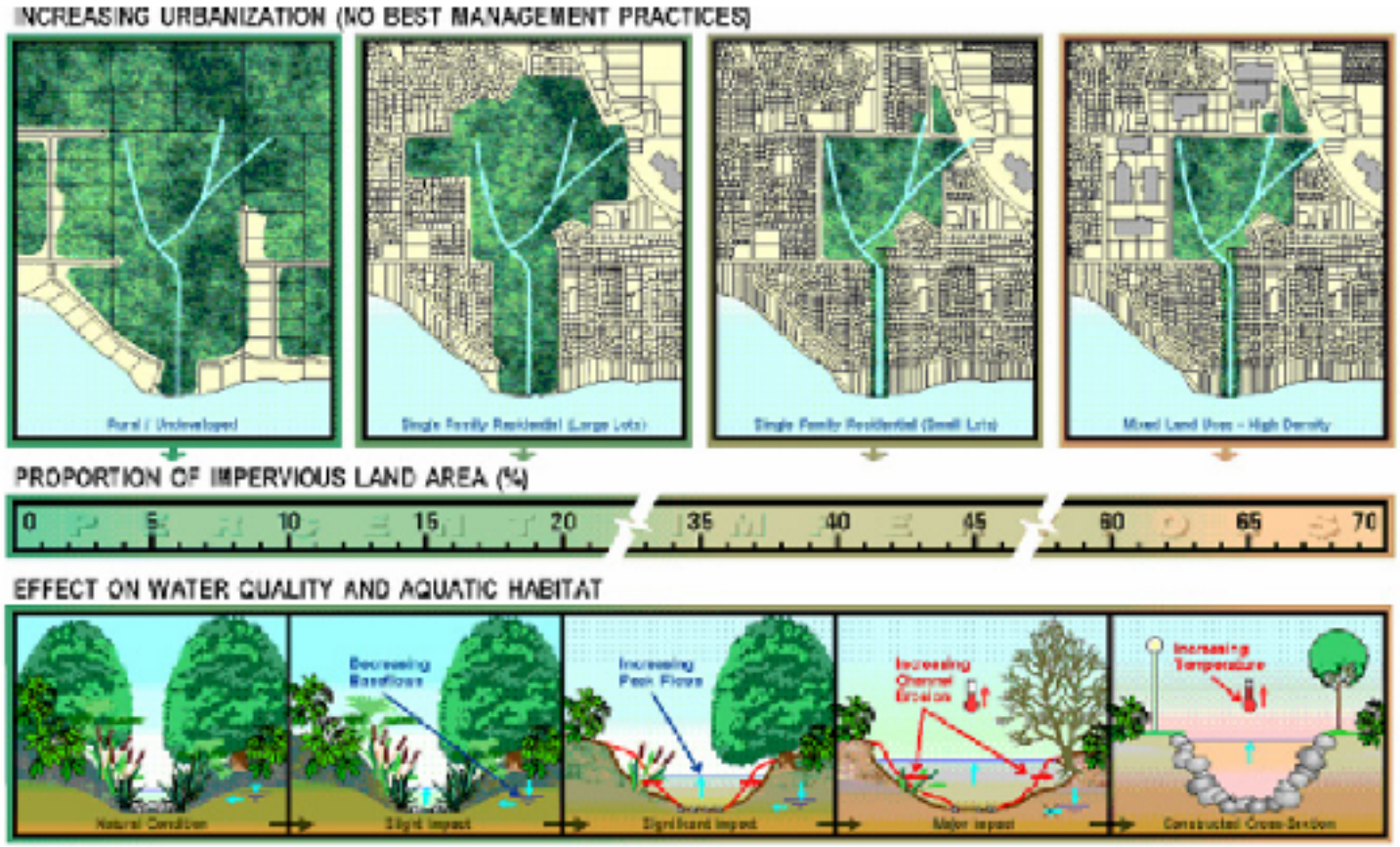


**Figure 3-3. A continuum of watershed and related stream conditions in urbanized areas. Image provided to Seattle Public Utilities from CH2M Hill.**

**Table 3-2.** Examples of common human activities that can impact and limit the ecological health of Seattle's waterbodies.

| Human activity | Purpose and justification | Impact on ecological health |
|---|---|---|
| Loss of native soil cover or compacting of native soils. | Construction of buildings, roads, and other structures. | Hydrology: native soils can store water. When removed or compacted, interstitial soil spaces are lost and water-storage capacity is lost as well. |
| Pesticide and fertilizer application. | Manage weeds, moss, insects, and other landscape problems with minimal time and effort. Promote plant health and growth. | Water quality: pesticides can affect more than target plants or animals; chemicals can travel down-slope into aquatic areas; some are toxic to benthic invertebrates and fish. Fertilizers can increase biological activity, which can reduce dissolved oxygen levels. |
| Operating and maintaining motor vehicles. | Distances between residences and employment often require motorized transportation. | Water quality: tailpipe emissions, brake pad linings, leaking oil and other lubricants and fluids, car washing can introduce pollutants into stormwater and air; pollutants can eventually end up in receiving waters. |
| Use and storage of potentially toxic materials like cleaning products, gas, oil, paint, etc. Surface spills and leaks in underground storage tanks. | Variety of uses for transportation, heating, commodity production, maintenance, and other activities. | Water quality: improperly stored or used materials can infuse surface and groundwater with toxic load that can bio-accumulate, some persist in the environment, and affect human and ecological health. |
| Replacement of native vegetation with buildings and landscaping. | Development; aesthetic preference for ornamental plants. | Riparian and instream habitat: Loss of productivity, shade, and/or food web basis. |
| Tree removal or topping to gain or maintain views | Views are aesthetically pleasing and create higher property values; small residential lots are often crowded by large trees. | Hydrology and riparian habitat: affects interception and increases surface runoff, reduces shading, particularly a problem along Lake Washington, Duwamish and Puget Sound. |
| Growing and maintaining lawns and landscaping to water's edge. | Extension of usable lot areas for views and recreation. | Riparian habitat and water quality: riparian diversity decreases; lawns are sometimes maintained with pesticide and fertilizer applications. |
| Clearing and removal of wood from streams | Wood can damage culverts, bridges, and other structures during storms. | Instream habitat: removal of "flow obstructions" reduces bank protection and removes important cover and habitat complexity for aquatic organisms. |

| Human activity | Purpose and justification | Impact on ecological health |
|---|---|---|
| Use of toxic compounds for building construction and maintenance, such as zinc to kill moss on roofs, and copper in flashing and roof drains | Roof replacement delayed, thus saving roof materials, using a labor-saving chemical instead of physical labor; aesthetics. | Water quality: copper and zinc are highly toxic to aquatic organisms and can persist in stream gravels and sediment. |
| Construction and maintenance of bank armoring, which often is backfilled with loose dirt and un-engineered fill. | Protection of shoreline property. | Instream habitat: natural channel adjustments are restricted; eliminates shallow nearshore habitats for fish. |
| Filling of wetlands or nearshore shallow areas. | Fill adds to useable area of property, flattens and smoothes recreational areas. | Instream habitat and hydrology: reduces infiltration; eliminates habitat complexity and reduces suitability of aquatic and riparian species at key life history stages. |
| Construction of houses or outbuildings too close to stream. | Lack of building sites, desirability of living close to stream, and in-filling within City preferable to increasing suburban sprawl. | Instream and riparian habitat: Intrusion by construction into otherwise suitable habitats may limit actual use by species. |
| Construction of impervious surfaces (buildings, driveways, roads). | Housing; travel | Hydrology and water quality: storm related stream discharge increases, stormwater runoff can carry pollutants that accumulate on roadways; higher peak flows damage instream habitat and reduce habitat refuge areas. |
| Illegal dumping, litter. | Lack of inexpensive and readily available waste disposal areas or services, and carelessness. | Hydrology, water quality: Litter can "choke" streams by plugging culverts and minimizing conveyance volume. |
| Construction and maintenance of recreational areas and trails along streams and shorelines. | Especially within urban environments, people wish to experience open and "wild" space. | Riparian habitat: maintenance of open space is generally environmentally beneficial, but heavy trail use can lead to trampled vegetation, litter, compacted soils. Incorrectly built trails can cause bank and valley wall erosion. |
| Construction and maintenance of stormwater drainage networks. | Stormwater control reduces flooding. | Hydrology: directs runoff directly to streams and other receiving water bodies. |
| Occurrence of Combined Sewer Overflows (CSOs). CSOs occur when the capacity of the combined system (storm and sanitary draining to sewage treatment plant) is exceeded and combined sewage is discharged to surface waters. | CSOs are a historical carryover from practices of installing one pipe, rather than installing systems that carry wastewater and storm water separately. | Water quality: periodic loading of pollutants into surface waters. |
| Development of new road networks which require stream crossings using culverts or bridges. | Automobile travel is an essential aspect of current lifestyles. Bridges are more expensive than culverts. | Culverts can create impassable barriers to migrating aquatic organisms; roads extend areas of human impact. |

