DRAFT

Stormwater Monitoring and Assessment Strategy for the Puget Sound Region

Volume 1: Scientific Framework

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Acknowledgements

The Stormwater Work Group would like to express our appreciation to the many people who have provided us input and ideas for creating this strategy. Dozens of local technical experts and interested parties have attended our meetings and workshops, sent emails, and made phone calls to help us achieve our goals. This document is stronger because of their contributions.

This is Volume 1 of 2

This document is the first of two documents that will compose the *Stormwater Monitoring and Assessment Strategy for the Puget Sound Region*. This document, "Volume 1," describes the scientific framework for the monitoring and assessment that will be implemented: what decisions were needed and were made about priorities for data collection, what information needs to be collected, and what analyses need to be conducted. The next document, "Volume 2" (due in June 2010), will propose an implementation plan for conducting the monitoring and assessment activities: who will collect what data when, where, and how; what methods, protocols, and data reporting standards will they adhere to; and how the collective capacity and resources of the region will be brought together to provide the regional understanding of stormwater impacts and efficacy of management actions that is needed to recover Puget Sound and the waters that feed it.

How to Read this Document

- Section 1 *Introduction* describes our problem, our charge, and our approach.
- Section 2 *Monitoring Priorities* describes "the universe" of the stormwater problem, the monitoring priorities we recommend, and why.
- Section 3 *Experimental Designs for the three Monitoring Categories* describes the experimental designs we propose, and why.
- Section 4 *Summary and Next Steps* describes the strategy we recommend, and some of the additional support tools, activities, and coordination mechanisms needed to successfully implement a regional stormwater monitoring and assessment strategy.
- Section 5 *Guide to Appendices* describes the information contained in the six appendices to this document.

Suggested Citation

Puget Sound Stormwater Work Group, 2009. Draft Stormwater Monitoring and Assessment Strategy for the Puget Sound Region, Volume 1: Scientific Framework. Prepared by Derek Booth, Karen Dinicola, Leska Fore, John Lenth, and Jim Simmonds. 90 pp.

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EXECUTIVE SUMMARY

Dear Readers: This document is a work in progress. Throughout the document you will see text boxes like this bringing things we are struggling with to your attention. Please help us achieve our objective by providing suggestions and proposing solutions for us to consider. We anticipate significant revisions to this document based upon your input. Sincerely, the Stormwater Work Group.

Stormwater is a significant stressor affecting the health of the Puget Sound ecosystem. Efficiently and effectively managing stormwater to prevent, reduce, and mitigate harm to the ecosystem is a common goal of local, state, and federal governments and agencies, tribes, environmental groups, the business community, and the citizens of Puget Sound. To achieve that goal, a coordinated, integrated approach to quantifying the stormwater problem in Puget Sound and evaluating the effectiveness of stormwater management activities is needed and does not currently exist. The Puget Sound Stormwater Work Group was created to recommend such an approach.

The scope of our effort is limited to stormwater-related monitoring and assessment. Because the stormwater problem in Puget Sound is extensive and complex, this document has an even narrower scope: namely, to describe the extent of the problem and propose a scientific framework that provides a reasonable scope and foundation for building a regional stormwater monitoring and assessment program. We explicitly acknowledge that we cannot monitor everything everywhere. We define "the universe" of the stormwater problem and, using a caucus-based stakeholder committee and broader public process, have narrowed that universe to what we judge to be an achievable starting point: a more tractable set of priority questions. This narrowing was challenging, and some conditions that are perhaps of great local significance are not included.

We recommend an adaptive management framework for this effort, and so propose an initial set of hypotheses to be tested for each of three monitoring categories and scales to provide different types of information useful for decision making: long-term regional status-and-trends monitoring, mid-scale targeted effectiveness studies, and local source identification efforts. A subset of these hypotheses has been translated into experimental designs. Our intent is not to define a comprehensive suite of stormwater monitoring actions, but rather to establish an overarching scientific framework for stormwater monitoring that will allow otherwise independent efforts or whole programs to contribute to our greater understanding and evaluation of progress.

We propose long-term regional status-and-trends monitoring focused on biological communities in small streams and nearshore areas to improve understanding of whether stormwater management programs are helping to achieve the larger goal of restoring the Puget Sound ecosystem. We recommend implementing a regional probabilistic sampling design that addresses biota, water and sediment quality, and streamflow; the design can incorporate additional sampling sites within smaller subregions.

We recommend conducting effectiveness studies of best management practices in major land-use categories to assess whether the practices achieve intended outcomes of water quality improvements or stormwater volume reductions or other protective or corrective measures. We

recommend focusing source identification monitoring on targeted activities typically conducted by local jurisdictions to identify and quantify stormwater volumes and sources of pollutants and conducting collective assessments to identify regional issues.

The next step in creating a regional approach to stormwater monitoring and assessment is to develop an implementation plan that provides specific recommendations for (1) the mechanics by which data collection and analysis will be conducted and information will be shared, and (2) how the region's monitoring and assessment resources and various entities can be brought together in a coordinated and efficient manner to conduct the monitoring and assessment. That step will be presented in Volume 2 of this strategy, due in June 2010.

1 INTRODUCTION

Stormwater is a significant stressor affecting the health of the Puget Sound ecosystem. Efficiently and effectively managing stormwater to prevent, reduce, and mitigate harm to the ecosystem is a common goal of local, state, tribes and federal governments and agencies, environmental groups, the business community, and the citizens of Puget Sound. A broad, comprehensive, regional stormwater monitoring and assessment strategy is needed for Puget Sound to provide an unbiased assessment of whether our actions are resulting in genuine progress towards regional conservation targets. The monitoring and assessment results must be closely linked to potential management and regulatory actions to ensure that a cycle of adaptive management is created and maintained.

This project was initiated in response to a request for a coordinated monitoring and assessment program by the Puget Sound Partnership (PSP) and the Washington State Department of Ecology (Ecology). PSP is the state agency charged with overseeing ecosystem recovery efforts for Puget Sound. Ecology is the state agency with delegated with federal Clean Water Act implementation. This document describes the scientific framework, including the goals of regional stormwater monitoring, priorities for data collection, analyses that need to be performed, and ways the resulting information will be used to inform management activities.

A subsequent document will describe an implementation plan detailing how the capacities of the region will be harnessed to take the necessary steps to successfully implement the strategy. These are the first of several steps toward developing an integrated, comprehensive stormwater monitoring and assessment strategy for the Puget Sound region. The efforts of the Puget Sound Stormwater Work Group (SWG) will be ongoing and iterative as monitoring and assessment are conducted, information is shared, and additional needs and future priorities are identified.

1.1 Background and Context

The Puget Sound region has been the locus of numerous widely-cited scientific studies designed to understand and reduce the effects of stormwater. Although many types of human activities threaten the health of the Puget Sound ecosystem, there is considerable agreement among regional scientists and community leaders that the alteration and loss of habitat and the ongoing input of pollution are the most immediate and pervasive threats to the ecosystem (Beyerlein *et al.* 2006 and 2008; Puget Sound Partnership 2008). Surface water and stormwater runoff in urban and rural areas are now recognized as the primary, unaddressed transporters of toxic, nutrient, and pathogen pollutants to surface and groundwater resources throughout the Puget Sound basin (Ecology 2007), and are also now recognized a one of the primary causes of habitat degradation in small streams due to alterations in flow volumes (Beyerlein *et al*. 2006).

Water quality and stormwater management practices in the Puget Sound region need to be anchored within an ecosystem approach and better coordinated so they can effectively address the ubiquitous nature and diffuse sources of pollutants in our freshwater and marine systems. Current stormwater management programs in the Puget Sound region evolved from local programs focused on drainage and flooding problems; the pollution carried by stormwater was not a driving factor in creating these programs (or infrastructure) until relatively recently. Measures address the site or project scale, and so fall short of protecting the larger ecosystem.

What is "Stormwater"?

"Stormwater" is a term that is used widely in both scientific literature and regulatory documents. It is also used frequently throughout this document. Although all of these usages share much in common, there are important differences that benefit from an explicit discussion.

Most broadly, stormwater runoff is the water associated with a rain or snow storm that can be measured in a downstream river, stream, ditch, gutter, or pipe shortly after the precipitation has reached the ground. What constitutes "shortly" depends on the size of the watershed and the efficiency of the drainage system, and a number of techniques exist to precisely separate stormwater runoff from its more languid counterpart, baseflow. For small and highly urban watersheds, the interval between rainfall and measured stormwater discharges may be only a few minutes. For watersheds of many tens or hundreds of square miles, the lag between these two components of storm response may be hours, a day, or more.

From a regulatory perspective under the Clean Water Act, stormwater must pass through some sort of engineered conveyance, be it a gutter, a pipe, ditch, concrete canal, or even along a roadside curb. If it simply runs over the ground surface, or soaks into the soil and soon reemerges as seeps into a nearby stream, it may be water generated by the storm but it is not regulated stormwater.

This document emphasizes the first, more hydrologically oriented definition. However, attention is focused mainly on that component of stormwater that emanates from those parts of a landscape that have been affected in some fashion by human activities. Mostly this includes water that flows over the ground surface and is subsequently collected by natural channels or artificial conveyance systems, but it can also include water that has infiltrated into the ground but nonetheless reaches a stream channel relatively rapidly and that contributes to the increased stream discharge that commonly accompanies almost any rainfall event in a human-disturbed watershed.

Glossary definition (from NRC 2009)

Stormwater: That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels, or pipes into a defined surface water channel or a constructed infiltration facility. According to 40 C.F.R. § 122.26(b)(13), this includes stormwater runoff, snow melt runoff, and surface runoff and drainage.

The types and magnitude of threats vary in different places, but the entire region faces challenges from a growing human population and a changing climate that will exacerbate the many existing pressures to Puget Sound.

The Puget Sound Stormwater Work Group (SWG) includes representatives from cities, counties, tribes, and state and federal agencies responsible for monitoring and managing stormwater and water quality. We are charged with developing a regional, cooperative stormwater monitoring and assessment strategy focused on enabling us to know whether our management actions are

successfully reducing harm caused to Puget Sound by stormwater runoff from developed and developing lands.

Three approaches have been comingled in the creation of this document:

- Scientific understanding and inquiry serve as the foundation for the development of specific, testable hypothesis related to reducing the impact of stormwater throughout the Puget Sound basin.
- Tenets of adaptive management are adopted to ensure that the results of monitoring are relevant and used to inform management and policy decisions.
- Development of the strategy is an inclusive, transparent process.

A comprehensive monitoring and assessment program will be developed over time, in iterative steps. This document represents the first step, that of defining the initial scientific framework. As such, it lays out the foundation of an overarching stormwater monitoring and assessment strategy for Puget Sound. Further, it recommends which monitoring and assessment strategies should be undertaken first. The need to prioritize is linked to resources: given limited resources, and the need to efficiently uncover vital information to improve our stormwater management efforts, we cannot afford to undertake every potential stormwater monitoring and assessment activity. We therefore recommend a prioritized list of monitoring and assessment efforts that can more rapidly and affordably provide the region with critical information to improve stormwater management.

An implementation plan will follow that needs to be completed in time to inform state agency budgets and the monitoring requirements in the next cycle of Clean Water Act permits for local governments. This second document will be completed by June 2010, and will lay out a detailed proposal for *how* this regional stormwater monitoring and assessment strategy should be implemented.

This overall effort is intended to constitute one portion of an overall ecosystem monitoring program for Puget Sound by satisfying the need to learn more about the effects of stormwater on beneficial uses and the most effective stormwater management and mitigation measures to control those effects. An overall monitoring and assessment program for the Puget Sound ecosystem is being established so that the region can clearly see if the health of Puget Sound is improving, and whether the legislative goal of restoring the Puget Sound ecosystem by 2020 is being met. The Puget Sound Stormwater Work Group (SWG) is a model for other topical work groups that will eventually compose that overall ecosystem monitoring and assessment program.

1.2 Purpose, Scope, and Timeline

The purpose of this document is to articulate the scientific framework for an integrated, coordinated and comprehensive stormwater monitoring and assessment strategy for the Puget Sound region. The SWG was charged with this task by both the Puget Sound Partnership (PSP) and the Washington State Department of Ecology (Ecology). Specifically, PSP and Ecology requested a stormwater monitoring and assessment strategy that provides meaningful management data; promotes greater understanding of stormwater and other surface water pollution source issues; and supports a larger, integrated effort to protect and restore the Puget Sound ecosystem by enabling us to know whether or not we are reducing harm caused to Puget

Sound by stormwater and other surface water sources. The SWG's initial work plan envisioned developing an approach to (1) assess the effects of stormwater on receiving waters and beneficial uses throughout the Puget Sound basin, (2) identify and characterize sources and loadings of pollutants in stormwater throughout the basin, and (3) evaluate the efficacy of management actions to prevent, reduce, or mitigate those sources and effects.

The scope of our effort is limited to stormwater-related monitoring and assessment. Because the stormwater problem in Puget Sound is so extensive and complex this document has an even narrower scope: namely, to describe the extent of the problem and define a scientific framework for moving forward. We define "the universe" of the stormwater problem and then narrow that universe to what we judge to be an achievable starting point, using a caucus-based stakeholder committee and broader public process (see Appendix A). Not every recommended priority, however, is included here.

The subsequent implementation plan document will recommend roles and methods for local jurisdictions, state and federal agencies, businesses, and others who are directly or indirectly responsible for managing stormwater or affected resources, to participate in implementing the strategy. That document will also answer Ecology's request that we include recommendations for allocating responsibilities in the next cycle of Clean Water Act National Pollutant Discharge and Elimination System (NPDES) municipal stormwater permits.

The final strategy (the scientific framework and the implementation plan) will be delivered to PSP and Ecology in June 2010.

1.3 An Overarching Strategy

The many groups interested in and responsible for collecting information about stormwater impacts in Puget Sound all agree that an overarching stormwater monitoring and assessment strategy is needed to ensure that the information is meaningful and useful for decision makers, prioritize the types of data to be collected, and coordinate the efforts of the multiple parties involved.

It is the SWG's intent to develop and carry out a stormwater monitoring and assessment strategy that improves how we manage stormwater and provides decision makers with critical information to help them make more informed, more successful decisions. We expect PSP to use information gained from this strategy to inform and improve future revisions to the *Action Agenda* and regional stormwater management policy. We expect Ecology to use information gained from this strategy to refine the best management practices recommended in stormwater guidance manuals and required in permits, determine monitoring components of future NPDES stormwater permits, and improve regional stormwater management efforts. Some of the actions needed to reduce the impacts of stormwater are currently addressed under the *Puget Sound Action Agenda* (PSP 2008). PSP is using an Open Standards model (Conservation Measures Partnership 2007) approach to adaptive management to frame and support implementation of the *Action Agenda*, and we believe that the approach presented here is fully compatible with that model. Results from stormwater monitoring will be linked to specific objectives related to the reduction of stormwater runoff through permits, modification of land use practices, retrofits, incentives, and other mechanisms.

Science can provide defensible and replicable insights regarding the ecological outcomes of management prescriptions, but it can not offer absolute certainty. Policy can be and should be informed by science but is ultimately based on a variety of considerations that are not always amenable to the limitations of the scientific process (Van Cleave *et al*. 2004), and the time frame needed to generate robust information may not be responsive to the much shorter timeline of social and political policy- and decision-making. These are uncomfortable truths for agency managers and elected officials to acknowledge, and they commonly result in funding decisions and public pronouncements using the "language" of science but not its substance. This overarching strategy seeks to avoid such a bifurcated outcome.

1.4 Purpose of this Document as an Adaptive Management Tool

***"Adaptive implementation is, in fact, the application of the scientific method to decision making"* (NRC 2001).**

This document articulates a recommended scientific framework for stormwater monitoring and assessment across the Puget Sound region. We invoke the principals of Adaptive Management, as first articulated over 30 years ago and more recently embraced through various conservation efforts worldwide. Fundamental to this approach is the integration of management and monitoring, recognizing that any management action in the context of a complex ecological system is ultimately experimental, requiring feedback to make progress (see Figure 1). This principle has been articulated in a variety of past ecosystem monitoring and assessment efforts,

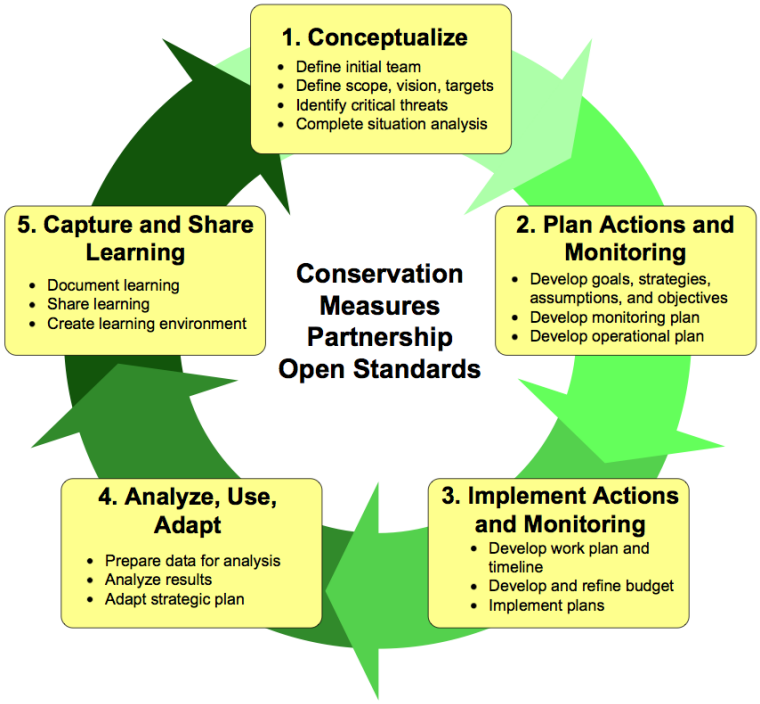

Figure 1. The Adaptive Management Cycle (Open Standards Conservation 2007). With this document, the Puget Sound Stormwater Work Group (SWG) is addressing "Step 1" and beginning "Step 2" of this cycle.

both regionally and nationally, and they provide worthwhile lessons for current efforts (see Appendix B). We are using these lessons to craft a robust conceptual scientific framework in which to identify significant ecosystem threats from stormwater runoff; to stratify the landscape into major categories of land use and receiving water; and to articulate credible, testable hypotheses that can guide future monitoring and assessment efforts.