| Human activity | Purpose and justification | Impact on ecological health |
|---|---|---|
| Release of pollutants such as greenhouse gases | Transportation; production of goods and services | The implications of global warming are far reaching – hydrology, water quality, and habitat are all affected. |

## 3.3 Strategies for Making Improvements

The Evaluation Cycle for adaptive management includes identifying strategies to achieve improvement objectives (Figure 3-2). Successful and sustainable improvement actions need to:

- Be based on science, with clear goals, objectives and stated assumptions,
- Identify (or hypothesize) the underlying cause and effects relationships that the improvement project seeks to address,
- Include a monitoring component,
- Be properly sequenced and timed with other ongoing or planned improvement projects, and
- Be economically and politically feasible.

Clear project goals and objectives are important for design of the improvement project and to monitor project effectiveness. Project objectives should include all hypothesized project outcomes, from physical and chemical changes to resulting biological conditions and communities, that the improvement project intends to affect.

Identifying (or hypothesizing) the underlying cause and effect relationships is also critical when attempting to correct perceived problems in urban streams (Table 3-3, 2nd column). Often, a grouping or suite of improvement actions is undertaken to limit or correct an adverse change in environmental conditions; however, hypotheses supporting the improvement actions—either individually or as a whole—are seldom explicitly stated, and operating assumptions are seldom questioned. This lack of reflection can result in improvement actions that do not always produce their intended results. In our review of other cities' stream ecological health programs, we found that explicit formulation of improvement projects and their hypotheses was rare (see Appendix B). Testing underlying cause and effect assumptions is also important for reducing uncertainty in making management decisions in ecological systems.

Monitoring the effects of improvement projects is instrumental for (1) being accountable for spending limited restoration funds most effectively, and (2) understanding how projects cumulatively contribute to ecological health improvements. Monitoring a project for physical, chemical, and biological changes allows managers to assess true project benefits and to identify potential ways to improve project designs for future projects. Effectiveness monitoring often involves a "before and after" or "control versus treatment" study design; it can assist in understanding the sequence of events leading up to some desired change, and it can reveal controlling factors that were poorly understood. Monitoring also allows an understanding of project limitations and, in some cases, can lead to deeper analysis of the underlying relationships between different response variables. For example, on six urban streams within the Puget Sound Lowland, introduction of large woody debris did not produce "any detectable improvement in biological conditions" (Larson et al. 2001). (The authors note, however, that detectable improvement may occur if a longer monitoring period is allowed.) Unmet project objectives, particularly those for biological outcomes, do not necessarily mean that the projects were

unsuccessful, but do indicate that other factors are likely influencing biological conditions (e.g., stream flow, water quality).

Improvement hypotheses that address major stream impairments and associated rehabilitation actions are listed (Table 3-3). Possible project effectiveness indicators are also included. Some of the project effectiveness indicators listed in Table 3-3 are not included on the lists of primary or secondary status and trend indicators (Tables 2-1 and 2-2) due to differences in the goals of each type of monitoring. As shown in Figure 3-4, project effectiveness monitoring examines a project or type of project in order to inform future project design and benefits. Status and trend monitoring evaluates the cumulative response to many watershed actions, including stream improvement projects, to inform trends in the ecosystem and further management decisions.

The simple listing of indicators (Tables 2-1, 2-2, and 3-3) does not address two extremely important aspects of monitoring: temporal and spatial scales (Figure 3-4). The spatial and temporal scales of an individual improvement action are relatively limited and of shorter duration; assuming well designed hypothesis testing, effectiveness monitoring will likely indicate results with an acceptable degree of certainty. On larger and longer spatial and temporal scales, such as might be the case when monitoring a suite of improvement actions and their cumulative effects, greater uncertainty is likely, and the uncertainty may be large enough such that " cause and effects" between actions and outcomes are never adequately defined. Lack of the definitive "answer" does not dictate a flawed planning procedure however, and when decisions must be made, reducing uncertainty is better than not, even if the remaining uncertainty is still significant.

**Table 3-3.** Improvement actions, their associated hypotheses, their intended effects and benefits, and possible indicators once the AM process has been implemented for many years.

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| Increased flows (frequency, magnitude, and duration) | Increasing infiltration and reducing stormwater runoff and direct drainage discharges will reduce stream flashiness and extreme peak flow events. | Measurable move toward a normal hydrograph<br>…so that productive instream habitat is created and maintained<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive<br>…so that bank erosion and property damage is minimized | • Removing and reducing impervious surfaces<br>• Using porous concretes<br>• Installing rain and roof gardens/cisterns<br>• Installing and maintaining natural drainage systems Retrofitting formal drainage systems<br>• Increasing upland and riparian forests and wetlands<br>• Flow duration control ponds | Stream flow:<br>- TQmean<br>- High pulse count<br>- Monthly or daily flows<br>- erosivity index<br>Physical channel:<br>- Channel gradient<br>- Channel width<br>- Depth diversity<br>- Channel incision<br>- Streambank condition<br>- In-channel erosive forces/scour |
| Poor water quality (pollutants, nutrients, temperatures) | Increasing infiltration and reducing storm water runoff and direct drainage discharges will decrease water temperatures and pollutant loads. | Measurable improvement in targeted water quality parameters<br>…so that streams are safe for contact recreation<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • See improvement actions for reducing stream flashiness and extreme peak flow events (above) | Water Quality:<br>- Water temperature<br>- Dissolved oxygen<br>- Total and dissolved metals (water and sediment)<br>- Total suspending solids |

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| | Increasing natural and engineered artificial storm water treatment will decrease pollutant loading. | Measurable improvement in targeted water quality parameters<br>…so that streams are safe for contact recreation<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Installing and maintaining natural drainage systems<br>• Installing and maintaining storm water treatment facilities<br>• Preserving, and enhancing riparian wetlands (re-creation in appropriate places) | Water Quality:<br>- Water temperature<br>- Dissolved oxygen<br>- Total and dissolved metals (water and sediment)<br>- Nutrients<br>- Total suspending solids<br>- Fecal coliform bacteria<br>- Pesticides and petroleum-based pollutants (water and sediment) |
| | Planting and maintaining riparian trees to provide a stream canopy and shading will reduce stream water temperatures and increase DO levels. | Measurable improvement in targeted water quality parameters<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Removing invasive species<br>• Planting conifers and deciduous trees<br>• Reducing number of access points to streams | Water Quality:<br>- Water temperature<br>- Dissolved oxygen |
| | Improving sediment management activities will reduce total suspended solid loads to receiving waters. | Measurable improvement in targeted water quality parameters<br>…so that productive instream habitat is created and maintained<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive<br>…so that stream-side property is not damaged by sediment-induced flooding | • Cleaning catch basins<br>• Using proper sediment and erosion control methods during earth-disturbing activities | Water Quality:<br>- Total suspending solids<br>Physical Channel:<br>- Bed surface size distribution<br>- Embeddedness |

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| | Improving source control activities will reduce pollutant loads to and concentrations in receiving waters. | Measurable improvement in targeted water quality parameters<br>…so that streams are safe for contact recreation<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Restricting pesticide/herbicide use<br>• Implementing pollution prevent plans<br>• Proper use, storage, and disposal of potential pollutants | Water Quality:<br>- Water temperature<br>- Dissolved oxygen<br>- Total and dissolved metals (water and sediment)<br>- Nutrients<br>- Total suspending solids<br>- Fecal coliform bacteria<br>- Pesticides and petroleum-based pollutants (water and sediment) |
| Poor riparian habitat (loss of shade, nutrient inputs, bank stability) | Planting and maintaining native riparian vegetation will contribute woody debris, leaf litter and other allochthonous materials to supply the food web and increase instream wood. | Measurable increase in riparian forest<br>…so that instream habitat remains productive<br>…so that riparian wildlife can thrive<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Removing invasive species<br>• Planting native shrubs and trees, including conifers and native deciduous trees. | Riparian Habitat:<br>- Canopy cover<br>Physical channel:<br>- Woody debris volume<br>- Woody debris density<br>- Pool frequency and dimensions<br>Periphyton:<br>- Total organic matter |
| | Planting and maintaining riparian vegetation will assist in stabilizing banks | Measurable increase in riparian forest<br>…so that instream habitat remains productive<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive<br>…so that bank erosion and property damage is minimized | • Removing invasive species<br>• Planting of native shrubs and trees, including conifers and native deciduous trees | Riparian Habitat:<br>- Vegetation type and condition<br>- Erodability index |

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| | Maintaining and re-creating riparian wetlands in appropriate places will increase stream productivity. | Consistent or measurable increase in wetland area<br>…so that instream habitat remains productive<br>…so that wetland and stream-dwelling organisms (fish, invertebrates) can thrive | • Maintaining and re-creating riparian wetlands in appropriate places | Stream flow:<br>- TQmean<br>- High pulse count<br>- Monthly or daily flows<br>Physical channel:<br>- Channel gradient<br>- Channel width<br>- Depth diversity<br>- Channel incision<br>- Streambank condition<br>- In-channel erosive forces/scour |
| Poor instream habitat (simple channel, no resilience | Increasing stream floodplain area will allow the stream to dissipate high flow energy and promote creation and maintenance of complex instream habitat | Measurable increase in accessible floodplain area<br>…so that instream habitat remains productive<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Removing bank armoring<br>• Setting back bank armoring<br>• Re-grading of streambank<br>• Installing grade controls | Physical channel:<br>- Frequency and duration of overbank flows<br>- In-channel erosive forces/scour<br>- Peak flow channel velocity distribution<br>- Entrenchment ratio<br>- Bed surface size distribution<br>- Erosivity<br>- Erodability index<br>Hyporheic zone |

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| | Increasing amounts of instream wood debris will increase the area and depth of pool habitat and increase sediment storage and stream gradient control, leading to more complex instream habitat and more diverse or abundant biota. | Measurable increase in instream wood<br>…so that instream habitat remains productive<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Planting and maintaining native riparian trees, particularly conifers<br>• Use woody debris and plant native trees and shrubs to stabilize banks, instead of using concrete.<br>• Encouraging property owners to maintain wood in streams<br>• Adding wood to streams<br>• Minimizing/avoiding dredging activities, when dredging necessary, protect riparian vegetation and look for options to improve stream gravels and woody debris. | Physical channel:<br>- Gradient<br>- Bed surface size distribution<br>- Woody debris volume<br>- Woody debris density<br>- Pool frequency and dimensions<br>- Habitat diversity<br>(see biological community metrics below) |
| | Controlling the introduction of fine sediments into the stream and increasing the recruitment of coarse sediments will lead to more complex sediment distribution, improving instream habitat. | Measurable decrease in stream fine sediments<br>…so that instream habitat remains productive<br>…so that stream-dwelling organisms (fish, invertebrates) can thrive | • Implementing best management practices during construction and maintenance activities<br>• Minimizing exposed bare earth<br>• Minimizing ground-disturbing activities<br>• Removing bank armoring from areas with gravels and cobbles<br>• Adding and preserving stream buffers | Physical channel:<br>- Bed surface size distribution<br>- Relative roughness<br>- Bulk size distribution/embeddedness<br>- Sub-surface size distribution<br>- Surface to sub-surface size ratio<br>(see biological community metrics below) |

| Urban stream impairments | Improvement action hypothesis | Intended effect and benefit(s) | Example improvement actions | Potential cumulative project effectiveness indicators [1] |
|---|---|---|---|---|
| Simple biological communities with an abundance of species tolerant of degraded conditions | Improving stream flow, instream water quality, and instream and riparian habitat will support abundant and diverse benthic and fish communities.[2] | Measurable change in benthic and fish communities …so that stream-dwelling organisms (fish, invertebrates) can thrive | • See all project types above | Periphyton<br>- Organic matter density<br>- Inorganic matter density<br>- Chlorophyll-a density<br>- Diatom taxonomic composition<br>Benthic Invertebrates and Fish:<br>- Taxonomic composition<br>- Density<br>- Total biomass |

[1] Project-specific monitoring parameters need to be chosen based on project goals and objectives, as well as the project scale and location. The parameters listed here are examples only and do not represent an exhaustive list nor those that are recommended.

[2] Biological results are tied to many project types and may be best measured from multiple projects, however, appropriate biological monitoring should also be conducted on individual projects as well.