In this document, a subset of these hypotheses has been translated into concrete experimental designs that meet the necessary criteria for sensitivity, statistical power, and feasibility. The intent of this document is not to define a comprehensive suite of stormwater monitoring actions, but rather to establish an overarching scientific framework for stormwater monitoring that will allow otherwise independent efforts or whole programs to contribute to our greater understanding and evaluation of progress.

The effort to create this document was undertaken believing that our efforts would be focused on Step #2: *Plan Actions and Monitoring*, in the cycle depicted in Figure 1. However, we have found that we frequently need to revisit Step #1: *Conceptualize*. In parallel with our development of this strategy, an adaptive management approach is being pursued by PSP to implement the *Action Agenda* to recover the Puget Sound ecosystem by 2020 (PSP 2008).

1.5 What is Adaptive Management, and How Does it Apply to our Problem?

Adaptive management, as first outlined by Holling (1978) and later revised, renamed, and recast by others (*e.g.*, Walters 1986; Lee 1999), is an approach for overcoming uncertain ecological outcomes associated with land-use and natural resource management actions by treating management activities as experimental components within the larger structure of a monitoring program (Ralph and Poole 2003). Specific management decisions that affect ecological processes and functions are systematically evaluated in ways that affirm or refute expected outcomes. Uncertainty is embraced and serves as a focal point for more specific evaluations. The process of adaptive implementation is iterative and continuous; new knowledge is actively incorporated into revised experiments, a practice best described as "learning while doing" (Lee 1999). The key difference between this approach and other environmental management strategies that are often implemented is the application of scientific principles, such as hypotheses-testing, to explicitly define the relationships between policy decisions and their measured ecological outcomes. Further, the adaptive implementation approach provides a means to understand and document these cause-and-effect relationships, as well as to evaluate alternative actions that may produce more desirable outcomes.

Scientifically credible and relevant information can only be generated when the monitoring "experiments" are designed with clear hypotheses about the effects of proposed management prescriptions. These hypotheses must be testable at multiple scales using available technology and methods (Conquest and Ralph 1998; Currens *et al*. 2000). Hypotheses that cannot be tested, or only account for site-specific conditions, are not useful in considerations of cumulative effects.

In order to retain clear linkages between key questions, hypotheses, and monitoring protocols, the experimental approach must be designed before determining which goals and targets are appropriate (Ralph and Poole 2003) since appropriate goals should be *outcomes* of the effort, not

a precondition; and the approach must explicitly tie stated hypotheses to the key ecological questions. For example, in order to judge the relative capacity of rivers, lakes and marine waters to support "beneficial uses," existing state regulatory programs for water quality typically use a suite of evaluation criteria that provide specific thresholds above (or below) which it is assumed that the water quality is "unacceptable." In this case, there is a water quality indicator, and a target value to judge acceptability. In recent years, comprehensive monitoring programs are beginning to be developed to provide statistically valid designs to characterize water quality across state waters. New programs will be able to provide more clear insights into the ultimate and proximate causes when water-quality criteria are exceeded. Thus when the management objectives are stated, the underlying assumptions and hypotheses can be better articulated and more systematically tested.

Wagner (2006) asserts that [stormwater] regulatory programs in the past often failed because they were designed in ways that ignored technological and scientific limitations. "Science-based" does not simply mean the monitoring of status and trends followed by responding to imposed benchmarks and goals, but rather that scientific principles must be the foundation of regulatory program design, and that these programs must rely on scientific methods to demonstrate results. Wagner suggests that regulations can still be designed despite incomplete or developing knowledge, but that gaps and limitations must be acknowledged and used to inform ongoing investigations. His argument clearly echoes those of scientists who insist that monitoring experiments and testable hypotheses must frame management decisions and land-use objectives.

1.6 What <u>is not</u> Adaptive Management, and What are Some Pitfalls to Avoid?

In natural resource management, the following process traditionally dominates:

(1) a problem is identified, but not translated into a well-defined key question, and a cause is simultaneously assigned (*e.g.*, "increased sediment inputs into a stream are negatively impacting salmonid survival");

(2) a solution or set of solutions is proposed (*e.g.*, timber harvest is restricted and riparian buffer width is increased), but the prescription is not translated into a testable hypothesis associated with the problem or question;

(3) if the problem is not solved within an arbitrarily reasonable period of time (*e.g.*, a few years) then a different solution is proposed (*e.g.*, "augmented upland and riparian restoration must be implemented").

Although simplified, even this outline displays its divergence from adaptive management and from the basic principles of the scientific process, and the resulting process is perpetually reactive.

Recent efforts to build large, collaborative programs are commonly characterized by increasing stakeholder involvement, information sharing, outreach, and voluntary participation. These reflect the movement to extend natural resource management decision-making processes beyond just technical experts in order to reflect evolving social values (Pahl-Wostl *et al*. 2007). This shift implies "an adaptive co-management of social and ecological systems in which combines

the dynamic learning of adaptive management with the linkage characteristics of cooperative management" (Berkes *et al*. 1998), but it does not require it. Greater participation does not necessarily mean that true adaptive management is occurring, or that scientific principals are being applied to either the choice of management actions or their evaluation. If successful, however, it also opens a path to achieving the best of both realms, namely scientific rigor with a broad base of community support. This document reflects such an effort.

2 MONITORING PRIORITIES

If we are to help inform and guide, through existing and future monitoring activities, effective management of stormwater across the Puget Sound region, we need a robust scientific framework. The scientific framework must ensure that the work fills gaps (*i.e.*, gathers information about outcomes that are not yet well understood), and targets issues of primary importance and of known (or at least strongly suspected) major influence. Results of the stormwater monitoring and assessment activities should be linked to specific objectives related to the reduction of stormwater runoff through permits, modification of land use practices, retrofits, incentives, and other mechanisms. In order to achieve these objectives we must set priorities.

This section presents the monitoring priorities to be addressed by the proposed strategy. These priorities are envisioned to support the adaptive management structure for stormwater management that PSP is developing and for the NPDES stormwater permits Ecology issues and oversees. Our intent is that the monitoring and assessment activities be specifically designed to provide information needed by stormwater and resource managers to improve decision-making.

2.1 Identifying the Scientific Information Needs of Stormwater Managers

The development of the strategy depends on the ability to articulate the type of information that would be useful to help stormwater and resource managers make better decisions. These decisions may be related to small- or large-scale issues, and they may require small or large expenditures to implement. In the first half of 2009, the SWG in a series of meetings and workshops articulated a set of Assessment Questions (Appendix C) that captured the collective judgment of the most important types of information needed to help decision-makers.

We used these key assessment questions as the basis for developing this scientific framework. It is important to acknowledge that various monitoring efforts are already under way or completed that may partially answer some of the assessment questions. To date, however, no coordinated, integrated program has been developed to ensure these questions are answered in a rational, prioritized, and comparable fashion.

The key assessment questions can be summarized as follows:

1. Are we making progress in protecting or improving beneficial uses and biological resources from the impacts of stormwater runoff?
2. What is the effectiveness of specific stormwater management techniques, either individually or in combination, with regards to preventing harm from new development, retrofitting existing development, and controlling sources?
3. Where in the landscape are the sources of pollutants in stormwater and volumes of stormwater that impact beneficial uses?

2.2 Conceptual Model of Stormwater Impacts and Information Needs

The effects of stormwater on the ecosystem of Puget Sound, and the various pathways by which those effects are transmitted, are fortunately rather well studied (*e.g.*, Horner and May 1997, Booth *et al*. 2004, and NRC 2009). They are summarized by the graphic in Figure 2, which shows the types of stressors or threats that should be considered, the pathways by which those threats are transmitted, and how the outcomes of our management efforts should be assessed.

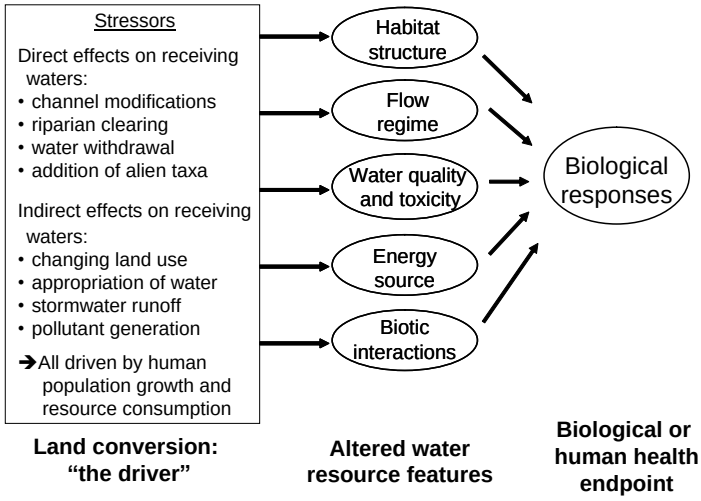

Figure 2. Conceptual model of the varied stressors resulting from human actions that alter biological conditions (modified from Booth *et al.* 2004 and Karr and Yoder 2004).

Management actions intended to minimize or eliminate the effects of stormwater on downstream systems are addressing (whether knowingly or implicitly) linkages between land alteration and one or more of the five "water resource features" in the center of the diagram. To be effective, those actions need to be applied in the right places in the landscape, and they need to "work." Whether stated explicitly or not, *what to do* and *where to do it* are both hypotheses, and so their accuracy should be tested and their guidance modified, if and as needed.

The integrated success of our various efforts to avoid impacts to water features can only be determined by evaluating the condition of integrating attributes, here designated the "biological endpoint." Other such integrators relating to human health and well-being have been suggested in the course of developing the *Action Agenda*, PSP's plan for recovering the Puget Sound ecosystem by 2020 (PSP 2008); they occupy the same conceptual position in this approach.

Within this broad conceptual approach, each element can be further deconstructed. Land conversion, or more specifically "urbanization" itself is multidimensional, and it has been defined in many different ways (McIntyre *et al.* 2000). It may constitute industrial, retail, housing developments, or farms; an urbanized watershed may contain polluting or nonpolluting industries, many roads or only a sparse road network. The topography, soils, vegetation, and channel networks in an urban basin may be altered in ways that vary within the same category of urban development. Across a single region, however, attributes of urbanization generally

correlate with broad land-use categories, and so for purposes of outlining the overall scope of this adaptive management program we will structure the discussion using common land-use categories: agriculture, residential, commercial, and industrial. Largely undisturbed areas that are classified as "forestry" are not included in this discussion, not because forestry isn't also a land-use category or that there are no stormwater issues associated with that particular land use, but because the hydrologic response of a forested catchment does not typically include a significant component of what is commonly considered "stormwater" (see the box on p. 4 in the introduction).

Substantial differences exist even within each land-use category, however, that must be incorporated into the specifics of any stormwater-management approach (and the monitoring necessary to evaluate its effects). Most prominent of these differences is between disturbed land, structures, and roads: each of these landscape elements contribute to stormwater but in very different ways, suggesting an alternative organizational structure to that of land use. However, runoff from one such element (*e.g.*, a rooftop) may be conveyed by the road network even as it comingles with additional wash-off from the road surface itself, suggesting no simple method (or rationale) for discrimination. We therefore consider roads within the land uses that contain them, recognizing that they generate a particular set of stressors, may require targeted management alternatives, and pose specific monitoring needs. Further information on this simplifying assumption may lead to future differentiation between roads and major highways; as highways in particular might indeed not act within the land uses that contain them, but rather should possibly be considered as a separate land-use category.

Just as land alteration has multiple facets, so "water features" comprise a variety of aquatic environments in the Puget Sound region. Not all of them are equally affected by urban stressors or stormwater runoff, and the pathways by which those stressors are expressed will vary with the nature of the receiving water (as well as with the nature of the stressor itself). In keeping with common usage, the receiving waters for stormwater runoff in the Puget Sound region have been categorized in this document into seven categories (marine, nearshore, small streams, large rivers, lakes, groundwater, and wetlands), recognizing that their location, potential impacts, and sensitivity to those impacts will vary across the landscape.

Thus, no single set of measured parameters or indicators should be expected to capture every potential combination of conditions expressed by even the (nominally) simple conceptual model of Figure 2. Tabulating the various combinations of land use and receiving water, and identifying some of the major potential impacts from stormwater that are known to occur, displays some of the complexities (and the commonalities) that emerge from this perspective into the universe of stormwater impacts.

Table 1 depicts the many sources of stormwater runoff (land uses), the many receiving waters it affects, and the many ways stormwater affects the receiving waters. Forestry is not included in Table 1 for reasons mentioned above in this section, and transportation is not included in Table 1 because transportation infrastructure is an important part of every land-use category, as both a source and a conveyor of pollutants. Whereas Table 1 outlines the currently understood range of stormwater effects on water resources and highlights some of the better known and most significant impacts, it is not a comprehensive catalog of those impacts. However, the current understanding suggests that these are some of the most pervasive impacts and most threatened resources in the Puget Sound region, offering an approach by which to prioritize management (and monitoring) efforts. It also can readily admit new information or evaluation efforts as they

Dear Readers: Do you think Table 1 accurately reflects our current understanding of stormwater impacts in the Puget Sound region? We recognize that there could be impacts in articulated every box: do we capture the *most significant* stormwater impacts?

Table 1. A summary of current understanding of the most significant stormwater impacts to beneficial uses, categorized by receiving water and major land-use category.

	Agricultural	Residential	Commercial	Industrial
Marine		• toxics accumulation in food chain		• toxics accumulation in food chain
Nearshore	• shellfish growing areas • contact recreation	• shellfish growing areas • toxics accumulation in food chain • contact recreation	• shellfish growing areas • contact recreation	• shellfish growing areas • toxics accumulation in food chain • contact recreation
Small streams	• benthic invertebrates • acute toxicity • contact recreation • physical habitat • eutrophication	• benthic invertebrates • acute toxicity • contact recreation • physical habitat • eutrophication • flooding	• benthic invertebrates • acute toxicity • physical habitat • flooding	• benthic invertebrates • acute toxicity • physical habitat
Rivers				• benthic invertebrates
Lakes	• benthic invertebrates • contact recreation • eutrophication	• benthic invertebrates • toxics accumulation in food chain • contact recreation • eutrophication • drinking water		
Groundwater	• drinking water	• drinking water	• drinking water	• drinking water
Wetlands	• physical habitat	• physical habitat	• physical habitat	• physical habitat

emerge, even though there is no effort to include them all here. Please note that non-stormwater-related impacts also associated with these land uses (*e.g.*, shoreline armoring in the nearshore environment) are not included in Table 1; they are outside our scope.

A truly comprehensive stormwater monitoring and assessment program would address every cell in Table 1. However, our region lacks the resources and the time required to complete such a long list. Nor does the ecosystem have the luxury of waiting for so many studies to be completed before stormwater management policy and implementation improves.

Starting with a smaller list of questions is also practical considering that launching the regional monitoring and assessment strategy is, itself, an experiment. As we gain experience with its

implementation, we can refine and add additional questions. We anticipate that the strategy will be refined and updated in an iterative process over a long period of time.

2.3 Identifying Categories of Monitoring to Include

How to organize the scientific framework was also considered in the course of developing the key assessment questions (see Section 2.1). We decided to focus on three categories that are somewhat interrelated but that utilize a division commonly expressed by other ecosystem monitoring programs, including the interests of both PSP and Ecology in creating the SWG:

1. **Status-and-trends monitoring** by which we mean an integrative assessment of whether (biological or other) endpoint indicators are showing any consistent, statistically significant change over time. We recommend tying this monitoring to ongoing efforts in a way that fills gaps in knowledge and provides a more comprehensive regional understanding of the impacts of stormwater.
2. **Efficacy studies** by which we mean the assessment of how well specific management actions or suites of actions reduce or eliminate the direct impacts of stormwater to receiving waters. We propose an initial set of studies to be undertaken to evaluate key practices associated with major land-use categories.
3. **Source identification** by which we mean the determination of what specific physical, chemical, or biological stressors (see Figure 2), emanating from which locations or from which elements of what specific land use, in what quantities, and affecting what specific types of receiving waters, are causing significant impacts to beneficial uses. We recommend that that the collective information gained from local source identification activities be routinely assessed to inform a regional perspective.

Other categories that we considered include **characterization monitoring** and **research**. Characterization monitoring is typically conducted to allow one to understand the range of existing conditions. This information may used for a variety of purposes, including identifying and quantifying sources of pollution in stormwater so that we can target and assess actions intended to reduce pollutant concentrations and loadings. Although once anticipated to be a category of this scientific framework, characterization monitoring is not further considered as a separate activity. Instead, we recognize that characterizing the condition of a water body or an outflow discharge at a particular time and place can be the product of the other kinds of monitoring. We strongly encourage that any "characterization" monitoring efforts be clearly articulated in either hypothesis-testing or systematic trend evaluation. As noted by NRC (2009, p. 508), "…monitoring under all three [NPDES municipal, industrial, and construction] stormwater permits is according to minimum requirements not founded in any particular objective or question. It therefore produces data that cannot be applied to any question that may be of importance to guide management programs, and it is entirely unrelated to the effects being produced in the receiving waters." We seek to proactively avoid this problem.

Research can include any number of various types of studies and monitoring programs. Under most types of scientific frameworks, research is encouraged to highlight new and emerging issues and to explore essential unknown relationships between various environmental factors necessary to improve management actions. Research efforts have clearly been of use locally; for example, research to characterize Lake Washington's degraded water quality in the 1950s led to the formation of Metro to divert and treat sewage flowing into the lake. This type of monitoring

is best described as essential basic research, where the results might indeed be used to improve management efforts or policy. But at the outset it is unknown how, or if, the results will be used, and so we do not include that category here.

2.4 Attributes of Hypotheses for an Adaptive Management Program

A key element of any adaptive management approach is the set of hypotheses that guide both the management actions and their associated monitoring. Because these management actions are recognized as "experimental" (because in a complex system most outcome(s) cannot be predicted with absolute certainty), their selection must be guided by assumptions about what *might happen,* or what is *expected* to happen. This defines the first attribute of a useful hypothesis: it is **credible**, typically because it is based on prior knowledge or scientific understanding of the system. Indeed, some hypotheses may already be so well evaluated and understood (*e.g.*, "Stormwater runoff from freeways carries measurably elevated concentrations of toxic pollutants") that there is little point in going into detail about them in this scientific framework or to recommend that scarce monitoring resources be allocated to test hypotheses that are unlikely to result in new information or knowledge that would change management practices.