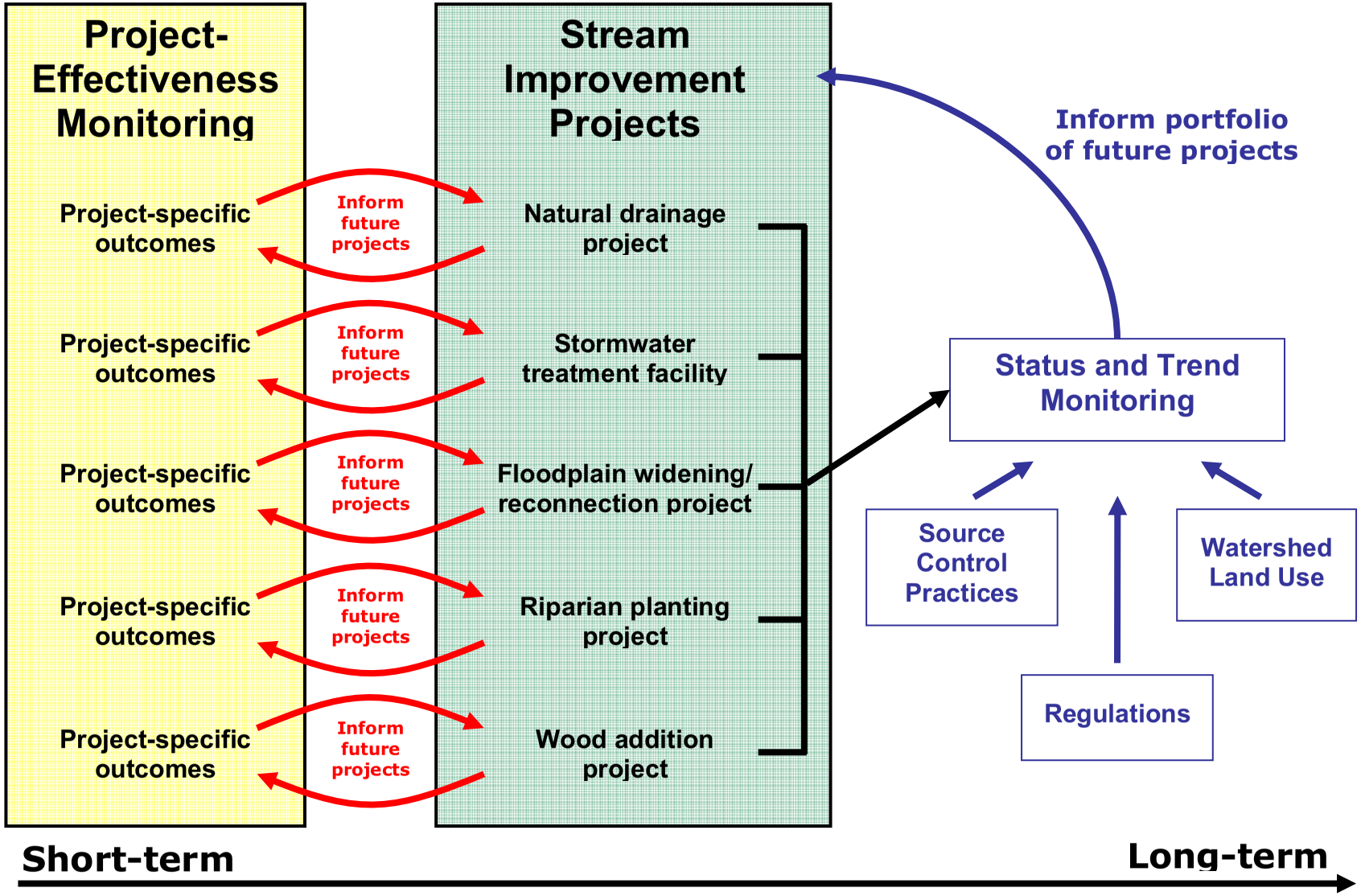


Figure 3-4. Relationships between individual improvement actions (such as capital improvement projects), effectiveness monitoring, and status and trend monitoring. Blue text indicates activities that affect or are affected by status and trend monitoring. Red text indicates feedback loops that can be used to adaptively manage improvement actions in Seattle's urban streams.

## 3.4 Strategic Planning of Improvement Actions

Even after results from AM studies become available, and we can more easily prioritize improvement projects, factors in addition to those based on AM studies should be considered. Factors to consider in prioritizing and implementing ongoing stream improvement actions include:

- Management goals and objectives for ecological characteristics of the stream,
- The scale and location at which relationships between underlying stream impairments and improvement actions occur,
- Stream type and habitat associations,
- Sequence and timing of the activity.

**Management goals.** Restoration needs to be planned, designed, and constructed with an ultimate management goal in mind, which is measurable and easy to understand. This document used an assumed goal of streams sustaining anadromous and native fish; however, this assumed goal should be revised based on current conditions, public input, and political and financial realities. During the adaptive management discussions, agreement on the overall management goal should be obtained. Implemented improvement projects should support overall management goals.

**Scale and Location.** Stream conditions are affected by watershed-scale characteristics such as the area of impervious coverage or areas of forest. Stream conditions are also influenced by reach-scale characteristics at a specific site. Improvement actions need to consider the scale of the problem and the scale of the intended effect. For example, stream flow and water quality are results of watershed-scale land uses. Individual homes and yards do not cause problems, but when considered cumulatively, pavement and buildings cover a large percentage of the watershed, and stream flows become flashier and create more damage. Therefore, projects intending to improve stream flow and water quality need to consider the stream's entire drainage area. Instream habitat improvements, such as reconnecting the floodplain or adding large woody debris, should be considered with respect to watershed and project scale.

**Stream Type.** In considering instream habitat improvements, recognizing that Seattle's streams exhibit some unique characteristics is important because these unique conditions will affect the suitability of different actions. Stream channel types respond to disturbances in different ways, and respond to different approaches (Appendices D and G). This consideration also gives insight into variability from site to site, and will aid in distinguishing between changes attributed to a specific action taken versus natural variability. Given that each of Seattle's streams exhibit individual riparian and bank conditions and sediment sources, tailoring restoration plans to stream and watershed-specific factors (e.g., land uses, current conditions, stream channel type) will be important (Figure 3-5). Specific improvement recommendations for Fauntleroy, Longfellow, Piper's, Taylor, and Thornton watersheds are available within this document (Appendix G).

**Sequencing.** With stream improvements affected by the project's and stream's scale and location, as well as by its stream type, considering the order of processes that drive stream habitat is important. Just as one would construct a building's foundation before hanging doors, a sequence of steps must be followed when improving stream habitat. Features that control the delivery of water, wood, and sediment are important drivers for shaping a stream. In urban streams, changed hydrology--especially the magnitude, duration and frequency of peak flow events—may "trump" all other processes that shape the biotic community. Thus, addressing perceived channel inadequacies (e.g., adding wood debris to address poor pool habitat) will likely

fail to address the underlying cause of very limited capacity to support native fish communities. In prioritizing projects, the driving processes of stream habitat should be considered to determine how well a proposed project will perform. In addition, projects within the same area could be staged to test project outcomes, according to hypothesized system limitations. For example, to test the relative importance of flow, a learning opportunity would be to implement natural drainage projects aimed at controlling flows in a stream or tributary, followed several years later by woody debris addition projects.

## 3.5 An Example Conceptual AM Plan

This conceptual outline of an adaptive management plan for Fauntleroy Creek is a contrived example only; it is presented here to illustrate some key steps and thought processes necessary to formulate such a plan for an urban creek. It does not represent all of the constraints or opportunities for restoration of this creek. In this example, we focus on only one potential improvement action: culvert replacement that would minimize migration barriers. This example does not imply that Fauntleroy Creek has undergone extensive restoration planning and that culvert replacement was found to be the highest priority action: no such analysis has occurred. Culvert replacement is just one of the many potential improvement actions that should be considered when developing an adaptive management program, and it was used here because it is a relatively straightforward improvement project. In this example, we present graphs that hypothetically display the "data" that would result from experimental testing of a stated hypothesis. In an adaptive management plan for Seattle streams, graphed quantities would be factors that are relevant to aquatic ecology, and that can be measured and monitored (i.e., graphs would be plotted from real data).

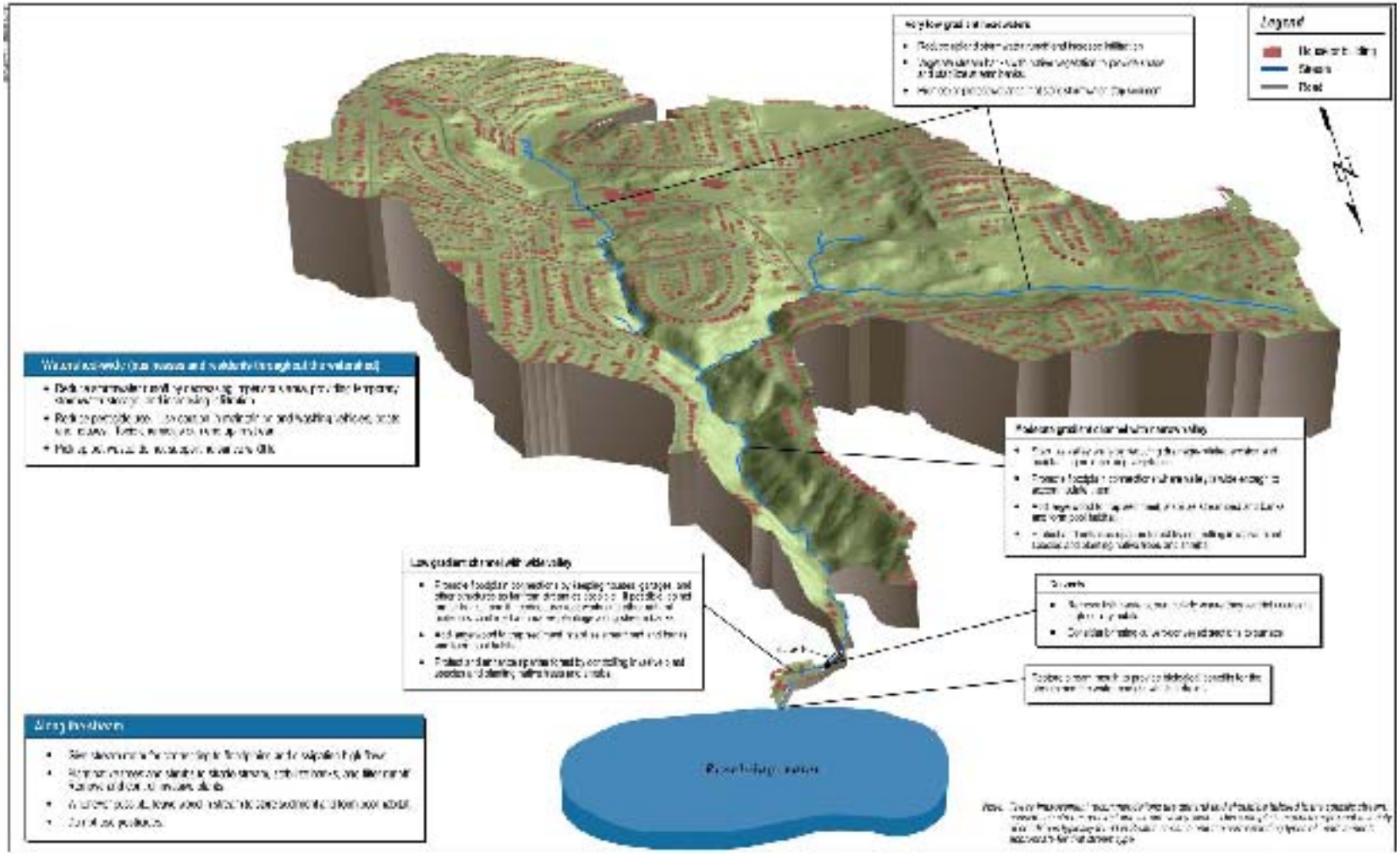


**Figure 3-5. General stream improvements based on stream types, considering impairment location and scale and potential remedial actions. Graphic provided by Herrera Environmental Consulting, Seattle, Washington.**

This page intentionally left blank.

**Example: An adaptive management plan outline for a single improvement action: culvert replacement in Fauntleroy Creek**

**1. Introduction.**

**1.1 Problem statement:** The public perceives that fewer coho salmon return to Fauntleroy Creek; their perception has been verified by recent fish surveys and historical fish accounts. The public has conveyed their concerns to elected officials, who then directed resource agency staff to formulate a management plan that would result in more coho salmon returning from the ocean. Problem: should resource agency staff recommend that culvert replacement be considered, so that coho would have additional spawning and rearing habitat?

**1.2 Need for adaptive management:** Habitat conditions in currently inaccessible areas of the stream appear suitable for supporting limited coho salmon spawning and juvenile rearing, and historical evidence suggests that coho salmon and steelhead were present in Fauntleroy Creek. Scientists and engineers have identified at least two important factors that affect fish: (1) high and flashy stream flows that may scour redds and "push" fish downstream, and (2) existing barriers (culverts) that may block or delay in-channel migration and impede access to upstream spawning and rearing habitats. Coho pre-spawning mortality is another factor that can limit survival of returning adults and the resulting production of juvenile fish in the system. Resource managers, the public, and elected officials wish to prioritize the various problems and potential solutions so that wise investments and sequencing of restoration actions can be defined.

**1.3 Project objectives:** Given the existence of Fauntleroy Park in the upper part of the watershed and the relatively low degree of impervious surface cover (compared with other Seattle streams), the general objectives of improving the stream's fundamental processes and resultant ecological health seem realistic. Specific objectives are eliminating migratory barriers (impassable culverts) and improving juvenile production. (Flow and water quality remain of concern and would need to be considered in a complete adaptive management plan.)

**1.4 Key scientific issues:** The primary factors that limit stream health are uncertain. For example, the effects of coho pre-spawning mortality (PSM) may "trump" the effects of upstream adult migration hindered by impassable culverts or barriers. Is the investment of removing impassable barriers worth the expense, given the yet unknown causes of PSM? To what extent do high winter flows eliminate suitable habitats? Frequent high scouring winter flows may also trump other restoration efforts.

**2. Monitoring and targeted research.**

**2.1 Investigating the implicit assumption: expanding accessible habitat through culvert replacement will increase fish.**
By replacing or retrofitting culverts identified as fish migration barriers, we make an implicit assumption that the numbers of fish are related to the lineal length (or area) of stream "opened up" once barriers are removed (Graph 1, Figure 3-6). But we have inherently made "hidden" assumptions too. Our further hidden assumptions are that the cumulative length of stream habitat opened is related to the rearing and spawning habitat areas that become available (Graphs 2 and 3, Figure 3-6). Our final hidden assumptions are that areas of rearing and spawning habitat are related to fish (juvenile and adult spawners) abundance and productivity (Graphs 4 and 5, Figure 3-6).

*Example continued.*

The step-wise sequence of assumptions is:

More fish depends on the number of culverts replaced, i.e., *our implicit assumption*

Meters of additional stream available to fish depend on the number of culverts replaced

Rearing habitat area depends on number of meters of additional stream available to fish

Spawning habitat area depends on the number of meters of additional stream available to fish

Abundance of juvenile fish depends on rearing habitat area, x # spawners, water quality, flow

Abundance of spawning fish depends on spawning habitat area and water quality

The above relationships illustrate the potential problems with implicit assumptions such as "culvert replacement will increase fish." In the above example, resident and migratory fish numbers are also functions of processes unrelated to culvert replacement, specifically, water quality (Graphs 4 and 5) and flow. If culverts are replaced, fish numbers could increase not because habitat area increased, but because water quality improved (through some other improvement action such as reducing stormwater inputs responsible for high flows, or through no action such as favorable weather conditions). Only by designing studies that examine each link can a cause and effect be established, and the relative contributions of remedial actions be fairly assessed.

Scientists and engineers would design the study plan(s) and would convey to decision makers and stakeholders how the results could be interpreted and how much the studies would cost. Given the assumptions and uncertainties inherent in the study plans, stakeholders and decision makers could prioritize which studies to fund now, and which could remain unfunded.

**2.2 Monitoring and applied research required to confirm hypotheses and assumptions (i.e., effectiveness monitoring).**

By inspecting the graphs in Figure 3-6, the types of studies required to establish and verify links between improvement actions and ecological health goals become apparent. For example, Graph 2 would require identification of suitable rearing habitat areas (say, by depth, velocity, and cover) along the longitudinal profile of Fauntleroy Creek, which will vary as a function of various flows. The data could then be transformed into plots similar to Graph 2. For the y axes of Graphs 4 and 5, fish surveys at fixed locations in the stream, sampled every year and over several seasons, would track relative distribution and abundance of fish.

If each graph represents data from one targeted, scientific study (and in reality, there would be more studies and data graphs, because for example, rearing habitat area is a function of depth, velocity, cover, temperature, etc.), then the commitment to the studies and to evaluating all lines of evidence must be consistent. Sufficient time and funding should be allocated for the studies to produce reliable information, so that scientists can make relatively certain recommendations to stakeholders and decision makers. Given funding available and the degree of uncertainty that the public and decision makers can accept, the decision makers then state which improvement actions should be taken, and in what order, as part of the overall recovery strategy.