The second attribute of a useful hypothesis stems from the scientific reality that any experiment, whether conducted in the laboratory or across the landscape, provides value only insofar as its outcomes are measured and the effects are distinguishable from the influence of other, unrelated factors. Thus, the hypothesis that guides the experiment should not only be credible but also **testable**. Otherwise, why bother making measurements at all?

Lastly, these actions and measurements and analyses do not occur in a vacuum. In the present context, their purpose is to improve the management of stormwater and to reduce the associated impacts on the ecosystem of Puget Sound. Thus, the final guiding principle for any hypothesis in an adaptive management approach is that it be **actionable**, or that that different outcomes, as revealed by monitoring, can (and will) result in different management responses. If no difference occurs, then clearly there is no reason to have made the effort in the first place.

2.5 Identifying Hypotheses for the Monitoring Categories

As described above, hypotheses used to guide the adaptive management approach must be credible (though not already known), testable, and actionable. These criteria were applied to develop an initial set of priority hypotheses for more rigorous development. About 50 preliminary hypotheses were developed during development of the assessment questions (Appendix D). These hypotheses were used as the starting point for developing a shorter list of priority hypotheses.

As hypotheses have been developed, we have aligned them with the three categories of monitoring listed above because these categories best reflect the underlying structure of the assessment questions and thus the broadly articulated stormwater-monitoring needs of the region. Within each category, we turn to Table 1 for organizational guidance: which land uses, which receiving waters, and which impact(s) to beneficial uses are most likely to be most problematic,

given our current scientific understanding; and where is it most important to improve our understanding of the effectiveness of our management actions?

As with most other programs, an optimal approach will encompass multiple, nested scales of monitoring, and thus scales for any particular hypothesis that will guide their implementation. The broadest scale of monitoring is that of the integrated effect of stormwater impacts and stormwater management on receiving waters. *Status-and-trends monitoring* addresses these questions, and it also allows stormwater and resource managers to measure the broad benefits obtained from management investments. This follows the horizontal dimension of Table 1, recognizing that impacts will differ by water body and will reflect multiple stressors and the effect of multiple management actions. Individual conditions normally cannot be traced back to specific generators of pollution (NRC 2009), and so identifying conditions at this scale requires a larger spatial scale over longer time frames, the essence of status-and-trends monitoring.

If status-and-trends monitoring (or long-standing prior knowledge) indicates that there are impacts on beneficial uses, a second (and relatively site-specific) scale is invoked, that of *effectiveness monitoring:* which of our many stormwater-management actions achieve the greatest reduction in downstream impacts? On the whole, these stormwater control measures, both structural and nonstructural, vary by land use; the measures suitable for a residential neighborhood will likely be impractical or ineffective (or both) in an industrial setting. We therefore anticipate that most effectiveness monitoring will be stratified by land use, acknowledging that truly homogenous land uses are rare. Nonetheless, this organizational approach is used successfully by the Nationwide Stormwater Quality Database, which contains water-quality data from more than 8600 events and 100 municipalities throughout the country, of which 5800 events are associated with "homogeneous land uses." We see no basis to eschew the approach of this nationally recognized and funded effort in Puget Sound, and so we embrace the conceptual approach of land-use stratification for evaluating the effectiveness of our stormwater control measures.

The finest scale of monitoring in this scientific framework is that of *source identification:* what specific locations and which parts of the landscape generate stormwater of sufficiently deleterious quantity and quality to cause impacts to beneficial uses, be they direct or indirect? This question is widely posed in stormwater management programs, and a number of existing monitoring programs seek to provide answers. The science of stormwater suggests where the greatest attention is probably warranted, namely a particular focus in all land uses on areas of well-connected (or "effective") impervious area (NRC 2009, p. 120, 231, 232), high vehicular traffic (NRC 2009, p. 232), and exposure to toxic chemicals (NRC 2009, p. 330). We have used these categories to define our areas of highest priority.

The hypotheses initially generated following development of the assessment questions (Appendix D), provided the starting point for the development of the priority hypotheses for this document. We used Table 1 (see Section 2.2) to identify which to recommend as priorities.

2.6 Priority Hypotheses for Monitoring Activities

2.6.1 Status and Trends

Historically, the impacts of urbanization on receiving waters have been tested by comparing water quality to various sets of standards or guidelines. However, to truly assess cumulative

impacts, "[b]iological monitoring of waterbodies is critical to better understanding the cumulative impacts of urbanization on stream condition" (NRC 2009, p. 233). To this end, hypotheses that address the integrated effects of stormwater-management actions on the biota of receiving waters are the recommended emphasis for status-and-trends monitoring. We recommend further narrowing of the initial scope to creeks and the nearshore environment, to support the recommended approach for source identification and effectiveness monitoring (see Section 2.2 above). Specific hypotheses should identify which links between urbanization and impacted water resource features are being affected, as characterized on Figure 2, and how those influences are likely to be expressed in the biota. Clearly, there are a vast number of unique combinations around which hypotheses could be constructed, and for which conditions could be monitored. The challenge at this level of hypothesis-generation is to identify a more limited, tractable number of such combinations. They must also each meet the test of being credible, testable, and actionable.

For the status-and-trends monitoring, we propose to prioritize those hypotheses that address those receiving-water impacts that are currently understood to be associated with stormwater (Table 1). *Small streams* (or "*creeks*") are an obvious choice, given the decades of research on them in the region, their recognized sensitivity to adjacent land-use activities, and their critical role (both direct and indirect) in the life history of anadromous salmon and our corresponding lack of information about the efficacy of proposed management actions to prevent these harms. We also recommend similar attention to the *nearshore*, because of the importance and sensitivity of this interface between land-based activities and Puget Sound, and its importance to both natural and human (especially food- and recreation-based) resources.

Experimental designs for status-and-trends monitoring in small streams and nearshore areas are discussed in Section 3.1 and presented in Appendix E.

> Dear Readers: Do the hypotheses proposed below represent a reasonable starting point for focusing our efforts to collect region-wide information about stormwater impacts? These are the hypotheses we came up with but the list is not final. We need your input: are these the right hypotheses? Is each one credible, testable, actionable? (See Section 2.4 for an explanation of these criteria.)

The proposed priority hypotheses for status-and-trends monitoring are:

1. Salmon in small streams show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.
2. Instream biological metrics (*e.g.*, B-IBI) show statistically significant improving trends in Puget Sound lowland streams in concert with increased and improved stormwater management efforts.
3. Resident fish in nearshore areas show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.

4. Forage fish in nearshore areas show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.
5. Bacteria levels in water and shellfish along the nearshore show decreasing trends over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.

> Dear Readers: Do you think this scientific framework should include hypotheses (and experimental designs) for status-and-trends monitoring in more types of water bodies than small streams and nearshore areas? What other specific types of water bodies, and why?

2.6.2 Effectiveness Studies

A series of priority hypotheses is proposed that would have programs designed to address each, acknowledging that additional hypotheses could be added over time. To initiate this structure, effectiveness hypotheses are here grouped into three subcategories:

(1) testing low-impact development (LID) techniques to minimize impacts from future new development,

(2) testing retrofit techniques to decrease impacts from the built environment, and

(3) testing non-structural (*i.e.*, operational, behavior-change) approaches used in stormwater programs.

Some effectiveness monitoring of public domain structural BMP designs is already being performed through current NPDES permit requirements for the largest three counties and two cities in Puget Sound, and effectiveness monitoring of proprietary BMP's is done through Ecology's Evaluation of Emerging Stormwater Treatment Technologies program (the TAP-E protocol, see http://www.ecy.wa.gov/programs/wq/stormwater/newtech/index.html). In general, we recommend that effectiveness monitoring move away from asking, simply, "what level of pollutant or flow reductions do we see at the end of the pipe?" to a broader examination of whether these pollutant or flow reductions protect or improve beneficial uses in the receiving water.

We do not recommend that these studies all be undertaken simultaneously, but rather that an implementation cycle be set up whereby these hypotheses all are tested in the next decade. Example experimental designs for effectiveness monitoring are discussed in Section 3.2 and presented in Appendix F.

> Dear Readers: Do the hypotheses proposed below represent a reasonable starting point for focusing our efforts to collect region-wide information about management actions? Are these the right categories of practices? These are the hypotheses we came up with but the list is not final. We need your input: are these the right hypotheses? Is each one credible, testable, actionable? (See section 2.4 for an explanation of these criteria.)

The proposed priority hypotheses for testing the effectiveness of LID techniques to minimize impacts from new development are:

6. LID approach and techniques implemented as the primary/sole method of flow control in a new residential development not only meet Western Washington Stormwater Manual requirements for flow control but also a) maintain values of surface discharge volumes, durations, and peak flow rates observed in undisturbed Puget Sound Lowland catchments of similar size and surficial geology; and b) achieve flow control performance superior to that measured on a similar size and type of project where ponds and/or vaults are used.
7. LID on infiltrative soils are more effective, and more cost-effective, at achieving measureable flow control and meeting flow control standards (relative to undeveloped conditions on the same soil) than LID on non-infiltrative soils.
8. LID techniques used for high-capacity roadways (*e.g.*, freeways) on favorable sites achieve water-quality and water-quantity of runoff superior to that provided by stormwater ponds and/or vaults, and groundwater quality is not measurably compromised.
9. Accumulation of metals in bioretention soils does not reach levels of concern after 10 years of use.

The proposed priority hypotheses for testing the effectiveness of retrofit techniques to decrease impacts from the built environment are:

10. Runoff-treatment technologies adapted to retrofit conditions achieve long-term reductions in pollutants commensurate with presumptive regulatory performance.
11. Stormwater treatment retrofits in existing residential developments achieve long-term reductions in pollutants and meet water quality standards at the point of discharge.
12. Retrofitting existing residential areas with bioretention swales in the street right-of-way significantly reduces stormwater discharge volume and loadings of pollutants.
13. Stormwater flow control retrofits in existing areas of high density urban development not only meet Western Washington Stormwater Manual requirements for flow control but maintain values of surface discharge volumes, durations, and peak flow rates observed in undisturbed Puget Sound Lowland catchments of similar size and surficial geology.
14. LID stormwater treatment retrofits adjacent to existing highways achieve long-term reductions in pollutants and meet water quality standards at the point of discharge.

> Dear Readers: Do you think the set of five hypotheses proposed above will help us find the most cost-effective, environmentally beneficial retrofit BMPs? What alternate or additional hypotheses would you propose, and why?

The proposed priority hypotheses for testing the effectiveness of operational and programmatic approaches used in stormwater programs are:

15. Intensive pollutant source control programs at industrial sites achieve long-term reductions in pollutants and meet water quality standards at the point of discharge.
16. Intensive public educational outreach efforts related to pollution control in existing residential developments achieve long-term reductions in pollutants relative to residential developments not receiving commensurate outreach.
17. Enhanced enforcement of "good-housekeeping" practices at industrial sites achieves significant reduction in pollutant releases.
18. Street sweeping and other source control methods are more cost effective at reducing pollutants from existing developments than stormwater treatment retrofits.
19. Full implementation of all recommended waste management best management practices from the Natural Resources Conservation Service at existing livestock/dairy farm sites achieve long-term reductions in pollutants and meet water quality standards at the point of discharge.

2.6.3 Source Identification

We recommend a targeted, hypothesis-driven effort to investigate sources of stormwater pollution based on the extent and severity of impacts suggested by the last several decades of study in the Puget Sound region and by existing and proposed status-and-trends monitoring programs, on the assumption that focusing on identifying sources where beneficial uses are known to be impacted will achieve direct benefits to the region.

Again, we do not recommend that these studies all be undertaken simultaneously, but rather that an implementation cycle be set up whereby each hypothesis is tested in the next decade.

> Dear Readers: Do the hypotheses proposed below represent a reasonable starting point for focusing our efforts to collect region-wide information about stormwater sources? Would they satisfy your need for quantifying pollutant loadings? These are the hypotheses we came up with but the list is not final. We need your input: are these the right hypotheses? Is each one credible, testable, actionable? (See Section 2.4 for an explanation of these criteria.)

The proposed priority hypotheses for source identification are:

20. In all locations where impacts are observed on beneficial uses in small streams due to altered flow volumes, the causes can be traced to specific sources such as connected impervious area without flow control measures or with improperly functioning or inadequate flow control measures.
21. In all locations where impacts are observed on beneficial uses in the nearshore area due to fecal coliform bacteria pollution, the causes can be traced to specific sources such as agricultural runoff, sewer cross-connections, failing septic systems, and urban runoff.
22. Toxic chemicals in runoff from visually identified high-risk industrial sites (Duke 2007, Duke and Augustenborg 2006; see also NRC 2009, p. 537, 554) contribute the majority of industrial-source pollutants.

23. Vehicle miles traveled is an adequate surrogate for estimating pollutant loads from residential land uses and can be used in place of detailed measurements everywhere to identify significant source areas.

2.7 Ensuring the Strategy is Comprehensive

As stated earlier, the *Stormwater Monitoring and Assessment Strategy for the Puget Sound Region* is intended to be comprehensive, or at least sufficiently broad-based that:

- local governments, industries, agriculture, and others throughout the region are interested in joining and contributing to the effort;
- the geographic, biological, geologic, meteorological, social/political ranges, and variations in land use combinations within the basin are covered; and
- the results of the monitoring and assessment are meaningful and robust.

To ensure the strategy is comprehensive, we must include and undertake sufficient monitoring and assessment actions in multiple locations around the Sound so variations are considered and limited resources are efficiently employed. Our intent is to create a comprehensive monitoring and assessment strategy by:

1) monitoring and assessing the most critical elements of stormwater;
2) conducting monitoring that helps answer the most important questions for decision makers;
3) collecting sufficient data to account for regional variations;
4) conducting a sufficient number of assessments to produce robust information;
5) ensuring data collection and assessments follow standardized protocols; and
6) compiling and sharing the results so that all interested parties can learn from the effort and regional decision makers can revise and improve stormwater management policy.

> Dear Readers: Does the set of monitoring priorities identified in Section 2 comprise a sufficiently comprehensive scientific framework for stormwater monitoring and assessment for the region? Why, or why not?

3 EXPERIMENTAL DESIGNS

The following sections describe how the different types of monitoring designs would be used within an adaptive management structure. Information gathered under each category of monitoring can and should inform work under each of the other categories. The designs are given hierarchically, from the broadest and most general design to the most local site-specific designs.

3.1 Status and Trends

Status-and-trends monitoring designs are summarized below, and presented for small streams and for nearshore areas in Appendix E.

3.1.1 Sound-wide Probabilistic Design

The first three priority hypotheses for status-and-trends monitoring are designed to evaluate the status of water resources, *e.g.*, the percentage of stream miles supporting their beneficial uses, and to detect trends over time in water resources affected by stormwater. The ultimate goal of this monitoring is to determine whether stormwater management is protecting the resource.

A probabilistic survey design starts with a complete master list of all possible sampling sites and selects a random subset for site visits to evaluate access and suitability prior to selection for monitoring. The Washington State Department of Ecology is charged with designing and implementing a statewide monitoring program to assess stream habitat and watershed health (Ecology 2006). We propose utilizing and building upon Ecology's probabilistic survey design for small streams in the Puget Sound region to assess status and measure trends over time. Figure 3 shows an example of the sampling locations for probabilistic stream monitoring in the Puget Sound region. Similar probabilistic survey designs will be developed for nearshore monitoring of bacteria in shellfish and toxic chemical accumulation in sediment, resident fish, and forage fish. This type of design allows for a quantitative understanding of the extent and magnitude of the impacts on beneficial uses across the multiple jurisdictions and projects in the Puget Sound region.

The U.S. Environmental Protection Agency encourages states to adopt a probabilistic sampling design for the following reasons:

- A probabilistic survey design is, by definition, integrated [across land uses] because it includes all possible sites in the sampling frame (Larsen *et al*. 2001; Stevens and Olsen 1999).
- The design is flexible because the same design can be expanded to increase sampling densities based on geographic area, land use or some other factor (Ode and Rehn 2005).
- The magnitude of the problem can be evaluated, *e.g.*, "50% of stream miles are failing to support their designated uses" (Urquhart 1998; Stevens and Olsen 2003).
- The random nature of the design supports risk analysis to determine the most important drivers of degradation associated with stormwater (EPA 2006).
- The potential exists for agencies to support each other's program by sharing the burden of data collection across projects (for example, Snohomish County might volunteer to sample

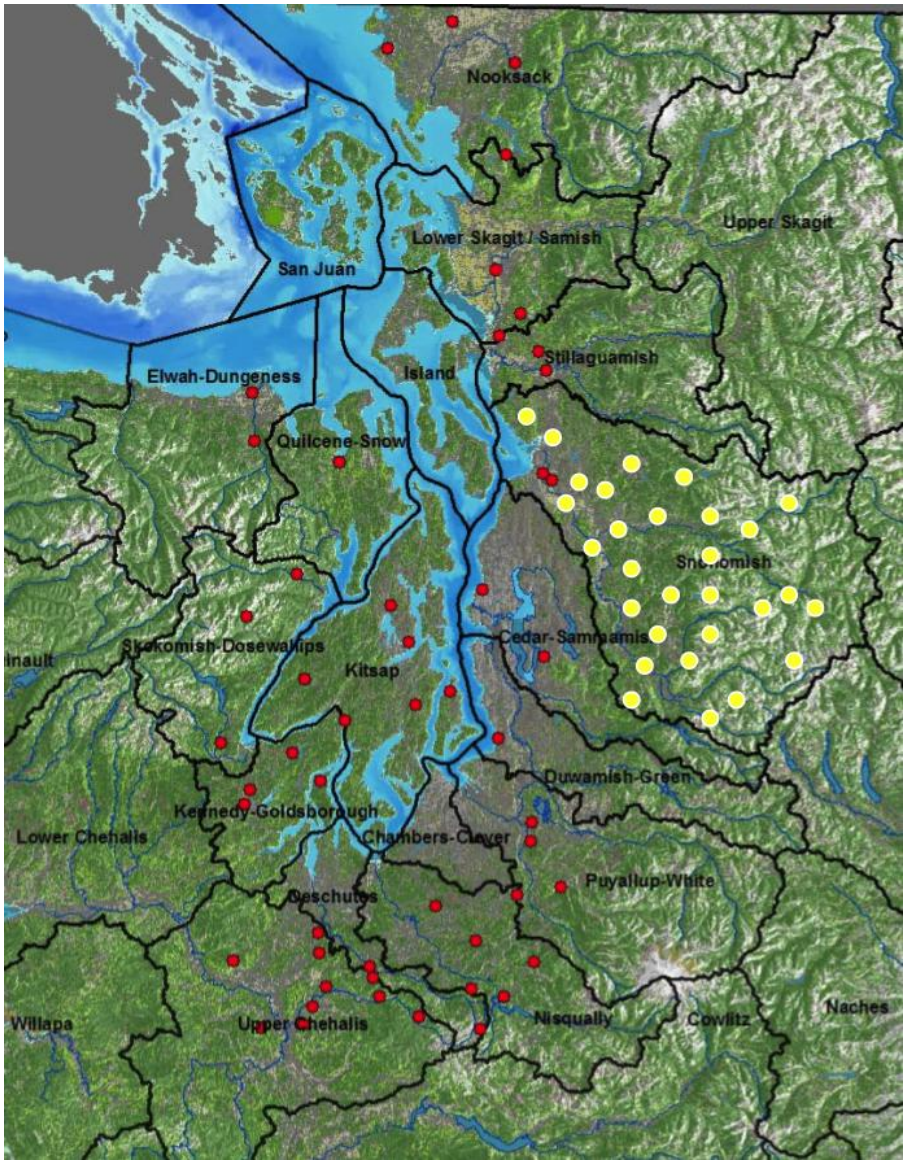

Figure 3. Probabilistic survey design for stream sampling in the Puget Sound watershed (red dots) and an example of high density stream sampling in the Snohomish watershed (yellow dots). Both sets of points are derived from the same master set of sampling sites.

the state's random sites in their jurisdiction as part of their own probabilistic sampling design if Ecology agreed to collect additional samples to characterize pollutant loadings upstream).