**3. Incorporating new information into prioritizing many and various improvement actions**.

Defining and implementing components of a recovery strategy for urban streams is an emerging science and policy arena, and is therefore experimental and iterative. Each stream will require a tailored approach that addresses the specific characteristics and properties of that stream. Information gained through experience and monitoring will allow the City and others to decide and prioritize what improvement actions should be taken in a given stream. A process should be defined for vetting information with scientists, resource managers, the general public, and concerned stakeholders. The adaptive management process typically engages advisory committees and subgroups to evaluate new and important information as it becomes available. Such meetings allow an open process for consideration of restoration options and formal documentation of how this new information is considered in making management and policy decisions.

### 3.5.1 Using AM studies to inform realistic expectations

Intuitively, we know that we cannot expect pre-development conditions in an urbanized environment. In a development continuum from pristine to densely urbanized (Figure 3-3), we can locate where on the continuum a particular stream lies through measured indicators (Section 2.3). However, locating the continuum point that represents where the stream could realistically improve is more difficult; the direction of movement is clear, but the distance moved is not. The AM studies can assist in quantifying the degree of improvement possible, therefore determining whether a desired level of improvement is realistic.

In our Fauntleroy Creek example, let us assume that the adaptive management committee recommends enough funding for replacement of "C" number of culverts per decade (see Graph 1, Figure 3-6). Stepping through the graphs formulated from the scientific studies, we arrive at rearing habitat area "A," from which we can estimate an abundance of juvenile fish "J" (see Graph 4, Figure 3-6). Therefore, a realistic expectation of juvenile fish can not exceed "J" number of juvenile fish. (As noted in Graph 4 of Figure 3-6, the effects of water quality and flow must also be considered, and would be investigated in additional scientific studies.)

The adaptive management graphs can be utilized in the reverse direction too; if thresholds can be identified either through literature review or through the scientific studies, then realistic estimates of the financial resources needed to implement a required series of restoration actions can be realized. For example, say we determine that "J" is the minimum number of juvenile fish that are required such that the resident population in a given stream can be reliably self-sustaining (see Graph 4, Figure 3-6). We would call "J" the threshold value for juvenile fish. Again stepping through the graphs, we would find that area "A" of rearing habitat is required, which would require "B" meters of additional stream, which become available when "C" number of culverts are replaced (Graphs 2 and 1, Figure 3-6). The adaptive management committee can then be concerned with two issues: 1) Does monitoring confirm our expectation that replacing culverts increases juvenile production? And 2) If monitoring does confirm that replacing culverts increases juvenile production, are there adequate resources to replace 'C' number of culverts? Replacing less than "C" culverts would not allow the juvenile fish threshold to be crossed, and expecting significant increases in juvenile fish would be unrealistic. If the monitoring does not confirm expectations, then other improvement actions should be proposed. Through this process, scientific monitoring (e.g., data on fish production) and decision-making (e.g., concern about opportunity and resources) come together to determine future actions.

As previously stated in Section 3.5, the graphs in Figure 3-6 are conceptual and are presented as examples of studies and their results from an adaptive management program. We reiterate that sufficient time and funding should be allocated for the studies to produce reliable information. Scientists can make better recommendations to stakeholders and decision makers given sufficient time and funding for carefully designed studies. However, if either is limited, an adaptive management program can still be implemented—decision makers must be willing to accept a higher level of uncertainty. At minimum, hypotheses associated with ongoing improvement projects can be explicitly declared, and monitoring budgets can then be spent judiciously. Information that would allow graphs similar to those of Figure 3-6 could be obtained through literature review and assuming similar conditions of nearby creeks, if field studies can not be performed.

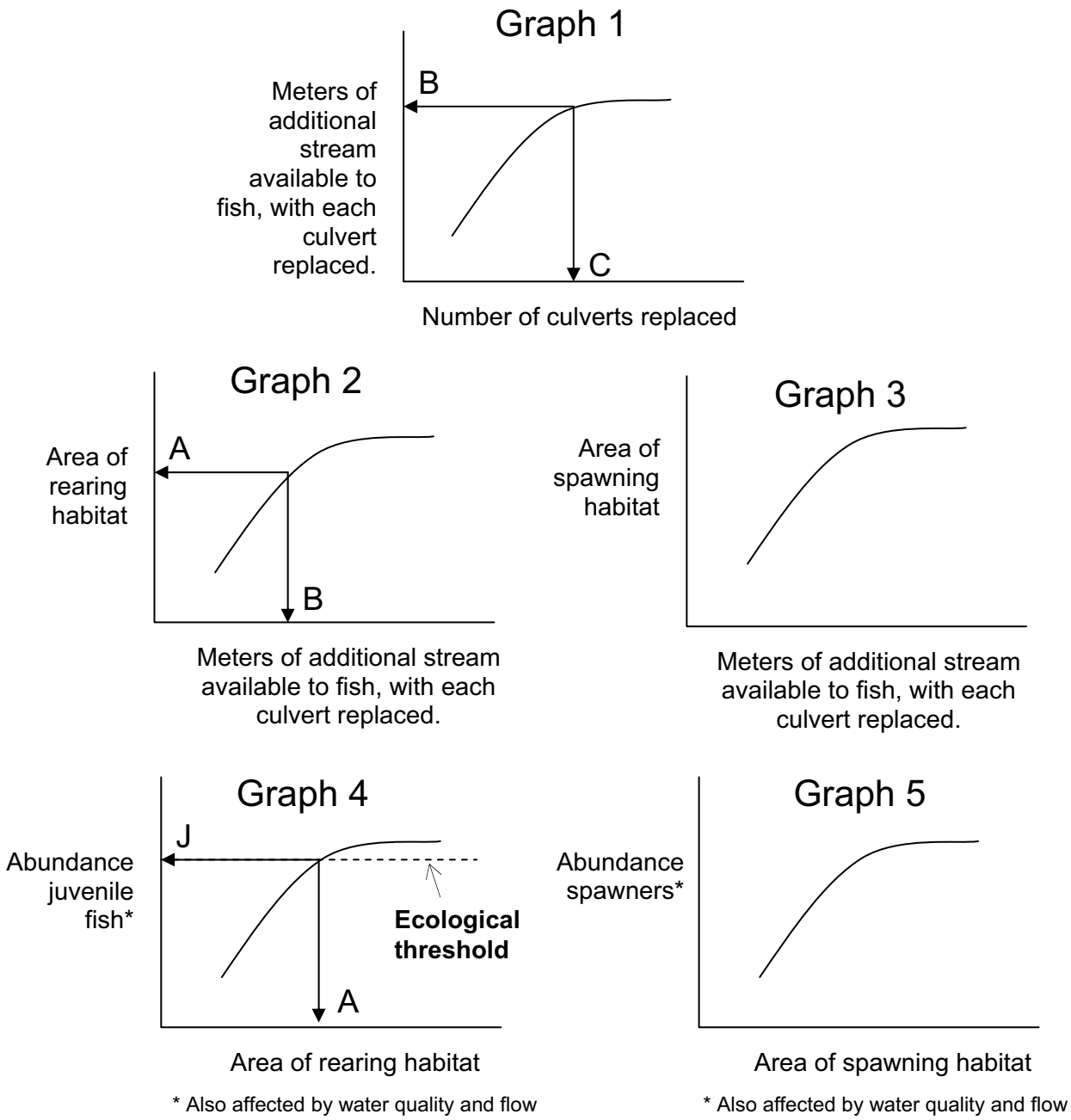


**Figure 3-6. The graphs represent adaptive management studies needed to determine if culvert replacement would increase fish.** In Graph 4, say the threshold **J** is the minimum number of juveniles needed for a self-sustaining fishery. Then rearing habitat area **A** is needed to produce **J** number of juveniles. From Graph 2, we then determine that rearing habitat area **A** corresponds to **B** meters of additional stream needed. Once **B** is known, in Graph 1 we determine that **C** number of culverts must be replaced, which costs some $ amount. We have now tied the ecological threshold of juvenile fish to $ required for culvert replacement. Graphs 3 and 5 represent additional studies necessary, unless a limiting factors analysis indicates that juveniles, not spawning adults, are the ecological "bottleneck." Graphs 4 and 5 also indicate the importance of other factors such as water quality that would need to be studied.

# 4 WHO HAS A ROLE IN MAKING IMPROVEMENTS?

Many different entities affect stream conditions and all play a role in achieving improvements in stream conditions. Those with opportunities to make stream improvements include:

- Watershed residents and businesses: Many citizens own buildings and land that drain to streams and other watercourses, often without any storm water detention or treatment facilities. Delaying the release of storm water on individual properties could reduce "flashiness" and reduce impacts to downstream habitat. On-site treatment of stormwater runoff, such as installing systems that mimic natural drainage systems or engineered methods, or other pollution source control measures can improve water quality. Reducing use and ensuring proper storage and disposal of potential pollutants (e.g., pesticides, oil) is important for improving water and sediment quality.
- Shoreline and stream-side property owners: Stream-side property owners can improve stream health by maintaining a native plant community with riparian trees and shrubs, and by setting any structures as far as reasonable from the stream itself. Property owners could also opt for "soft" bank protection methods, or could provide wide riparian areas without any bank armoring; such areas would create very beneficial habitat. Avoiding pesticide use along the stream would also ensure that stream and riparian animals are not adversely affected.
- City government: Many departments in the City of Seattle government can contribute to improving stream conditions. Prominent departments include:
  - Mayor and City Council: The Mayor and Council members make political and financial commitments, including those for environmental improvements.
  - Seattle Department of Parks and Recreation ("Parks"): Parks maintains a number of shoreline and stream-side parks. Maintaining riparian communities and minimizing bank armoring and pesticide use, as suggested for stream-side property owners above, can help to improve stream and riparian habitat conditions.
  - Seattle Department of Planning and Development: DPD is responsible for developing, implementing, and enforcing regulations, such as the Critical Areas Ordinance and the Shoreline Master Program. Working with landowners and developers to protect and enlarge riparian corridors and improve shoreline habitat is needed for healthier conditions.
  - Seattle Public Utilities: SPU manages the storm water and waste water collection systems within the City of Seattle. Storm water runoff management and CSO controls are important for improving the hydrology and water quality in Seattle streams and larger waterbodies.
  - A number of other departments can also contribute to improvements (e.g., Office of Sustainability and Environment, Department of Transportation). Education, outreach, and financial incentives are tools that the City of Seattle can use to influence Seattle citizens and businesses to lead to more environmentally responsible practices and behaviors. City departments can also police their own projects to reduce potential impacts and propose beneficial mitigation when necessary.
- Land developers: Seattle's development patterns include infilling vacant areas and re-building older structures. Working with developers, land use planners, architects, and builders to create new housing, industrial and commercial areas using "green" technology, and protecting or improving storm water management, water quality, and riparian and shoreline habitats, could contribute to an overall improvement in aquatic ecosystems.

- State and Federal government: Following state and federal regulations, state and federal agencies influence streams and other water body conditions through their permitting processes. Coordination among City, state, and federal government agencies will facilitate improved stream health.

To achieve stream health improvement, we need to tie together all the actions, from potentially harmful to improvement, undertaken by various groups and agencies. Each group and agency would benefit from seeing their piece as a part of the whole; any additional and ongoing actions can be specifically planned to "fit in" with the creek-specific goals and objectives. Because the current state of Seattle's urban streams is the result of many management actions by many entities, a return to improved ecological states will similarly require a substantial number of actions that cumulatively restore important ecological components of these stream systems.

# 5 WHAT ARE NEXT STEPS TO MOVE FORWARD?

Ultimately, improving the ecological health of Seattle's waterbodies relies on: (1) developing a better appreciation for the consequences of how we live on the land, (2) using that understanding to reduce harmful impacts through directed action, (3) tracking progress over time through a well designed monitoring program, and (4) committing to making additional changes to increase the effectiveness of improvement actions. To be successful, these actions will require creativity and considerable commitment from the entire community because changes are needed in how we go about doing business, how we get around, how we live, and how we manage our land. With this Science Framework, we provide a technical basis for the changes needed to restore our waters. Further, through the conceptual adaptive management process presented here, we provide a scheme that will promote constructive conversations about balancing human uses of watersheds with the needs of other species and the health of all communities.

The information within this Science Framework should be made available to City departments; other local, state and federal agencies; and citizens and community groups. To clearly articulate the information, it is critical to have a common understanding and vocabulary about our respective contributions, monitoring, stream processes, ecological health, visions, and goals. In explaining the Science Framework and the ways in which it can be used, a number of efforts can be informed (Figure 5-1). These efforts include on-going, planned, and conceptual improvement actions and land use activities; these efforts could be linked together through development of an adaptive management program that operates at a City-wide level.

As presented in the Evaluation Cycle and the adaptive management process, a first effort includes defining a process for setting management goals, or "destinations", for Seattle's streams. The process should include Seattle citizens, businesses, and interest groups. Given the continuum ranging from pristine creeks to completely armored and urbanized conduits, the Science Framework can help people and policy makers identify each stream's desired destination while considering financial investment, human needs, private property rights, and realistic expectations of what is possible. Differences in Seattle streams' geology, hydrology, land uses, and fish uses (see Appendix G and SPU 2007, in prep.) should be considered when determining long-term goals, as a "one-size fits all" strategy is likely not suitable. These goals should be measurable (see Section 2.3) and short-term numerical benchmarks can also be set (see Appendix H).

This Science Framework emphasizes the need for accountability in making ecological improvements through a carefully designed and implemented monitoring and research program. Without a monitoring program, we will be unable to determine if we are doing no further harm or contributing to the "no net loss" of existing habitat areas. By monitoring stream conditions and the watersheds that contribute to them, City resource managers will be able to make informed decisions on the nature and extent of future investments in actions that may help restore Seattle's streams.

Therefore, the next steps to move forward are: to make this Science framework information available to City departments; other local, state and federal agencies; and citizens and community groups; to begin planning for and implementing status-and-trend monitoring, which will be important for tracking the cumulative progress of future and ongoing improvement actions and programs; and to begin planning for and implementing effectiveness monitoring, which will help us understand whether our improvement actions "work." Identifying goals for each of Seattle's

primary streams, and developing status-and-trends and effectiveness monitoring programs, are central to adaptively managing our watersheds, understanding our return on investment, and truly making progress in improving aquatic ecosystems.