To be truly comprehensive, a status-and-trends stormwater monitoring program would address all receiving waters: small streams, rivers, lakes, groundwater, nearshore areas, and the open marine system; and it would be regional in scale. We have prioritized status-and-trends stormwater monitoring in small streams and nearshore areas. Status-and-trends stormwater

monitoring for other water bodies may be tied into programs designed by other work groups included in the overall ecosystem monitoring program (see the last paragraph in Section 1.1).

The types of information provided by a Puget Sound-wide probabilistic survey design include:

- The percentage of the region supporting its beneficial uses change after 5 years.
- Locations of possible "hot spots" for disturbance.

The types of information not provided by a Puget Sound-wide probabilistic survey design include:

- The percentage of each subregion (*e.g.*, stream miles in each WRIA, nearshore miles within each action area) that is supporting its designated beneficial uses, or the trends over time in changes to these percentages. This information would not be available because the sampling density would not be sufficient to generate this information for each subregion. To evaluate trends within a subregion, a greater density of sampling point are needed (see Section 3.1.2 *Subregion Probabilistic Design*).
- The random nature of the design means that specific information about sites of interest cannot be addressed, *e.g.*, sites with BMPs. Some sampling design need sites from specific locations to make comparisons and test for differences (see Section 3.2 *Effectiveness Monitoring Study Design*).

3.1.2 Subregion Probabilistic Design

The probabilistic design allows for the nesting of monitoring programs of different densities in a comparable manner. Using the small streams example described above, the probabilistic survey design can be scaled to smaller watersheds, basins, and subbasins by increasing the density of sampling sites. The density can also be increased according to other factors, *e.g.*, stream size, land use, etc. Results from these areas of greater sampling effort should be rolled up in the regional reporting. In short, one probabilistic survey can be nested within another. (See the yellow dots in Figure 3 showing an example of additional sites for Snohomish watershed.)

The types of information provided by a subregion probabilistic survey design include:

- The change in percentage of the subregion supporting its beneficial uses after 5 years.
- How areas with different land uses, *e.g.*, urbanizing areas with LID construction vs. areas with predominantly existing residential, compare regarding their relationship to the supporting of beneficial uses.
- Identification of the greatest threats to water resources in the subregion and their relative risks.

The types of information not provided by a subregion probabilistic survey design include:

- Effectiveness of specific BMP treatments (see Section 3.2 *Effectiveness Monitoring Study Design*).
- Identification of sources of pollutants and diagnosis of stressors. (see Section 3.3 *Source Identification Study Design*).

3.2 Effectiveness Studies

The effectiveness monitoring we propose will test our assumptions about whether or not selected stormwater management approaches are functioning as anticipated and (at a more localized scale than is evaluated by status-and-trends monitoring) result in improvements in beneficial uses. Information collected through effectiveness monitoring will help quantify the costs and benefits of stormwater management approaches.

The priority hypotheses for effectiveness monitoring are grouped into three subcategories addressing the effectiveness of:

(1) Low impact development (LID) techniques, in minimizing impacts from future new development,

(2) Retrofit techniques, in decreasing impacts from the built-environment, and

(3) Non-structural operational and programmatic approaches used in stormwater management programs.

Example effectiveness monitoring study designs are presented in Appendix F.

This monitoring provides unbiased information about whether specific management actions are preventing, reducing, or mitigating known stormwater impacts to beneficial uses in receiving waters. To be successful, effectiveness monitoring must be performed at sites selected within relatively small spatial scale (*e.g.*, site or catchment) to reduce influences from other actions or natural phenomena. Reducing influences not related to the management action itself is necessary for a robust experimental design. A final component of this monitoring is the linkage to specific "land uses" and "outcomes" as shown in Table 1.

The monitoring design for effectiveness monitoring requires a relatively small-scale focus. Also required are treatment locations, where the stormwater management actions are applied. For each treatment location, the monitoring design may include upstream/downstream monitoring, before/after monitoring, or treatment/control monitoring. The selection of the appropriate approach is dependent on the specific hypotheses to be tested.

The types of information provided by the effectiveness monitoring design include:

- The amount of change in flow parameters or water quality parameters downstream relative to upstream of the stormwater management location, OR
- The amount of change in flow parameters or water quality parameters from before and after installation of the stormwater management action, OR
- The amount of difference in flow parameters or water quality parameters between a site receiving stormwater management action and a control site not receiving stormwater management action.

The types of information not provided by the effectiveness monitoring design include:

- Identification of sources of pollutants and stressor diagnosis. (see Section 3.3 *Source Identification Study Design*).
- Cumulative impact of multiple stormwater management actions at the watershed or regional scale (see Section 3.1 *Status-and-trends monitoring Design*).

3.3 Source Identification

Source identification monitoring is typically conducted on the smallest scales, and can include: detailed monitoring to trace sources of pollutants or altered flow volumes upstream from the observed impacts on beneficial uses to their sources on the landscape; business inspections; on-site septic system inspections; illicit connection detection; and other programs.

Most source identification activities are appropriately undertaken by local jurisdictions because they have detailed knowledge of their respective land uses, receiving waters, and potential pollutant sources. Unfortunately, while some local jurisdictions have in-house expertise and capacity to undertake these types of source identification monitoring efforts, many do not. In addition, many source identification efforts require working across departments (*e.g.*, the local health department and surface water management utility) within each jurisdiction and across multiple jurisdictions since the receiving water cross jurisdictional boundaries. Specifically, if the status-and-trends monitoring of small streams identifies stream segments that are more directly degraded by stormwater relative to others, this information will used to implement more intensive investigations within associated upstream tributaries and stormwater conveyance systems to identify the specific source of the degradation.

Conversely, more specific contaminants associated with particular land uses (or specific high-risk activities within particular land uses) identified through local source identification activities may be recognized as problems that should be addressed regionally. We recommend that the collective information gained from local source identification activities be routinely assessed to identify such regional issues. *Volume 2: Implementation Plan* will identify SOPs and data reporting requirements to enable a collective assessment of the source identification information gathered locally.

A key component of this approach is timely and proactive communication of monitoring results from status-and-trends monitoring of small streams to local jurisdictions tasked with the implementing source identification programs, and also ensuring that the expertise and capacity is available to implement these source identification efforts. To that end, the implementation plan that is developed to accompany this scientific framework document also should identify special provisions to ensure this communication occurs.

The types of information provided by source identification monitoring include:

- The locations on the landscape of the sources of pollutants or altered flow volumes.

The types of information not provided by source identification monitoring include:

- The locations of receiving waters not meeting their beneficial uses (see section 3.1 *Status and Trends*).
- The most effective approaches for controlling identified sources (see section 3.2 *Effectiveness Studies*).

> Dear Readers: We have not yet specifically tied the hypotheses to the experimental designs presented here. Is too much presented on faith? What more do you need to buy into this approach? To be certain that it will result in meaningful and useful information?

4 SUMMARY AND NEXT STEPS

We have proposed a set of monitoring priorities and the beginnings of an experimental approach for regional stormwater monitoring in Puget Sound. Table 2 shows a summary of the proposed monitoring activities for priority water bodies within each of the three categories of monitoring. See Appendices F and G for details descriptions of experimental designs. Empty cells in Table 2 indicate that no monitoring activities are described in this document for these water bodies or in these categories of monitoring, but new designs and additional activities could be added based on future recommendations.

Table 2. Summary of proposed monitoring approaches to address status and trends, effectiveness, and source identification organized by receiving water body type.

	Status and Trends	Effectiveness Studies	Source ID
Marine			
Nearshore	• Probabilistic survey design (resident fish, forage fish, shellfish, bacteria, sediment, toxics)		• Fecal coliform bacteria • Industrial (toxics)
Small streams	• Probabilistic survey design (salmon, invertebrates, toxics)	• Low-impact development (hydrology, biota, water quality) • Urban retrofits (pollutants, toxics, water quantity) • Industrial source control (pollutants) • Public education (pollutants) • Street sweeping (pollutants)	• Altered flows • Impervious surface (hydrology) • Industrial (toxics) • Vehicle miles as surrogate (pollutants)
Rivers			
Lakes			
Groundwater			
Wetlands			

To successfully implement this strategy, other support tools and assessment approaches are needed. To support this new, integrated monitoring system, local jurisdictions, state and federal government agencies, and others will need to work together to develop and adopt new methods and infrastructure such as regional standardized operating protocols, data repositories, and regional conferences.

Volume 2 of this strategy, the implementation plan, will recommend roles and methods for local jurisdictions, state and federal agencies, businesses, and others who are directly or indirectly

responsible for managing stormwater or affected resources, to participate in implementing the strategy. That document will also answer Ecology's request that we include recommendations for allocating responsibilities in the next cycle of Clean Water Act National Pollutant Discharge and Elimination System (NPDES) municipal stormwater permits. Anticipated critical elements of *Volume 2: Implementation Plan* include:

- Creating a coherent description of our process so that key state and local government policy makers, scientists and managers understand our intentions and make an informed decision about how and where to join us in this regional effort. We intend that the monitoring and assessment results will inform regional policy and guide allocation of resources to address problems caused by stormwater.
- Recommending an ongoing process for establishing standard operating procedures, methods, and protocols for collecting, reporting, storing, sharing, and analyzing the data collected (see below).
- Recommending an ongoing process for review of the results generated and re-evaluation of the monitoring and assessment strategy.
- Identifying the resources and capacities for conducting monitoring and assessment in the region and proposing incentives for parties to cooperate collaboratively.

Dear Readers: Do you have a suggestion for us to consider regarding any of the following specific issues to be addressed in Volume 2 of this strategy? How would you like to be involved in solving these problems?

4.1 Standard Operating Procedures and Data Reporting Requirements

To ensure data comparability across the multiple monitoring efforts, it is essential that a common set of standard operating procedures be developed and used throughout the region. Ecology has funded the development of an initial set of standard operating procedures for stormwater monitoring, though many more have been identified for future development. Volume 2 of this strategy will include recommended SOPs to use –and to develop and use– to successfully carry out this strategy.

4.2 Coordinated Information Management

Much of the information currently available on the status and health of Puget Sound has been collected by numerous agencies through preexisting monitoring programs; however, this information has generally not been coordinated or shared in a way that helps make good decisions. Other entities in Puget Sound, including the Washington Forum on Monitoring Watershed Health and Salmon Recovery and the Pacific Northwest Aquatic Monitoring Partnership, are addressing regional data management needs. We will benefit from these efforts and make recommendations specific to stormwater information management needs on Volume 2 of this strategy.

4.3 Ancillary Data

Many additional types of data are useful and necessary to understand stormwater impacts and effectiveness of management activities in Puget Sound. Two examples include:

- Land use and land cover data. To allow for the extrapolation of information to unmonitored areas and at different scales, it is necessary to have land use and land cover data for the region. We recommend a standardized means to routinely update and verify this information across the Puget Sound region.
- Climate data. Many different state and federal agencies, local jurisdictions, tribes, individuals, and businesses operate climate modeling systems throughout the Puget Sound region. Some of these systems have been in operation continuously for many decades, while others are recently installed. To allow for coordinated analysis of stormwater impacts, an agreed-upon set of climate data is important.

Volume 2 of this strategy will include recommendations for collecting and accessing ancillary data.

4.4 Modeling Activities

Modeling might utilize and expand the usefulness of the data obtained by the strategy in one or more of the following ways:

- To extrapolate and credibly transfer information obtained from localized monitoring efforts to larger scales or areas where monitoring does not take place, thereby extending the utility of the data to unmonitored areas.
- To examine different future-oriented and hypothetical scenarios for stormwater management that cannot be directly monitored, and
- To improve estimates of the origin and fate of contaminants in streams, interpretations of water quality patterns based on nonpoint and point pollution sources, and predictions of biota responses to water quality improvements or degradations.

4.5 Other Assessment Activities

In addition to, or to follow up on, analyses described in Section 3, standardized approaches for analyzing the data collected for this strategy need to be proposed in sufficient detail that sufficient resources are reserved for these analyses to be performed and the results communicated to stormwater managers and other key decision makers in a timely fashion.

5 GUIDE TO APPENDICES

The appendices provide additional detailed information about the stakeholder process, our connections to other efforts, adaptive management structure, assessment questions, hypotheses, and experimental designs. Here is a brief description of the contents of each appendix to this document.

Appendix A. The process to develop a regional stormwater monitoring and assessment strategy 39

The Stormwater Work Group was launched as a project of the Puget Sound Monitoring Consortium. The SWG includes 26 representatives of 7 caucus groups. We have a charter, bylaws, and work plan. We have sponsored workshops and are developing products to foster an integrated, strategic approach to monitoring and assessing stormwater.

Part of our charge is to act as a pilot model effort for creating PSP's regional ecosystem monitoring program. We will help Ecology develop a stormwater permit monitoring component that will be more relevant to regional needs. This is the most recent effort to develop an integrated approach to surface water management and builds on a long history of efforts.

Appendix B. Applying Lessons Learned from Adaptive Management at a Regional Scale 47

Many resource managers have recognized the need to integrate resource management and monitoring at a regional scale. A brief description and lessons learned from these efforts provide guidance for creating a regional stormwater monitoring and assessment program in Puget Sound.

Appendix C. Assessment Questions for Monitoring Stormwater 56

Starting with the request from PSP and Ecology, stakeholder workshops were convened to develop specific assessment questions that need to be answered for Puget Sound stormwater management. Under broad headings, we developed specific questions that were vetted by stakeholders, scientists, and managers.

Appendix D. Translating Assessment Questions into Hypotheses 58

Assessment questions were taken the next step and connected to more specific, testable hypotheses by regional stormwater experts. This table, combined with Table 1, provided the basis for identifying the priority hypotheses in Section 2.6.

Appendix E. Status-and-trends monitoring Design 62

Description of probabilistic survey designs for small streams and nearshore areas. Includes lists of potential indicators, descriptions of methods, and proposed sampling schedule.

Appendix F. Effectiveness Monitoring Example Experimental Study Designs 76

Description of two possible effectiveness monitoring designs, for low-impact development and for industrial source control. Includes lists of potential indicators, descriptions of methods, and proposed sampling schedule.

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Appendix A THE PROCESS TO DEVELOP A REGIONAL STORMWATER MONITORING AND ASSESSMENT STRATEGY

Running steadily in the background behind the visible production of documents and the articulation of goals are the meetings and discussions and experiences of the people involved. The ultimate success of a regional monitoring and assessment program depends on cooperation of individuals and the agencies and groups they represent; therefore, we have tried to organize, involve and engage people in a way that is as inclusive and transparent as possible.

The risk associated with creating a regional stormwater monitoring and assessment program is that the complexity of the effort can overwhelm its purpose. Our efforts to date provide an example: because a large number of professionals and stakeholder participated in workshops designed to identify the most important questions that a regional monitoring program should address, the process generated more questions about stormwater than we can answer in a reasonable time. Similarly the list of actions proposed to reduce stormwater impact is also long. Prioritizing which hypotheses to test and which actions to take is very difficult in the absence of more complete information; but if we wait until we know everything, or even 'enough', no action will ever be accomplished. In our case, the potential complexity associated with testing for what we don't know threatens to distract us from our purpose, which is to reduce the effects of stormwater.

The remainder of this appendix provides the interested reader a history of the Puget Sound Stormwater Work Group, an overview of the ways we have worked to engage the tremendous assets of the region in solving our problem, and a description of our relationship and connections to other key efforts to restore Puget Sound.

A.1 Creating the Stormwater Work Group

In 2006, a group of interested parties were brought together by the Washington Department of Ecology (Ecology) to consider development of a coordinated regional monitoring program for the Puget Sound region. This group evolved into the Puget Sound Monitoring Consortium (Consortium), funded by the Washington State Legislature. Information about the Consortium, including its and its predecessor's reports to the Legislature and others, can be found at http://www.ecy.wa.gov/programs/wq/psmonitoring/index.html.

The Consortium developed a set of recommendations for organizing and establishing a coordinated ecosystem recovery monitoring program for Puget Sound (see "Connections to Other Efforts" below). The structure the Consortium recommended provided an umbrella for topical work groups that provide a forum for key stakeholders to determine monitoring and assessment needs by geography or issue and to oversee collection of the data that help improve our understanding of the ecosystem. The Consortium anticipated work groups comprised of

members involved in monitoring and assessment activities. Some work groups already existed in other forms but a work group for stormwater was identified as a priority need. At the request of the Puget Sound Science Panel, the executive director of the Puget Sound Partnership, and the director of the Washington State Department of Ecology, the Consortium also oversaw the establishment and launching of the SWG.

In addition to launching the SWG, the Consortium launched pilot projects to meet pressing needs for coordination and improved credibility of the monitoring data that is routinely collected in the Puget Sound region, including: developing standard operating procedures for automated sampling of stormwater and subsequent analysis of the data. ; standardizing reporting methods and expand a database for stream benthos information that can be populated by all entities in Puget Sound that collect this information; and conducting an inter-laboratory calibration exercise. The SWG is building upon these efforts, and the lessons learned in conducting the pilot projects, in developing a monitoring and assessment strategy for Puget Sound.

The Consortium committees' recommendations (Surface Water and Aquatic Habitat Monitoring Advisory Committee 2007 and Puget Sound Monitoring Consortium 2008) are reflected in SWG mandates: transparency of the process, inclusivity of discussions and decision-making, specific focus on improving stormwater management to protect and restore designated uses, making an explicit connection to Clean Water Act NPDES permit monitoring requirements for municipal stormwater, clear connection to and coordination with other efforts, effective use of resources, meaningful and credible data and analyses produced and used by decision-makers.

The SWG is now a formal effort that has the support of the Puget Sound Partnership, Ecology, and others. A draft charter, bylaws, and caucus-based system of representation on an oversight committee were formally adopted in December 2008. An initial work plan was adopted in January 2009 and amended in April 2009. These founding documents and all SWG meeting agendas and summaries are available at http://www.ecy.wa.gov/programs/wq/psmonitoring/swworkgroup.html. Interim working documents, supporting information, and agendas for the SWG's working subcommittees are posted at http://sites.google.com/site/pugetsoundstormwaterworkgroup/.

The SWG is formally comprised of 26 representatives of business, environmental, agriculture, tribal, local, state, and federal government agency caucuses. The members are listed on the reverse side of the cover page of this document. All SWG members accept responsibility for communicating with their caucuses about the progress of and upcoming decisions to be made by the SWG. Each meeting agenda provides time for other parties in attendance to comment on decisions that are on the table. The SWG's efforts since October 2008 have been focused on the development of the draft *Stormwater Monitoring and Assessment Strategy for the Puget Sound Region*.

A.2 Steps to Achieve our Goals

- **Creation and vetting of Assessment Questions (Appendix C) by experts and stakeholders.**
    - February 17-19, 2009 technical expert workshops. Participants: Allison Butcher (Master Builders Association of King and Snohomish Counties); David Batts (King Co.); Jill Brandenberger (PNNL); Scott Collyard (Wash. Dept. of Ecology);

Ken Currens (NWIFC, for Puget Sound Partnership); Tim Determan (Wash. Dept. of Health); Karen Dinicola (Ecology); Jeff Fisher (Environ, for NMFS/NOAA); Mindy Fohn (Kitsap Co.); Jonathan Frodge (Seattle); Thom Hooper (NOAA Fisheries); Doug Hutchinson (Seattle); Bob Johnston (U.S. Navy); Heather Kibbey (Everett); DeeAnn Kirkpatrick (NOAA Fisheries); Andrea LaTier (U.S. Fish and Wildlife Service); Joan Lee (Parametrix); Jim Maroncelli (Wash. Dept. of Ecology); Doug Navetski (King Co.); Char Naylor (Puyallup Tribe); Dale Norton (Wash. Dept. of Ecology); Ed O'Brien (Wash. Dept. of Ecology); Kit Paulsen (Bellevue); Tom Putnam (Puget Soundkeeper Alliance); Randy Shuman (King Co.); Jim Simmonds (King Co.); Carol Smith (Wash. State Conservation Commission); Tom Sibley (NMFS); Heather Trim (People for Puget Sound); Gary Turney (USGS); Dean Wilson (King Co.); and Bruce Wulkan (Puget Sound Partnership).

- May 19, 2009 public workshop. About 170 people participated; the workshop facilitator produced a summary of the feedback provided. The report is posted at http://www.ecy.wa.gov/programs/wq/psmonitoring/ps_monitoring_docs/SWworkgroupDOCS/SWGWorkshopFinalReport.pdf.

- **June 11 and 16, 2009 "Sprint" workshops of technical experts to translate assessment questions into hypotheses.** (Appendix D, also see link to the document at http://www.ecy.wa.gov/programs/wq/psmonitoring/swworkgroup.html.) Participants: Howard Bailey, Nautilus; Abby Barnes, Kennedy/Jenks; David Batts, King County; Derek Booth, Stillwater Sciences; Jill Brandenberger, PNNL; Scott Collyard, Ecology EAP; Cat Curran, Nautilus; Jay Davis, U.S. Fish & Wildlife Service; Curtis DeGasperi, King County; Dana de Leon, City of Tacoma; Tim Determan, WA Dept of Health; Damon Diessner, ESAction; Karen Dinicola, Ecology; Mark Ewbank, Herrera; Jeff Fisher, Environ; Mindy Fohn, Kitsap County; Leska Fore, Statistical Design; George Fowler, Independent Consultant; Jonathan Frodge, City of Seattle; Dick Gersib, WA Dept of Transportation; Eric Greenwald, The Boeing Company; Julie Hampden, Herrera; Curtis Hinman, WA State University; Heather Kibbey, City of Everett; Joan Lee, Parametrix; John Lenth, Herrera; Julie Lowe, Ecology WQP; Tetyana Lysak, The Boeing Company; Curtis Nickerson, Taylor & Associates; Dale Norton, Ecology EAP; Mel Oleson, The Boeing Company; Kit Paulsen, City of Bellevue; Rob Plotnikoff, TetraTech; Steve Ralph, Stillwater Sciences; Scott Redman, Puget Sound Partnership; Rich Sheibley, U.S. Geological Survey; Jim Simmonds, King County; Glen Sims, Puget Soundkeeper Alliance; Bill Taylor, Taylor & Associates; Scott Tobiason, Brown & Caldwell; Heather Trim, People for Puget Sound; Gary Turney, U.S. Geological Survey; Dean Wilson, King County; and Bruce Wulkan, Puget Sound Partnership.

- **Small team identified to develop this document:** Derek Booth, Stillwater Sciences; Karen Dinicola, Ecology; John Lenth, Herrera; and Jim Simmonds, King County

- **Oversight and direction of writing team by subgroup:** Scott Collyard, WA Dept. of Ecology; Jay Davis, U.S. Fish and Wildlife Service; Dana de Leon, City of Tacoma; Tim Determan, WA Dept. of Health; George Fowler, Independent Consultant; Dick Gersib, WA Dept. of Transportation; Jonathan Frodge, City of Seattle; Heather Kibbey, City of Everett; Julie Lowe, WA Dept. of Ecology; Dale Norton, WA Dept. of Ecology; Kit

Paulsen, City of Bellevue; Gary Turney, U.S. Geological Survey; Bruce Wulkan, Puget Sound Partnership

- **Dynamic process of integration:** Oscillation from the small to the large; dynamic tension between structure and initiative; dynamic tension between process and content
    - This document provides the recommended starting point and approach to achieving a comprehensive regional understanding of the impacts of stormwater and the effectiveness of our management actions to prevent, reduce, or mitigate those impacts.
    - We anchor the strategy in adaptive management structure to support and evaluate alternative actions with scientific monitoring and hypothesis testing.
    - We still need to refine indicators, targets, and benchmarks as we better understand the relationships among ecosystem components and the impacts of stormwater on the Sound. Part of this process requires identifying any new indicators and developing indicator indices. Selection of the final set of indicators will be based on several factors, such as data availability, how well the set captures the full range of ecosystem functions impacted by stormwater, and the costs of monitoring and analysis.
- **Peer review by outside experts and stakeholders**
    - Review of strategy by stakeholders at public workshop on November 10, 2009.
    - Public comment period continues through November 30, 2009.
    - Formal peer review by team of five national and regional experts.
- **Final strategy completed in early 2010**.
- **Implementation plan developed January-June 2010.**
    - Includes mechanics of monitoring (*i.e.,* SOPs and data management requirements) and effective use of the region's collective capacity and resources to collect and analyze data
        - Commitment of agencies and individuals to implement the strategy
        - Better understanding of the roles of individuals and agencies
        - Better understanding of the relationships between individuals and agencies

A.3 Connections to Other Efforts

A.3.1 Puget Sound Partnership (PSP)

The Puget Sound Partnership (PSP) is charged with overseeing the efforts to restore Puget Sound and is also accountable for measuring the progress made towards ecosystem recovery goals by implementing specific activities articulated in the "Puget Sound Action Agenda: Protecting and Restoring the Puget Sound Ecosystem by 2020" (PSP, 2008). The SWG's development of a regional approach for monitoring stormwater is listed as a Near Term Action in the *Action Agenda* among many other key stormwater management activities.

Continued collaboration with the many governments and interests in Puget Sound will be essential in implementing solutions and sustaining actions that support a healthy ecosystem while moving forward with a vibrant economy. The *Action Agenda* calls for large-scale regional approaches and the creation of consistent protection and restoration standards for the region; reducing pollutant inputs at the source; prioritizing and retrofitting existing stormwater management facilities (particularly in areas that were urbanized long ago); and ramping up low impact develop techniques in urbanizing areas. The *Action Agenda* also calls for the reform of environmental regulatory programs as well as improvements to the capacity of local partners to implement actions and compliance efforts across Puget Sound.

The *Action Agenda* states the need to establish priorities and resource needs for creating a coordinated water quality monitoring program under National Pollutant Discharge Elimination System (NPDES), and the need to coordinate with the overall regional monitoring program identified in the Action Agenda. Utilizing the NPDES permit structure will enable the development of a regional program that works synergistically with the multiple local stormwater monitoring efforts and address both the local stormwater impacts and develops a program to address the cumulative Puget Sound wide stormwater impacts.

A.3.2 PSP's Regional Ecosystem Monitoring Program

As part of its mandate to oversee efforts to recover Puget Sound, PSP is establishing a coordinated ecosystem monitoring program to guide recovery efforts and provide feedback about progress toward recovery. The ecosystem monitoring program is envisioned to provide an umbrella under which multiple, topical monitoring efforts are overseen in three key ways: first, a science-policy interface is created and maintained whereby scientific knowledge can better inform key decisions and policies; second, efficiencies are gained by prioritizing and coordinating the work done by multiple entities operating under multiple mandates; and third, a better understanding of the complex ecosystem is achieved through cross-topic analysis and synthesis of information.

The Stormwater Work Group (SWG) is among the first work groups envisioned to be formally incorporated into this structure. The SWG is a test pilot model for setting priorities and developing a strategy to gather and analyze key data to solve the biggest problems facing the Puget Sound basin. Other Work Groups include but are not limited to:

- Chinook Recovery monitoring;
- the Puget Sound Assessment and Monitoring Program (PSAMP);
- Cooperative Monitoring Evaluation and Research (CMER); and
- the Toxics Loading Steering Committee that is coordinating ongoing efforts to fill gaps in knowledge and understanding of toxic pollutant sources, fate, and transport in the Puget Sound region.

All of these efforts are coordinated under the umbrella of the Puget Sound Action Agenda, populated with "Near Term Actions" to recover the Puget Sound Ecosystem.

A.3.3 The Clean Water Act (CWA) and National Pollutant Discharge Elimination System (NPDES) Permit Monitoring Requirements

The primary objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C. 1251, sec. 101). Reducing the impact of stormwater on receiving waters has been notoriously difficult because stormwater is produced everywhere that the landscape has been developed; stormwater is episodic and its impact on the natural hydrology is difficult to reduce; and stormwater accumulates and transports the toxins, waste, and sediment associated with developed lands (NRC, 2009). Under the CWA, are required to control urban and industrial stormwater through the National Pollutant Discharge Elimination System (NPDES) permit program (sec. 402) and effective BMPs to control nonpoint source pollution (sec. 208).

The Washington State Department of Ecology (Ecology) is delegated by the U.S. Environmental Protection Agency (EPA) to implement the CWA in Washington. Ecology requires monitoring as a condition of granting NPDES permits. In recent years, disagreements over permit monitoring requirements have motivated the permittees, the regulators, and other interested parties to work together to find a more efficient, meaningful and scientifically-based approach to monitoring. This strategy will include monitoring and assessment that can be used to formulate requirements in future stormwater permits.

Monitoring is a presumptive element of most CWA-permitted stormwater management programs. It can demonstrate compliance with regulations, identify sources and loadings of pollutants and characterize their effects on receiving waters, evaluate the effectiveness of stormwater control measures, and provide feedback to managers and the public about whether ecosystem improvements are occurring. As an example, the types of monitoring typically contained in NPDES Phase I municipal permits include:

(1) wet weather outfall screening and monitoring ("source identification"),
(2) dry weather outfall screening and monitoring (illicit discharge detection and elimination),
(3) biological monitoring to determine stormwater impacts ("status and trends"),
(4) ambient water quality monitoring ("characterization"), and
(5) measuring the efficacy of stormwater control measures ("effectiveness") (NRC, 2009).

Industrial and construction sw general permits require sampling of discharges from outfalls but not monitoring of the quality of the receiving water. Other types of stormwater monitoring have existing statutory requirements and others are responding to very local or site-specific needs. Ideally, a monitoring and assessment strategy will provide guidance on how all prescribed and local efforts can contribute to an increased, data-supported understanding of how stormwater affects receiving waters and what are the most effective, or most promising, stormwater management approaches.

EPA promulgated federal Phase I Stormwater Rules in 1990 that require NPDES permits for municipal separate storm sewer systems (MS4s) serving populations over 100,000 and for runoff associated with industry, including construction sites five acres and larger. In 1999 EPA issued the Phase II Stormwater Rule which expanded the requirements to small MS4s and construction sites between one and five acres in size. Stormwater discharges must be regulated and dischargers must establish a comprehensive regulatory program, which may include performance

standards, guidelines, guidance, and management practices and treatment requirements. With the addition of these regulated entities, the NPDES program has grown by an order of magnitude in the past decade to exceed a half million permittees.

EPA guidance (USEPA, 1999) listed Phase I stormwater permit requirements as:

Phase I MS4 permittees were required to submit an application that included source identification information, precipitation data, existing data on the volume and quality of storm water discharges, a list of receiving water bodies and existing information on impacts on receiving waters, a field screening analysis for illicit connections and illegal dumping, and other information. Following this submission, MS4 permittees were to gather and provide additional information including: discharge characterization data based on quantitative data from 5 to 10 representative locations in approved sampling plans; estimates of the annual pollutant load and event mean concentration of system discharges for selected conventional pollutants and heavy metals; a proposed schedule to provide estimates of seasonal pollutant loads; and the mean concentration for certain detected constituents in a representative storm event; a proposed management program including descriptions of: structural and source control measures that are to be implemented to reduce pollutants in runoff from commercial and residential areas; a program to detect and remove illicit discharges; and a program to control pollutants in construction site runoff.

The CWA also requires states to establish water quality standards for all surface waters and marine waters within three miles of shore. Water quality standards include designated uses, *e.g.*, aquatic life use, drinking water, navigation, criteria to determine whether waters are meeting their designated uses and an anti-degradation plan (sec. 303(d)). Water bodies that do not attain their designated uses are listed and states must develop TMDLs (Total Maximum Daily Loads) that quantify the pollutant load that will bring the waterbody back into attainment (Keller and Cavallaro 2008).

Recent Pollution Control Hearing Board rulings on the municipal stormwater permits issued in Puget Sound endorsed our process as a means of informing future permit monitoring requirements. This has provided additional incentive for permittees, environmental groups, regulators, and other interested parties to work collaboratively to create a solution.

Future efforts of the Stormwater Work Group may address specific general NPDES stormwater permits issued by Ecology and the WA Department of Agriculture, specifically, those for: construction sites, industrial activities, confined animal feeding operations, the WA State Dept. of Transportation, and others.

A.3.4 Previous Efforts to Address Stormwater to Protect Natural Resources

Stormwater management originated as a means to address local drainage and flooding problems. The pollution carried by stormwater was not a primary driving factor in developing stormwater management programs and infrastructure until relatively recently. Most institutional arrangements, political structures, and regulatory approaches for managing stormwater were also developed at local scales: drainage districts, cities, and counties were developed, funded (through local fees and taxpayers), and implemented programs to manage stormwater on a piecemeal basis along jurisdictional boundaries. These traditional institutions are insufficient to provide a

holistic regional approach to solving the problem on an ecosystem scale. The cumulative, regional impacts of stormwater from multiple pollution sources at a Sound-wide scale have not been systematically addressed, and efforts have been scattered, opportunistic, and disconnected from the physical processes that sustain or degrade the water quality of Puget Sound.