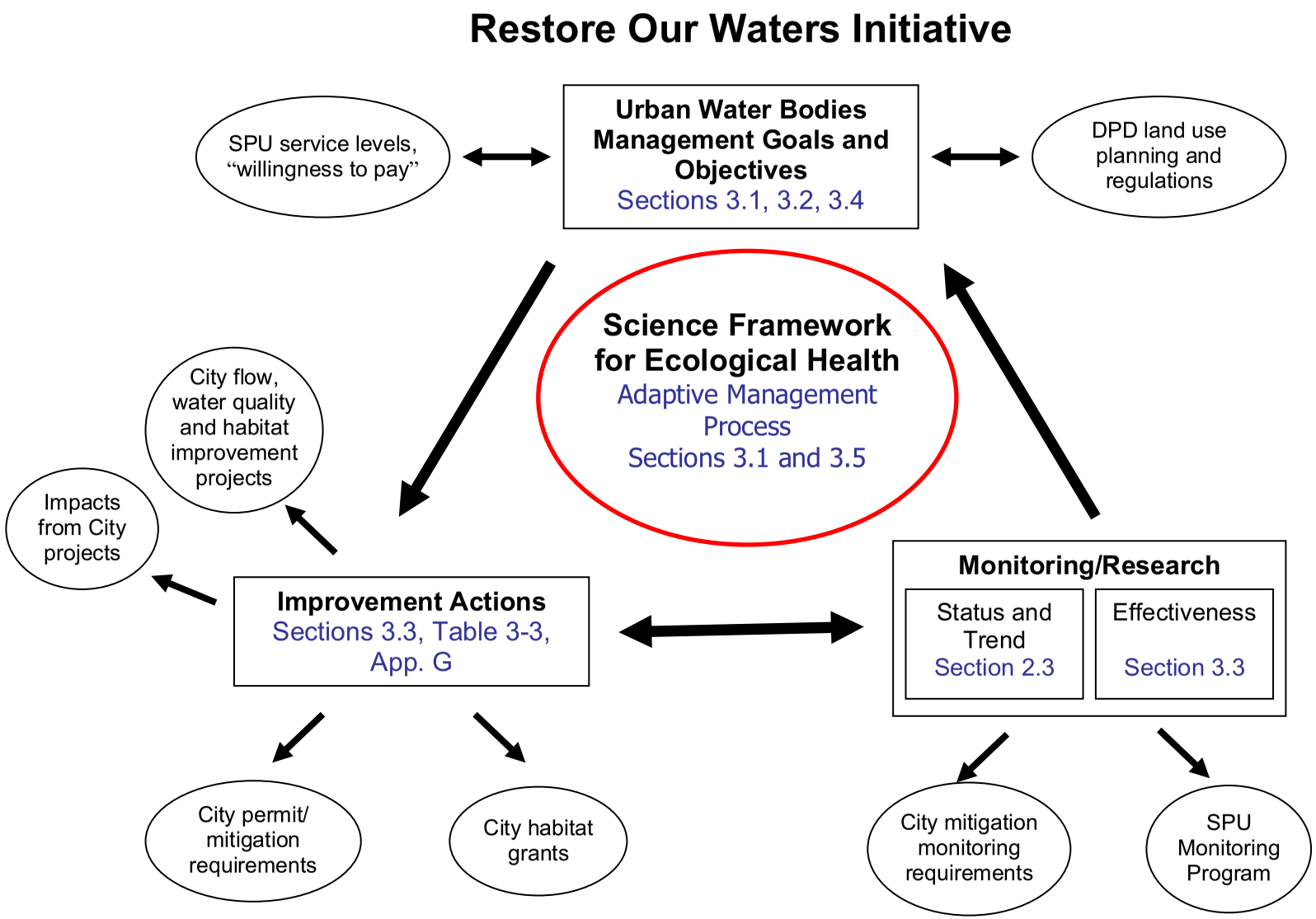


**Figure 5-1. Schematic of City of Seattle efforts and activities that could be informed by or are proposed in the Science Framework. Although not shown here, external factors include state and federal regulations and projects, regional efforts, local watershed groups, businesses, land developers, and Seattle citizens.**

# 6 LITERATURE CITED

Bauer, S. B., and S. C. Ralph. 1999. Aquatic habitat indicators and their application to water quality objectives within the Clean Water Act. EPA-910-R-99-014. U. S. Environmental Protection Agency Region 10, Seattle, Washington.

Buffington, J. M., R. D. Woodsmith, D. B. Booth, and D. R. Montgomery. 2003. Fluvial processes in Puget Sound rivers and the Pacific Northwest. Pages 46-78 *in* D. R. Montgomery, S. Bolton, D. B. Booth and L. Wall, editors. Restoration of Puget Sound rivers. University of Washington Press, Seattle.

Buffington, J. M., D. R. Montgomery, and H. M. Greenberg. 2004. Basin-scale availability of salmonid spawning gravel as influenced by channel type and hydraulic roughness in mountain catchments. Canadian Journal of Fisheries and Aquatic Sciences 61: 2085-2096.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. Special Publication No. 19. American Fisheries Society, Bethesda, Maryland.

Ecosystem Management Initiative. 2005. Ecosystem Management Initiative. Evaluation and adaptive management. Natural Resources and Environment, University of Michigan. http://www.snre.umich.edu/ecomgt/evaluation/index.htm

EPA (U. S. Environmental Protection Agency). 2003. Watershed analysis and management (WAM) guide for states and communities. EPA Watershed Analysis and Management Project

Fox, M., S. Bolton, and L. Conquest. 2003. Reference conditions for instream wood in western Washington. Pages 361-393 *in* D. R. Montgomery, S. Bolton, D. B. Booth and L. Wall, editors. Restoration of Puget Sound rivers. University of Washington Press, Seattle.

Government of British Columbia. 2001. Glossary of forestry terms. Government of British Columbia, Ministry of Forests and Range, Victoria. http://www.for.gov.bc.ca/hfd/library/documents/glossary/index.htm.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41: 540-551.

Gregory, S. V., L. Ashkenas, D. Oetter, and K. Wildman. 2002. 8. River restoration. Longitudinal patterns - revetments. Pages 138-139 *in* D. Hulse, S. Gregory and J. Baker, editors. Willamette River basin atlas: trajectories of environmental and ecological change. Prepared by Pacific Northwest Ecosystem Research Consortium. Oregon State University Press, Corvallis, Oregon.

Herrera Environmental Consultants. 2006. Thornton Creek and Matthews Beach microbial source tracking study. Draft Monitoring report. Prepared by Herrera Environmental Consultants, Seattle, Washington for Seattle Public Utilities, Seattle, Washington.

Holling, C. S., editor. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York.

Konrad, C. P., and D. B. Booth. 2002. Hydrologic trends associated with urban development for selected streams in the Puget Sound basin, western Washington. Water-Resources Investigations Report 02-4040. Prepared by U. S. Geological Survey, Tacoma, Washington in cooperation Washington Department of Ecology, University of Washington, Seattle, Washington.

Larson, M. G., D. B. Booth, and S. A. Morley. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. Ecological Engineering 18: 211-226.

Levine, J. 2004. Adaptive management in river restoration: theory vs. practice in western North America. University of California, Berkeley

Naiman, R. J., J. J. Magnuson, D. A. McKnight, J. A. Stanford, and J. R. Karr. 1995. Freshwater ecosystems and their management: a national initiative. Science 270: 584-585.

Pess, G., S. Morley, J. L. Hall, and R. K. Timm. 2005. Monitoring floodplain restoration. Pages 127-166 *in* P. Roni, editor. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Poole, G., J. Dunham, M. Hicks, D. Keenan, J. Lockwood, E. Materna, D. McCullough, C. Mebane, J. Risley, S. Sauter, S. Spalding, and D. Sturdevant. 2001. Scientific issues relating to temperature criteria for salmon, trout, and char native to the Pacific Northwest: a summary report submitted to the Policy Workgroup of the EPA Region 10 Water Temperature Criteria Guidance Project. EPA-910-R-01-007. U. S. Environmental Protection Agency, Washington, D. C.

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51: 37-51.

Ralph, S. C. and G. C. Poole. 2003. Putting monitoring first: designing accountable ecosystem restoration and management plans. *In* Montgomery D. R. , S. Bolton and D. B. Booth, editors. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, Washington.

SPU (Seattle Public Utilities). 2007, in preparation. The Seattle State of the Waters report. Draft report. Seattle Public Utilities, Seattle, Washington.

Sossa, C. S., and D. B. Booth. 2004. Comparing and evaluating rapid assessment techniques of stream channel conditions for assessing the quality of aquatic habitat at the watershed scale. T. W. Droscher and D. A. Fraser, editors. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. Draft report No. TR-4501-96-6057. ManTech Environmental Research Services Corporation, Corvallis, Oregon.

Suttle, K. B., M. E. Power, J. M. Levine, and C. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14: 969-974.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1: 1.