The following timeline identifies historic milestones and recent events related to monitoring and management of stormwater in the Puget Sound region:

1970s
Clean Water Act; Boldt decision
1980s
Creation of PSWQA: Puget Sound Plan addressed non point pollution and stormwater (1989)
Clean Water Act Amendments
NURP
Centennial grant program (stormwater a smaller element of nonpoint pollution)
ESA co-managers monitoring elements
1990s
Listing of PS Chinook, HC chum, bull trout.
First municipal and construction stormwater NPDES permits in 1995; Phase I permittees coordinated monitoring strategy (failed)
Governor establishes forum on monitoring salmon recovery
Legislature formed multiple stakeholder processes to develop a comprehensive monitoring strategy for the state and recommended a monitoring oversight group
Salmon in the City: 1998 conference highlighting urban impacts; dialogue with policy makers.
Ecology advisory committees – series of meetings about monitoring with separate stakeholder groups. The effort failed. The separate groups were never brought together.
Woodward Clyde unpublished manual
Watershed action plans – formation of stormwater utilities
PTI WQS 1994
Tri-County habitat monitoring coordination committee 1999 (failed)
Numerous studies linking urbanization and loss of forest cover to lowland stream degradation
Puget Sound Plan (mid to late '90s), Ecology's watershed planning process under WAC 400-12 (Nonpoint Pollution). Local Watershed Management Committees address nonpoint pollution and identified stormwater from the bottom up.
"Closure Response" planning in 1999-2000. DOH downgraded a shellfish growing area, local and state resource and health agencies developed cleanup plans. Stormwater often an issue
2000
LID added to PS Plan.
2000-2001 Phase I permit renewal; draft dropped until 2005
2001
Ecology monitoring strategy (failed)
2004
Current industrial permit issued
2005
First draft Phase I permit included ambient monitoring requirements later dropped; led to 2006 exploratory committee of PS Monitoring Consortium

Current construction permit issued
2006
Upgrade of Dyes Inlet shellfish beds
Kitsap Stormwater Maintenance Pilot Project
Surface Water and Aquatic Habitat Committee workshop and preparation for legislative session
2007
Surface Water and Aquatic Habitat Committee report in March
Legislative session creates Puget Sound Partnership, PS Monitoring Consortium, and gives new oversight responsibilities to Washington Forum on Monitoring as a new state entity.
Puget Sound Monitoring Consortium Governance Committee and Technical Advisory Committee formed.
Phase I and II permits issued and challenged
Monitoring Phase I meetings to identify issues/problems; underscore need for stakeholder process
Puget Sound Recovery Plans for salmon and bull trout
2008
Phase I and II permit appeal hearings
April meeting of Science Panel: PSMC set aside governance questions and start SWG now
PS Monitoring Consortium TAC identifies and conducts 4 pilot projects
PS Monitoring Consortium report to legislature; recommend PS Partnership decide governance of regional ecosystem monitoring
PSMC develops draft charter and work plan over summer and launches SWG in October
Phase I permittees begin characterization monitoring
Current boatyard permit issued, boatyard studies begin
2009
PCHB rulings on seven Phase I and seven Phase II appeals
LID committee formed
PS Partnership LC decides in May to create a regional ecosystem monitoring program as part of PSP; decision to review need for an independent non-profit entity in June 2010
PSMC 4 pilot projects done: SOPs, inter-lab calibration, BIBI database, inline ditch treatment
Kitsap regional IDDE program
Current industrial permit expired, revised and issued in October to be effective 1/1/10
2010
Regional stormwater monitoring strategy due to Ecology and PSP
Phase II permittees determine monitoring sites and questions
Next round of construction stormwater permits scheduled to be issued
2012
Next round of municipal stormwater permits scheduled to be issued
2015
Next round of industrial stormwater permits scheduled to be issued

Appendix B APPLYING LESSONS LEARNED FROM ADAPTIVE MANAGEMENT AT A REGIONAL SCALE

Land and water resource management agencies routinely make decisions that affect natural processes and ecological functions. Developing successful, large-scale management and restoration programs requires not only the identification of knowledge gaps but also a commitment to robust monitoring programs that are modeled on the concept and implementation of what is broadly termed "adaptive management."

Numerous large-scale ecological monitoring efforts have been implemented around the nation, and they offer recommendations for the key elements of a successful program:

- identifying clear and relevant goals
- setting measureable objectives
- using the best available science
- establishing an accountable organizational and funding structure that facilitates clear communication of stated objectives, methods, and results at all applicable levels.

Recent summaries of these "lessons learned" include the Puget Sound Nearshore Partnership's Application of the "Best Available Science" in Ecosystem Restoration: Lessons Learned from Large-Scale Restoration Project Efforts in the USA (Van Cleave *et al*. 2004)); the Surface Water and Aquatic Habitat Monitoring Advisory Committee's Report and Recommendations (2007); and PSAMP's Keys to a Successful Monitoring Program: Lessons Learned by the Puget Sound Assessment and Monitoring Program (2008). All of these syntheses echo the need for integrated monitoring programs and adaptive management mechanisms that provide not just a tracking of "success" or "failure," but insight into why objectives are or are not being met. The development of and the implementation of this stormwater monitoring and assessment strategy for the Puget Sound region attempt to apply the lessons articulated from comparable programs to frame a scientifically credible and useful approach based on the tenants of adaptive management and hypothesis-testing.

B.1 Large-scale Ecosystem Programs Around the Nation

Nationally and regionally, many systematic monitoring programs have been implemented over the past 1–2 decades. These programs vary in their adherence to the principals of adaptive management, and both their successes and their shortcomings provide instructive examples for the region. These examples are grouped into those that are broadly construed "ecosystem management/monitoring" programs (both nationwide and local to our regional) and those that focus explicitly on stormwater management programs. These examples were selected based on

our perception of their relevancy to the proposed stormwater monitoring and assessment strategy for the Puget Sound region, but they are by no means exhaustive.

Chesapeake Bay Program (CBP)

The Chesapeake Bay Program (CBP) was established in 1983 and has evolved as a voluntary partnership between states, local and inter-state advisory and steering committees, and the EPA with the stated goal of restoring and protecting the Chesapeake Bay and its tidal tributaries. A Science and Technical Advisory Committee was formed shortly after CBP's inception to facilitate scientific communication between academic institutions, engineering and technical professionals, and organizations within the program, as well as to identify research needs and provide overall assessments and recommendations. The Monitoring and Analysis Subcommittee is comprised of five technical working groups that are charged with implementing monitoring and modeling programs, managing data, etc. This organizational structure is commonly cited for its successful "vertical and horizontal coordination and integration" of science (Van Cleave *et al*. 2004) and its effectiveness at maintaining sustainable funding and participation commitments by providing readily accessible and scientifically credible monitoring data (Surface Water and Aquatic Habitat Monitoring Advisory Committee 2007).

Although widely recognized as a potential analog, if not a leader, for efforts in Puget Sound, we note that "No organized monitoring system currently exists in the [Chesapeake] Bay to conduct critical stormwater research and feed it back into the design process" (Schueler 2008, p. 11). Similar to most regions, local and state jurisdictions have been responsible for stormwater management and implementation of municipal and industrial stormwater regulations to meet NPDES permit requirements. Only recently has a new organization, the Chesapeake Stormwater Network, been created to encourage more sustainable stormwater and environmental site design practices and align the efforts of individuals, municipalities, and watershed resource organizations such as the Center for Watershed Protection. As noted in the Bay-Wide Stormwater Action Strategy (Schueler 2008), the Chesapeake Stormwater Network could provide stormwater management guidance beyond permitting assistance, but as yet an overall stormwater monitoring strategy has not been conceived.

San Francisco Estuary Institute (SFEI)

The San Francisco Estuary Institute (SFEI) is a non-profit organization established in 1986 to advance the development of the scientific understanding needed to protect and enhance the San Francisco Estuary by conducting monitoring and research. The Regional Monitoring Program for Water Quality (RMP) is a collaborative effort between scientists, the San Francisco Bay Regional Water Quality Control Board, and discharging industries to "collect data and communicate information about water quality in the San Francisco Estuary to support management decisions" (see SFEI's RMP website). Annual "Pulse of the Estuary" reports present selected monitoring results to a wide audience, and all reports and data are publicly available.

The RMP is subject to independent science review every five years to ensure that it is meeting its objectives and that appropriate adjustments are made in response to past reviews. For example, major elements of the status-and-trends monitoring program were modified in 2007 to better address pollutant source and distribution monitoring objectives, including the refinement of the episodic toxicity program goal to address the key question "what is causing the sediment toxicity in the Bay?" (SFEI 2009).

The mercury TMDL for the San Francisco Bay demonstrates a clear adherence to the process of adaptive implementation as outlined by the National Research Council's 2001 TMDL program review. The primary challenge for establishing a TMDL is to identify and implement actions that will solve the water quality problem in light of uncertainty about cumulative effects and technological and economical constraints (SFEI 2004). Recognizing that there are inherent shortcomings to a mercury TMDL based solely on management and measures of total mercury, the adaptive implementation plan includes provisions for: (1) immediate actions, (2) monitoring, (3) management questions, associated hypotheses, and a schedule for measuring benchmarks, (4) reviewing and incorporating monitoring and study results into the TMDL. Using urban runoff as one mercury source example, immediate actions include evaluating the benefits of specific management practices in terms of reduced loads and quantifying load reductions as a function of specific practices using interim benchmarks (SFEI 2004). This approach allows for quantitative results to inform practical management decision moving forward while research aimed to better understand methylation and other processes contributing to overall mercury loads continues.

The SFEI has been mentioned as a model for the Puget Sound regional monitoring and assessment effort because of the third party nature of the institute and their focus on "getting everyone to agree on the facts" in an objective manner.

Louisiana Coastal Area Ecosystem Restoration

Ecosystem restoration efforts in the Louisiana coastal area have received increasing attention due in part to annual coastal wetland losses that exceed 60 km^2 per year, as well as large weather events such as Hurricanes Katrina and Rita. The 1989 Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA; or "Breaux Act") served as a catalyst for small projects, and the 1998 federal and state and federal plan "Coast 2050: Toward a Sustainable Coastal Louisiana" proposed integrating restoration and protection measures to restore natural processes that build and maintain the coast (USACE 2009). Since that time the US Army Corps of Engineers (USACE) (in concert with Louisiana State DNR and other agencies) conducted the Louisiana Coastal Area Ecosystem Restoration Study (see USACE website) to identify the most critical human and ecological needs, establish near-term prioritization of restoration and protection projects, and present a strategy for addressing long-term ecological and protection concerns. Following Hurricane Katrina, USACE was directed to reexamine, assess, and present recommendations for a comprehensive approach to coastal restoration, hurricane storm damage reduction, and flood control. The Coastal Protection and Restoration Authority of Louisiana (state) released its Comprehensive Master Plan for a Sustainable Coast in 2007 and is still in the process of soliciting public input on concerns and proposed solutions for implementing outlined actions (letter from Governor Bobby Jindal's office to concerned citizens dated August 17, 2009).

While there have been numerous starts and stops along the way to implementing a large-scale ecological restoration strategy for the Louisiana coastal area, there have been and currently are several monitoring efforts of note. The Coastwide Reference Monitoring System uses a multiple reference approach consisting of hydrogeomorphic functional assessments and probabilistic sampling in order to provide information that can be used for effectiveness monitoring and assessing cumulative effects of management prescriptions (see CRMS website). In 2002, CWPPRA scientists conducted an adaptive management review of constructed projects to improve the linkages among planning, engineering, and monitoring. Constructed projects were

studied as they evolved from the concept stage through construction and several years of monitoring.

The CWPPRA review demonstrated the value of comprehensive information at multiple scales, from project-specific, to project-type, to ecosystem-wide. Notable recommendations consisted of asking key questions tied to ecological function and setting quantifiable objectives at the project inception phase. Monitoring programs are certainly recognized as an important component of restoration and protection of the Louisiana coastal area and copious resources are committed to research and monitoring. However, a cursory inspection of current efforts suggests that monitoring has not been the predominant framework of an experimental management design; thus, adaptive implementation is not fully integrated.

National Park Service Vital Signs Monitoring Program

Th National Park Service Vital Signs Monitoring Program has established long-term ecological monitoring for 270 parks in 32 identified ecoregional networks, with status and trends systems-based monitoring for a broad understanding to inform land management decisions. The authors of a recent publication outlining the program conclude that:

> "one of the most critical steps in designing a complex interdisciplinary monitoring program is to clearly define the goals and objectives of the program and get agreement on them from key stakeholders. In our evaluation of "lessons learned" by other monitoring programs, we found that *differences in opinion regarding the purpose of the monitoring* [emphasis added] as the program was being developed often led to significant problems later during the design and implementation phases" (Fancy *et al*. 2009, p. 4).

Monitoring, adaptive management, and the iterative assessment of management actions should be viewed as integrated parts of a long-term restoration program. Education about the scientific process of adaptive implementation and discussion amongst participants is an important component of program and project design (Van Cleve *et al*. 2004).

As a result of education and collaboration at program inception, objectives for vital signs monitoring evolved from general statements such as, "Determine trends in the incidence of disease and infestation in selected plant communities and populations," to objectives that met the test of being realistic, specific, and measurable (*e.g.*, "Estimate trends in the proportion, severity, and survivorship of limber pine trees infected with white pine blister rust at Craters of the Moon National Monument," Garrett *et al*. 2007)." In the context of the Puget Sound effort, we note that information from the local network of parks *(i.e.*, North Coast and Cascades) could provide useful baseline conditions from which to judge the extent of changes in altered landscapes.

B.2 Stormwater-specific Monitoring Programs

California Stormwater Monitoring: a comparison of land-use and industrial programs

Lee and Stenstrom (2005) and Lee *et al*. (2007) evaluated various stormwater monitoring programs within the state of California to determine their usefulness to planners and policy makers charged with abating stormwater pollution. The foci of the monitoring program evaluations were on data collection methods and the utility of data collected to identify discharge sources. General relationships between water quality and land use were confirmed (*e.g.*, highways convey a different suite of pollutants than residential lots); however, distinctions between industrial land uses were not defensible. The authors assert that the data reviewed did

not allow for hypothesis-testing and therefore could not be used to indentify high dischargers with any confidence. Furthermore, Lee *et al*. suggest that regulators must recalibrate their expectations about how they use stormwater data if statistical inferences are not well-founded.

The overarching conclusion of these studies is that that design and execution of many monitoring programs may not produce data with sufficient precision for decision-making, because the methods are not explicitly linked to goals and objectives within a scientifically sound monitoring structure. Data-collection methods and sampling strategies that produce statistically meaningful inferences can only succeed when framed by hypotheses.

Tahoe Basin Regional Stormwater Monitoring Program (RSWAMP)

The Tahoe Basin Regional Stormwater Monitoring Program (RSWAMP) is a collaboration between the Tahoe Science Consortium and other Tahoe Basin agencies to design and ultimately implement a science-based program to track progress and guide stormwater management revisions to improve and protect water quality within the Lake Tahoe watershed. A conceptual plan was completed in 2008 and the monitoring design is currently being developed, but no document is yet available for review (September 2009).

The conceptual development plan calls for monitoring and data analysis based on a unified set of key management questions generated within an adaptive management framework that can be applied to multiple projects and at multiple scales (see Heyvaert *et al*. 2008). While the Tahoe Basin RSWAMP acknowledges that it is only one piece of the greater "Tahoe Basin adaptive management system," it asserts that it will facilitate evidence-based management by presenting statistically robust and scientifically credible data and information. The plan states that the monitoring design will incorporate a well-articulated connection between different monitoring "sub-programs"—implementation, effectiveness, targeted, and status-and-trends monitoring—and overall critical questions identified for TMDL development (*e.g.*, are the expected reductions of each pollutant to Lake Tahoe being achieved?).

City of Seattle, Seattle Public Utilities, Street Edge Alternatives (SEA) Project

The Street Edge Alternatives (SEA) Project was conceived as a neighborhood-scale retrofit using low-impact design techniques, primarily impervious-area reduction and shallow infiltration, to reduce runoff rates and volumes. It was initiated following construction of the Viewlands Cascade Drainage System, which replaced traditional ditches with a series of wide, stepped pools. Pre- and post-construction monitoring indicated a one-third reduction in runoff volume during the wet season, and consequently the City increased its efforts to curtail runoff volume by reconstructing the entire street area of 2nd Avenue NW (adjacent to the Viewlands Cascade). They applied before- and after-treatment water quality and quantity monitoring of total site stormwater runoff following reconstruction of neighborhood stormwater conveyance facilities to evaluate effectiveness, and the overall success shown by these results has provided the basis for additional, expanded efforts in other parts of the city (Horner *et al*. 2002; see the City of Seattle website). This is an example of a clear linkage between an initial management action being an acknowledged experiment, with the measured results (in this case, showing a successful outcome) being reflected in a programmatic change (*i.e.*, expansion of the effort to other parts of the city).

B.3 Ecologically-based Monitoring Programs in the Puget Sound Region

Cooperative Monitoring Evaluation and Research (CMER)

The Cooperative Monitoring Evaluation and Research (CMER) committee is the "science branch" of Washington State Forest Practices Board Adaptive Management Program (which also consists of a Policy group, Independent Science Panel and Program Administrator). The CMER research and monitoring strategy is outlined in the CMER Work Plan, which is revised annually. The goal of the CMER Work Plan is to "present an integrated strategy for conducting research and monitoring to provide credible scientific information to support the Forest Practices Adaptive Management Program" (CMER 2008). Critical questions about forest practice rules and their effectiveness at meeting resource objectives are the cornerstone of CMER's *effectiveness, status and trends*, and *intensive* monitoring programs, and rule implementation tool development programs.

While prioritization of research efforts to evaluate whether forest practice rules achieve resource protection objectives and integration of study results continue to challenge CMER, the organization and operation of the Forest Practices Adaptive Management Program is consistent with the goal of science informing policy and generating a timely feedback loop.

In early 2009, the Washington Department of Natural Resources commissioned a comprehensive review of studies completed for the adaptive management program under CMER (Stillwater Sciences 2009) associated with the ten-year-old Forest and Fish Agreement. CMER is charged with evaluating the effectiveness of the forest practices rules in protecting public resources (*e.g.*, fish, wildlife, and water quality), and it has initiated or completed over 80 individual studies to that end. These studies were evaluated in light of their stated objectives, key questions, hypotheses, and interim performance targets.

The overarching finding of the 2009 CMER review was that the monitoring framework approach is well-founded but its implementation over the first ten years of the program has not been uniformly well-executed, primarily because of a preference for site-scale studies over integrative (status-and-trend) evaluations, and from insufficient cross-coordination amongst the various components of the program.

Puget Sound Nearshore Estuary Partnership (PSNRP)

The Puget Sound Nearshore Ecosystem Restoration Project (PSNRP) is a partnership between the U.S. Army Corps of Engineers (Corps), state, local, and federal government organizations, tribes, industries, and environmental organizations. PSNRP's goals are to identify significant ecosystem problems, evaluate potential solutions, and restore and preserve critical nearshore habitat in Puget Sound. While early restoration efforts have been encouraging, these efforts have paled in light of widespread on-going environmental deterioration. The agencies and tribes involved with this effort are determined to define and apply a much broader and systematic approach to reverse and prevent the harm by establishing a sound scientific basis to understand fundamental ecological processes and functions, establish reliable measures of current conditions, define and implement a research agenda to fill in knowledge gaps, and to identify and prioritize specific restoration actions that address the root causes of environmental damage.

While the focus of the project is on restoration, the group has embraced the application of scientific principals as the foundation of their work. Already, PSNRP has accomplished a considerable amount of research, including a comprehensive geomorphic classification of marine shorelines in Puget Sound; a comprehensive evaluations of marine biota including Orca whales and marine forage fish, shoreline and submerged marine vegetative communities, nearshore processes; a comprehensive research strategy for coastal habitats and a conceptual model to better understand restoration efforts of nearshore ecosystems; an historical change analysis of marine shorelines; and a report on best available science and "lessons learned" from large scale restoration efforts throughout the nation. The research agenda they have defined uses a hypotheses-based approach to defining appropriate indicators and laying out the logic of their inquiry.

PSNRP provides an example of an organizational structure with the inherent capacity to address environmental change and restoration needs at multiple spatial scales within Puget Sound. Their program, as of yet, does not appear to have a formal adaptive management component that would ensure that the outcomes of their efforts are well connected to inform policy makers.

To provide scientific direction for PSNRP, a "lessons learned" exercise (Van Cleve *et al*. 2004) characterized the role of science in five large-scale restoration programs beyond the Pacific Northwest: the Chesapeake Bay Program, the Comprehensive Everglades Restoration Plan (CERP), the California Bay-Delta Authority, the Glen Canyon Adaptive Management Program, and the Louisiana Coastal Areas Ecosystem Restoration Program. Many of those findings are already included in the discussions above. Overall, their review strongly suggests that using science as a foundation for making decisions will greatly improve a restoration program's ability to successfully conceptualize, design, and implement large-scale restoration efforts over the long term.

Puget Sound Assessment and Monitoring Program (PSAMP)

The Puget Sound Assessment and Monitoring Program (PSAMP) is a program established to coordinate research and monitoring in the Puget Sound marine waters by state, federal and local agencies. In 2008, the Steering Committee and Management Committee produced a review document of their process: Keys to a Successful Monitoring Program: Lessons Learned by the Puget Sound Assessment and Monitoring Program (PSAMP 2008). This report's purpose is well-aligned with the intention of the SWG's effort, namely to articulate:

> "…what organizational features and what technical elements are most important for a successful regional monitoring program. We believe that a successful monitoring program could be developed under any one of a variety of potential governance structures, so long as that structure supports and provides the necessary organizational features and technical elements…" (PSAMP 2008, p.7)

Their key relevant recommendations are listed below:

> To be successful, a coordinated, regional monitoring program must have:
>
> > **Clear monitoring objectives** derived from clear management goals through ecosystem-based assessment
> >
> > **Integrated monitoring, research and modeling activities**, implemented at appropriate scales, including:

a. Status-and-trends monitoring,
b. Compliance and effectiveness monitoring,
c. Implementation and validation monitoring,
d. Cause-and-effect studies,
e. Process and landscape models to synthesize monitoring and provide feedback, and
f. An adaptive management framework that targets restoration and conservation activities which improve environmental condition.

PSAMP has been collecting such data for over 20 years, and it has contributed much to our understanding of the decline in certain species and the increasing accumulation of toxicants in the environment and in biota. Unfortunately, this has not catalyzed a significant change in the way shoreline areas are managed nor how pollutants enter the system. The precautionary lesson here is that even a well-orchestrated program that tracks status or trends over time or space in key ecological indicators, if not directly linked to management decisions nor based on testable hypotheses about the underlying causal mechanisms, may not ultimately influence those decisions needed to forestall further decline in those indicators. Also, if the monitoring is conducted at too large a scale, it may also fail to provide much insight into how to reverse the trends of decline.

B.4 A Summary of "Lessons Learned"

From these (and other) examples of monitoring and assessment programs, some consistent themes emerge that show consistent success or, conversely, increase the likelihood of failing to meet program goals:

1. Clear and well-defined program goals must be articulated. Without this critical step, it is impossible to adequately frame the initial scope of investigations and the overall feasibility of the monitoring or restoration program.
2. Management or program goals must be translated into scientific and technical objectives that are measurable, and that define the means and mechanisms by which the ultimate goal will be realized. Once defined, the technical or scientific objectives are addressed through the application of scientific principals, including testable hypotheses.
3. Hypotheses can only be tested through the application of a robust scientific design. In examining 30 failed monitoring programs, Reid (2001) noted that 70% of the programs had problems in their fundamental scientific design that limited or precluded ultimate success.
4. Program goals must be phrased in ways that are meaningful to the public and directly address things that can be directly affected by management strategies (both current and alternative).
5. The application of science to a given set of resource objectives needs to be well integrated; that is, research, monitoring (in all of its forms), and modeling all need to work in harmony to address information needs and uncertainties.
6. Embrace uncertainty—defining what is not known is as important as what is known.
7. In a true adaptive management framework, the relationship between the policy sector and the science sector must be explicitly and formally defined. Science should inform policy, and

vice versa, but neither should regulate the role of the other. Policy-makers must clearly define the program goals, their practical objectives and the nature of the decisions they have some control over; and the scientists in turn must define the application of scientific tools to address achievement of those objectives.

8. Both "bottom-up" science (*i.e.*, arising from the initiative of individual researchers) and "top-down" science (*i.e.*, directed by an oversight panel) need to be integrated into large-scale ecosystem protection and restoration programs. Large-scale ecosystem restoration cannot be strategic if left to bottom-up science alone, but top-down direction is stifling and may reflect only the limited views and interests of the oversight group.
9. Approach the issue from multiple scales—Systematically evaluating alternative strategies for protection and restoration across the landscape must be appropriately scaled to protect and restore ecosystem processes. This is difficult if not impossible with ad hoc deployment of opportunistic, small-scale protection and restoration activities.
10. Multiple layers of independent scientific review are needed to ensure rigor and accountability.
11. Science and Policy makers need to understand constraints and opportunities in terms of considering management alternatives. Then allow the science analyze the range of all possible management strategies (both protection and restoration) and promote scientific assessment of emerging alternatives.

Appendix C ASSESSMENT QUESTIONS FOR MONITORING STORMWATER

The following priority assessment questions were officially adopted by the Stormwater Work Group on June 3, 2009. These questions were developed and vetted through a series of committee meetings and technical and public workshops culminating in the spring of 2009 (see Appendix A). Although interest was expressed in having an even larger number of questions, the final assessment questions were narrowed down in order to provide a manageable scope for this near-term strategy development effort.

Overarching questions:

1. Given limited resources, what combination of targeting new development and retrofitting existing development is most effective in minimizing the impact of land use/stormwater to receiving waters?
2. How effective are the Clean Water Act permit-mandated municipal (including highways), industrial, construction, livestock, and dairy stormwater programs?

For efficacy of management actions, the priority questions are:

- Among the most widely used practices and promising new practices that are available, what specific retrofits or restoration practices are most effective in reducing pollutant loads, restoring hydrologic function, and recovering damaged habitat?
    - To what extent can retrofits and application of BMPs at redevelopment sites reverse past impacts? To what extent can the water and sediment quality and hydrologic conditions necessary to support beneficial uses of water bodies be restored in sub-basins that already have some degree of development? At what degree of development, or under what other specific conditions, is a particular retrofit strategy most likely to be successful?
- Are our stormwater management actions preventing and reducing future disruption of natural hydrologic conditions and minimizing pollutant loads in areas of new development in Puget Sound?
    - What is the effectiveness of subbasin-scale to watershed-scale combinations of stormwater management actions (techniques) at reducing impacts?
- How effective are source control and other programmatic stormwater management practices in reducing pollutant loads from existing development and from other specific land use activities such as agriculture?

For impacts to beneficial uses, the priority questions are:

- *Where* does stormwater significantly impact receiving waters, resources, species, or beneficial uses in the lowland streams, lakes, rivers, ground, and marine waters of the Puget Sound basin?

- What is the current condition of streams, lakes, rivers, and nearshore marine waters, by representative land use?
    - What are the worst spots, when, and why?
    - What are the impacts to biota?
    - What areas should be targeted for protection?

- Over time, how effective are source control, prevention, and retrofit efforts? Are beneficial uses improving in response to our stormwater management actions?

For characterization and pollutant loadings, the priority questions are:

- How does land use influence pollutant concentrations, flow volumes, and loadings? What land uses or land use combinations are of greatest interest for applying and improving our stormwater management actions?
    - What is the variability in stormwater pollutant concentrations and flow volumes by land use and geographic area?
    - What is the variability within and among WRIA level basins for similar land uses?
    - What factors within a land use control pollutant concentrations and flow volumes?
        - How do differences in stormwater infrastructure (*i.e.*, pipes versus ditches, developments built at different times under different standards) affect pollutant loads and flows from similar land uses?
        - What proportion of the pollutant loads reach receiving waters and what are the explanations for the differences (*i.e.*, due to losses)?
    - What proportions of the pollutants in stormwater are from various sources such as air deposition and transport, spills, erosion and resuspension?

- What are the seasonal variations and long term trends in pollutant loads and what variables influence the temporal distributions?

For research, the priority questions are:

- What are the best indicators of stormwater impacts to water or sediment quality, streamflow, habitat, and biota?
    - What are the best indicators of various categories of chemical pollutants? Of solid-phase versus dissolved phase chemical pollutants?

- What are the synergistic effects of pollutants from stormwater?
- What is the toxicity in surface waters impacted by stormwater?
    - What is the seasonal and annual variation and the variation within the hydrograph?

- What are the effects of stormwater up through the food chain/food web?

Appendix D TRANSLATING ASSESSMENT QUESTIONS INTO HYPOTHESES

Shown in Table D.1 below are the Assessment Questions (abridged; see Appendix C for the complete list) with associated hypotheses developed by a group of regional stormwater experts (see Appendix A for the process; also Stormwater Work Group 2009). The next columns indicate the water body (WB) and land use (LU) to which they primarily relate; more columns are reserved describing which Near Term Actions (NTAs) articulated in the *Action Agenda* (PSP 2008) are related, and for an assessment of whether each hypothesis is credible (C), testable (T), and/or actionable (A).

Table D.1 combined with Table 1 (p. 13) provided the basis for identifying the priority hypotheses in Section 2.6. We developed both tables the course of trying to decide *how* to set priorities for stormwater monitoring. Table 1 helped us to focus the efforts articulated below on the combinations of land uses and receiving waters for which we know there are significant receiving water impacts. The blank cells in Table 1 might indicate research needs or they might indicate relatively lesser stormwater impacts that do not merit our attention. The most populated cells might indicate that we already know enough about stormwater impacts from those land uses and in those water bodies that we shouldn't need to gather more information. As noted earlier in this section, we have a good scientific understanding of the impacts of stormwater on small streams. However, we do not have good information about whether or not we do–or can–manage stormwater to adequately prevent, reduce, and mitigate these impacts. We do not have as thorough an understanding of the impacts of stormwater in other water bodies in Puget Sound, or of management practices to address those impacts.

Even ignoring the blank cells in Table 1, we could continue to postulate many more questions for each combination of land use, receiving water, and impact shown in Table 1. The result would still be a very long list of potential assessments, with an accompanying long list of resource requests to complete the studies.

The SWG will focus on implementing the current proposed strategy and dedicate future efforts to further prioritizing hypotheses to address.

Table D.1. Assessment questions, associated hypotheses, water body (WB), land use (LU); related Near Term Actions (NTAs) in the *Action Agenda* (PSP 2008); and whether or not the hypothesis is credible, testable, and/or actionable (C/T/A).

Type/ scale	AQ_short	Hypotheses	WB	LU	NTA	C/T/A
Effect.	What specific retrofits or restoration are most effective in reducing pollutants, restoring hydrology and habitat? What are limits to restoration	Retrofitted wet ponds (media filters and remove dead storage) will improve smolt prod	Streams	urban		
		Retrofitted wet ponds will mimic natural hydrology	Streams	urban		
		Physical limits exist to retrofitting capability	Streams	urban		
		Retrofits improve water quality	Streams	urban		
		Retrofit BMPs in urban areas improve beneficial uses	Streams	urban		
Effect.	Is management reducing disruption to hydrology and minimizing pollutant loads in new development?	Wet ponds increase nutrients	Streams	urban		
		Outflow from pond will not have natural flow regime	Streams	urban		
		End of pipe treatment better than reducing flow	Streams	urban		
		new LID improves water quality and discharge	Streams	urban		
		Ponds with filter media reduce temp, nutrients, pollutants	Streams	urban		
		Flow control practices fix hydrology	Streams	urban		
		BMPs influence public opinion	Streams	urban		
Effect.	Does source control and other management reduce pollutant loads from development, agriculture, etc.	Source control reduces load and concentrations	Streams	urban		
		Source control reduces flow and volume	Streams	urban		
		Source control improves biological integrity	Streams	urban		
Status & trends	*Where* does stormwater impact water resources? What is current condition of receiving waters by land use? Where worst spots?	Land use affects BMIs	Streams	all		
		Discharge affects BMIs	Streams	all		
		Shellfish harvesting impossible in urban	Nearshore	urban		
		Land use affects water quality	All	all		
		Land use affects hydrology	All	all		
		Is 80% removal of TSS adequate	All	all		
		Land use affects marine waters	Nearshore, marine	all		

		Pollutant concentrations independent of dry period	All	all		
		Public ed improves beneficial uses	All	all		
		Impervious area impacts lakes	Lakes	all		
		Stormwater affects swimming access	All	all		
		Degradation of beneficial uses correlated with land use	All	all		
Status & trends	*Where* does stormwater impact water resources? What are impacts to biota? Where should target protection?	Food fish impacted by PCB	All	all		
		Biota affected by changes in flow regime	Streams	all		
		Rural streams easier to restore	Streams	Ag, forest.		
		Fecal coliforms from pets and birds	Streams	urban		
		Fine sediment harms biota	Streams, nearshore	all		
		PAHs affect salmon embryos	streams	all		
		wetland fluctuations harm frogs	Wetlands	all		
		Geomorphology more important than land use for sediment	All	all		
		Contaminants from adjacent urban	Streams, nearshore	urban		
Status & trends	How effective are source control, prevention, and retrofit efforts? Are beneficial uses improving due to management?	Source control reduces pollutant loads and concentrations	All	all		
		Source control and retrofits reduce peak flow and volume	All	all		
		Source control and retrofits improve biological integrity	All	all		
Source ID	How do pollutant concentrations and flow volumes vary by land use and geographic area (WRIA)? Which land uses most important?	Land use (remote sense, tax parcel, or lump/split) does not change loads and concentrations of pollutants	All	all		
		Models can predict pollutants from land uses	All	all		
Source ID	How do infrastructure, land use, and losses control pollutant concentrations and flow volumes?	Pipe and ditch affects metal pollutant load	All	all		
		Pervious pavement decreases PAHs and high flow duration better than pond	Streams	urban		

		Flow volume, concentration and toxicity reduced by redirecting runoff	Streams	urban		
		Location of impervious area affects flow volumes and loads	Streams	urban		
Source ID	What proportions of pollutants from air deposition and transport, spills, erosion and resuspension?	Atmospheric dep from urban brings contaminants	Streams	urban		
		Concentrations of pollutants decrease with source control	All	all		
		Current and legacy contaminant increase with SW intensity	All	all		
		Atmospheric dep varies across region	All	all		
		Intensity of storms increases particle bound contaminant	All	all		
Source ID	What are the seasonal variations and long term trends in pollutant loads and what influences them?	PAHS, metals vary by season	All	all		
		Load and concentration is higher in wet season	All	all		
		Seasonal variation in loads affected by land use	All	all		
		Season pesticide and fertilizer affect water quality	All	all		
		Annual load driven by large storms not many small storms	All	all		
		Load and concentration equally representative for demonstrating trends in water quality	All	all		
		Seasonal variation in metal loads in urban affected by rainfall	All	all		

Appendix E STATUS-AND-TRENDS MONITORING DESIGN

Status-and-trends monitoring is included in this strategy to provide key indicators for stormwater impacts over time. Two water body types were selected for detailed status-and-trends monitoring plans: small streams and nearshore areas. The monitoring designs that are proposed for each water body are described in the following subsections.

E.1 Small Streams Status-and-Trends Monitoring

The proposed priority hypotheses for status-and-trends monitoring in small streams are, from Section 2.6.1:

1. Salmon in small streams show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.
2. Instream biological metrics (*e.g.*, B-IBI) show statistically significant improving trends in Puget Sound lowland streams in concert with increased and improved stormwater management efforts.

Small streams (here defined as 2nd and 3rd order streams) are a critical component of this strategy because the health of the biota can be directly linked to land use patterns and activities and their related impacts on beneficial uses. Status-and-trends monitoring of small streams will involve measuring a targeted suite of biological, chemical, hydrologic, and physical indicators for stormwater impacts at a randomly selected group of sites from a list of all possible stream locations. Selection of stream sites will follow EPA protocols that have been adopted by Ecology for the Watershed Health and Salmon Recovery Status and Trends (WHSRST) monitoring program (Ecology 2006). Specifically, stream sites will be selected from the list of random sites found in the Washington Master Sample (www.ecy.wa.gov/programs/eap/stsmf/); this list was also used by the Ecology for WHSRST monitoring program.

Using the same approach that was used for Ecology's WHSRST monitoring program, the experimental design for small stream status-and-trends monitoring under this strategy includes a fairly large number of randomly selected sites that will be permanently identified for monitoring in the Puget Sound lowlands. These sites will be grouped into two categories: permanent and rotating sets of sites. In general, this design represents an attempt to balance limited monitoring resources between a fewer number of permanent sites that will be sampled intensively over time to detect trends in stormwater pollutant concentrations and loads, and a larger number of rotating sets of sites that will be sampled less intensively but provide broader spatial coverage for assessing impairment from stormwater. Because these rotating sets of sites will be revisited over time, they can also be used to detect improving or deteriorating trends related to stormwater.

Given this objective, monitoring at the permanent sites will include: 1) relatively high frequency sequential storm event sampling annually, 2) annual sediment sampling, 3) annual macroinvertebrate surveys, 4) annual in situ toxicity tests, and 5) physical habitat surveys. In addition, to support loading analyses and to aid in interpretation of water quality observations during storms, water level, flow, and temperature will also be continuously measured at these sites.

In contrast, the rotating sets of sites will only be monitored two consecutive years out of every six. In addition, no emphasis will be placed water quality monitoring at these sites; instead, only annual sediment sampling, macroinvertebrate surveys, in-situ toxicity tests, and physical habitat surveys will be conducted at the rotating sites. These indicators were specifically selected because they inherently integrate pollutant inputs and other stormwater impacts over time.

E.1.1 Site Selection

As noted above, all sites for small streams status-and-trends monitoring will be selected from the list of random sites found in the Washington Master Sample. The first step in process will define a sampling frame for these sites (*i.e.* the spatial domain over which the sites are selected). For small streams status-and-trends monitoring the sampling frame is the set of 2nd and 3rd order streams draining to Puget Sound that are accessible for sampling (*e.g.*, not subject to private property restrictions) and below a defined elevation threshold (*e.g.*, below 2,500 feet). The elevation threshold will serve to focus the monitoring at streams within lowland areas where adverse stormwater impacts are known to be more prevalent.

The next step is assignment of probabilities of selection to all stream reaches in the sampling frame. This is done through the generalized random tessellation stratified (GRTS) method, an EPA-approved statistical model for probabilistic survey designs. The GRTS method has an advantage over a uniformly random sample set because selected sites are spatially balanced. Uniform random spatial distributions tend to be more clumped than GRTS samples. After defining the target population, the GRTS model will be used to select approximately 20 permanent sites and 90 rotating sites, which will allow three rotating sets of 30 sites each. The specific number of sites may be adjusted upward or downward in order to meet the statistical goals for this status and trend monitoring.

E.1.2 Data Types and Indicators

Table E.1 lists data types and indicators for small streams regional monitoring, along with corresponding monitoring frequencies. The rationale for selecting each indicator is identified below.

Biological Parameters

Benthic Macroinvertebrate Community Characterization and Index Scores:

- Integrates water quality and habitat impacts from stormwater over time (Karr 1998; Karr and Rossano 2001; Fore *et al*., 2001).

In situ Salmonid Embryo Toxicity Testing:

- Integrates water quality impacts from stormwater over time since tests are in site for several weeks

Water Quality Parameters

Total Suspended Solids (TSS):

- Pollutant of concern from a variety of land uses including residential development (Ecology 2005a)
- Key indicator used to measure the basic treatment effectiveness of a stormwater treatment technology
- Can reduce light penetration and lead to a smothering effect on fish spawning and benthic biota
- Associated with other pollutants that adsorb to particles such as nutrients, bacteria, metals, and organic compounds
- Inexpensive to monitor, minimal field and QA problems, reliable indicator

Total phosphorus (TP):

- Nutrients are a pollutant of concern from residential development (Ecology 2005a)
- High concentrations can lead to accelerated plant growth, algal blooms, low dissolved oxygen, decreases in aquatic diversity, and eutrophication in fresh water systems

Total nitrogen (TN):

- Nutrients are a pollutant of concern from residential development (Ecology 2005a)
- TN is a concern in Puget Sound, since nitrogen is typically the limiting nutrient in marine systems

Total and dissolved copper:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- Washington state has a surface water quality standard for dissolved copper (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

Total and dissolved zinc:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- Washington state has a surface water quality standard for dissolved zinc (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

Hardness:

- Required to calculate acute and chronic concentrations of dissolved copper and zinc

Temperature

- Key parameter affecting the health and survival of biological communities.

Total petroleum hydrocarbons (TPH):

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- TPH fractions, such as polycyclic aromatic hydrocarbons (PAHs), can accumulate in aquatic organisms and are known to be toxic at low concentrations
- TPH can persist in sediments for long periods, resulting in adverse impacts on benthic community diversity and abundance

Semi-Volatile Organic Compounds:

- A broad indicator of pollution from urban development
- PAHs are a more likely indicator of biological impacts than TPH measurements
- Commonly detected in Puget Sound sediments, with some monitoring stations observing increases in concentrations over recent years (Ecology 2005b)

Fecal Coliform Bacteria

- A common indicator of urban stormwater pollution or failing septic systems

OrganoPhosphorus Pesticides:

- Common class of pesticides identified in residential and agricultural runoff (Gilliom *et al*. 2007)

Sediment Quality Parameters

Semi-Volatile Organic Compounds:

- A broad indicator of pollution from urban development.
- Commonly detected in Puget Sound sediments, with some monitoring stations observing increases in concentrations over recent years (Ecology 2005b)

Heavy Metals (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Silver, and Zinc):

- A group of ecologically consequential heavy metals with defined sediment management standards in Washington

OrganoPhosphorus Pesticides:

- Common class of pesticides identified in residential and agricultural runoff (Gilliom *et al*. 2007)

Hydrologic Parameters

Continuous Water Level and Flow:

- Useful for interpretation of concentrations observed in sequential samples taken during storm events
- Required for analysis of loading rates and unit area loading rates
- Useful for interpretation of interannual variability in concentrations
- Can be combined with frequent sequential sample concentrations to statistically model flow effects on concentration and improve loading estimates

Physical Habitat Parameters

% Substrate by size

- Useful for assessing sedimentation or channel scour

Embeddedness

- Useful for assessing sedimentation

Bed Stability

- Useful for assessing channel scour

Bank Instability

- Useful for assessing channel scour

Table E.1. Monitored indicators of stormwater effects on small streams and corresponding monitoring frequencies

Indicators	Monitoring Stations	Monitoring Frequency	Target Number of Samples per Station
Biological Indicators			
Community characterization and index scores	All sites	Annual sampling	One per year
In-situ salmonid embryo testing	All sites	Fall and spring sampling during wet weather	Two samples per site per year
Water Quality Indicators			
Total suspended solids	Permanent Sites Only	4 base flow grab samples and 8 targeted storm samples per year. 6 time-paced sequential grab samples collected during each storm	52 samples per site per year
Total phosphorus			
Total nitrogen			
Copper, total and dissolved			
Zinc, total and dissolved			
Hardness			
Total petroleum hydrocarbons			
Fecal coliform bacteria		4 base flow grab samples and 8 targeted storm flow grab samples	12 per site per year
Semi-Volatile Organic Compounds			
Organophosphorus Pesticides			
Temperature		Continuous	>105,100/year

Sediment Quality Indicators			
Semi-Volatile Organic Compounds	All sites	Annual Sampling	One per year
Heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc)			
Organophosphorus Pesticides			
Hydrologic Indicators			
Water level	Permanent Sites Only	Continuous, with 5-minute logging interval	>105,100/year
Water flow			
Physical Habitat Indicators			
% Substrate by size	All sites	Annual Sampling	One per year
Embeddedness			
Bed Stability			
Bank instabiltiy			

E.1.3 Sampling Procedures

Water quality samples will be collected during base and storm flow and analyzed for the chemical indicators identified in Table E.1. Samples collected during base flow will consist of single grab samples that are collected at the permanent monitoring sites after a suitable antecedent dry period. Samples collected during storm flow will consist of time-paced sequential grabs that are collected at the permanent monitoring sites using automated samplers. Each automated sampler will collect six separate samples over the course of discrete storm events. These samples will be analyzed separately in order to evaluate variations in pollutant concentrations over different portions of the hydrograph (*e.g.*, rising limb versus falling limb). The resultant data will also be used to develop regression equations for predicting pollutant loads as a function of discharge (see Data Analysis Procedures).

Grab samples will also be collected during base and storm flow and analyzed for the following parameters: fecal coliform bacteria, total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, Diazinon, and Chlorpyrifos.

To facilitate monitoring for the hydrologic indicators indentified in Table E.1, automated equipment will be installed in connection with each permanent monitoring site. It is anticipated that this will include at a minimum a water level sensor (*e.g.*, pressure transducer), rain gauge, and data logger. Water level measurements at each station will be converted to estimates of discharge using a control structure (for outfall stations) or rating curve (for stream stations). This equipment will be used to continuously monitor precipitation and discharge at each station with a five-minute logging interval.

Benthic marcoinvertebrate samples will be collected at the permanent and rotating monitoring sites in the late summer or early fall (August through October). Sampling within this time window is intended to provide adequate time for the instream environment to stabilize following natural disturbances (*e.g.*, spring floods). In addition, representation of benthic macroinvertebrate species typically reaches a maximum during this period. The actual procedures used for benthic macroinvertebrate collection, processing, and analysis will follow Washington State Department of Ecology protocols for instream biological assessment (Publication #94-113).

Sediment sampling procedures at each permanent and rotating site will be adopted from procedures developed for King County's stream sediment monitoring program. Because contaminants are more likely to be concentrated in sediments typified by fine particles and high organic matter content, sampling locations will be selected where fines are present. If no such locations are found, a location with the smallest grain size observed will be sampled. Samples will be collected using a pre-cleaned PVC core tubes to penetrate to a depth of five to ten centimeters. The sediment in the tube will then be transferred to a compositing container. This process will then be repeated a minimum of five times to acquire the appropriate volume of material for the analyses specified in Table E.1. Sediment samples will be sieved prior to analysis to normalize concentrations for grain size. Grain size will also be measured in the composite sediment samples as an additional explanatory variable.

Sampling procedures for physical habitat indicators (% substrate by size, embeddedness, bed stability, bank instability) will be adopted from WHSRST monitoring program (Ecology 2006).

E.1.4 Sampling Frequency

Water quality sampling will be conducted at the permanent sites during four base flow and eight storm events using the procedures described above. Water level, flow, and temperature at the permanent sites will also be logged at a 5-minute interval for better characterization of peak flows.

Sampling for macroinvertebrates, sediment quality, and all physical habitat indicators at both the permanent and rotating sites will occur annually. This recommendation is based on the fact that these metrics integrate inputs that occur throughout the year.

Finally, *in-situ* toxicity testing will occur twice annually in the spring and fall during wet weather periods.

E.1.5 Expected Outcomes

The expected outcome from the small stream status-and-trends monitoring is a robust data set for assessing long-term trends in small streams from stormwater runoff with a defined level statistical certaining (*i.e.*, 80 percent confidence and a statistical power of 0.8).

The collected data will support other regulatory drivers for water quality improvement such as the 303(d) listing and de-listing processes and TMDL implementation.

These data will also be useful for a number of investigations of stormwater and other land use effects on water and sediment quality, stream biotic integrity, and toxicity. For example, collecting sequential water quality samples during storm events is uncommon: most sampling programs have focused on measuring event mean concentrations, valus which are not directly related to the concentrations stream biota experience during storms. The collection of water quality, sediment quality, toxicity, macroinvertebrate community, and physical variables at common locations will a also support a multi-disciplinary analysis of stormwater impacts. For example, water and/or sediment quality data could be analyzed to investigate why benthic index of biotic integrity (B-IBI) scores or toxicity results vary across the landscape.

Continuous flow and water quality data collected at the permanent sites, can also be used to calibrate coupled hydrologic and water quality models of runoff and pollutant generation. These models could be used to model pollutant loading rates at unmonitored locations or pollutant source control scenarios for the monitored watersheds.

Specific recommendations for analysis of the data will need to be carefully described and coordinated in the implementation plan for this strategy.

E.2 Nearshore Status-and-Trends Monitoring

The proposed priority hypotheses articulated in Section 2.6.1 for status-and-trends monitoring in the nearshore are:

3. Resident fish in nearshore areas show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.
4. Forage fish in nearshore areas show improving population health over time throughout the Puget Sound region in concert with increased and improved stormwater management efforts.

Nearshore areas are the aquatic interface between fresh and marine waters. It is generally considered to include the areas commonly known as shore, beach, intertidal and subtidal zones to a depth of about 10 meters relative to Mean Lower Low Water (average depth limit of photic zone). Due to the variations in physical processes such as wave, wind, and sediment transport, the nearshore zone supports a wide diversity of habitats and is considered the “nursery zone” of Puget Sound. Examining the nearshore marine area is a critical component of status-and-trends monitoring for ecological health. In addition, the nearshore area is directly associated with human health concerns since many of the fish and shellfish we consume are harvested from this part of the ecosystem and because our recreational activities are also concentrated in the nearshore zone.

E.2.1 Site Selection

Similar to the small streams strategy, a random approach will be used to select a fairly large number of sites that are spatially distributed across the Puget Sound. Approximately 10 percent of the stations will be identified as permanent sites and the remainder will be rotating sites. The permanent sites will be continually and consistently monitored, while the rotating sites will be monitored for two consecutive years out of every six years. This approach provides the benefits of consistent long term monitoring at some sites, while also allowing for many more sites and more spatial coverage through the system of rotating sites.

E.2.2 Data Types and Indicators

Table E.2 lists indicators that have been selected for monitoring in the nearshore marine area and a general summary of the monitoring approach that will be applied for each of the indicators selected. The indicators focus largely on toxic contaminants. The rationale for selecting each indicator is identified below.

Biological Parameters

Marine Benthic Invertebrate Characterization and Index Scores:

- Integrates water quality and habitat impacts over time and therefore of cumulative impacts.

Contaminant Levels in Mussel, Herring, and Liver Tissue of English Sole

- Indicator of contaminant bioaccumulation in shellfish, forage fish, and resident fish.

Toxicopathic Liver Lesions in English Sole

- General indicator of contaminant-related resident fish health

Water Quality Parameters

Fecal Coliform Bacteria

- A common indicator of urban stormwater pollution or failing septic systems
- Critical to shellfish and recreation industry
- Closely tied to watershed development impacts

Sediment Quality Parameters

Metals (arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc):

- All metals are specified in the State sediment management standards (WAC 173-204)
- Includes pollutants of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- Heavy metals contribute to toxic effects on aquatic life and impact the beneficial uses of a water body

Semivolatile Organic Compounds (SVOCs, includes polycyclic aromatic hydrocarbons, phthalates, chlorinated hydrocarbons, phenols, and miscellaneous organic compounds):

- Includes all organic compounds (except PCBs) that are specified in the State sediment management standards (WAC 173-204)
- Polycyclic aromatic hydrocarbons (PAHs) are pollutants of concern from a variety of urban land uses including residential collector streets
- Commonly detected in Puget Sound sediments, with some monitoring stations observing increases in PAH concentrations over recent years (Ecology 2005b)
- Semivolatile organic compounds contribute to toxic effects on aquatic life and impact the beneficial uses of a water body

<u>Organophosphorus Pesticides (diazinon, chlorpyrifos, and others):</u>

- Organophosphorus pesticides comprise approximately 70 percent of the insecticides in current use in the United States
- Includes organophosphate pesticides commonly identified in residential and agricultural runoff (Gilliom *et al*. 2007)

<u>Grain size and Total Organic Carbon</u>

- Required for data interpretation

Table E.2. Monitored indicators of stormwater effects on nearshore marine areas and corresponding monitoring frequencies.

Indicator	Matrix	Monitoring Stations	Monitoring Frequency	Target Number of Samples per Station
Fecal Coliform Bacteria	Water	All Sites	Monthly	12 per site per year
Heavy Metals [1]	Sediment	All Sites	Annual	One per year
Semivolatile Organic Compounds[2]	Sediment	All Sites	Annual	One per year
Organophosphorus Pesticides[3]	Sediment	All Sites	Annual	One per year
Total Organic Carbon	Sediment	All Sites	Annual	One per year
Grain Size	Sediment	All Sites	Annual	One per year
Marine Benthic Invertebrate	Biological	All Sites	Annual	One per year
Contaminant levels in Mussels, English Sole, and Herring	Biological	All Sites	Annual	One per year
Toxicopathic Liver Lesions in English Sole	Biological	All Sites	Annual	One per year

1 - Heavy Metals specified in the State sediment management standards (WAC 173-204) include arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc.
2 – Semivolatile organic compounds include polycyclic aromatic hydrocarbons, phthalates, chlorinated hydrocarbons, phenols, and miscellaneous organic compounds.
3 – Organophosphorus Pesticides include diazinon, chlorpyrifos, and others.

E.2.3 Sampling Procedures

Fecal coliform bacteria samples at each site will be collected as grab samples by submerging the sample bottle to a depth of 0.5 meters below the water surface (specific SOPs will be developed in the implementation plan for this strategy). Sediment sampling procedures at each site will follow procedures developed for the Puget Sound Assessment and Monitoring Program (PSAMP, Ecology 2007). Samples will be collected using a pre-cleaned stainless-steel sediment grab sampler (*e.g.*, VanVeen). The upper two centimeters of sediment will be transferred from the sampler to a compositing container. Additional grab samples may be needed to acquire the appropriate volume of material for the analyses specified in Table F2. Sediment samples from the nearshore marine sites will be sieved prior to analysis to normalize concentrations for grain size. Grain size will also be measured in the nearshore marine samples as an additional explanatory variable.

Marine benthic invertebrate sampling procedures at each site will follow procedures developed for PSAMP (Ecology 2008). Samples will be collected using a pre-cleaned stainless-steel sediment grab sampler (*e.g.*, VanVeen). Organisms will initially be sorted into the major phyla: Annelida, Arthropoda, Mollusca, Echinodermata, and other miscellaneous phyla. After sample preservation, identification and enumeration of sorted organisms will be performed to the lowest taxonomic level possible. Identifications will be checked against reference specimens in the Environmental Assessment Program Marine Monitoring Unit's Puget Sound Reference Collection, which is currently archived at Ecology Headquarters. English Sole sampling and tissue processing procedures at each site will follow those developed for PSAMP (Ecology 2006). Procedures for mussels and herring will be recommended in the implementation plan.

E.2.4 Sampling Frequency

Concerns about bacterial contamination extend across the entire year. While recreational area concerns are important during the summer months, shellfish area concerns are more significant during the winter months. Therefore, monthly fecal coliform bacteria monitoring year-round is proposed. However, the rest of the indicators are monitored as either sediment or benthic samples and can be collected on an annual basis.

E.2.5 Expected Outcomes

The sampling program outlined herein for nearshore marine areas will allow trends in pollutant loads to Puget Sound to be accurately tracked over time by looking at accumulation in sediments and the diversity and abundance of benthic macroinvertebrates. Fecal coliform bacteria monitoring will help to identify locations where shellfish and recreational restrictions may need to be imposed or relaxed.

Specific recommendations for analysis of the data will need to be carefully described and coordinated in the implementation plan for this strategy.

Appendix F EXAMPLE EFFECTIVENESS STUDY DESIGNS

These two designs for effectiveness studies are presented as examples of the types of effectiveness monitoring proposed in the strategy.

F.1 Effectiveness of Low-Impact Development in New Residential Areas

The proposed priority hypotheses articulated in Section 2.6.2 for testing the effectiveness of LID techniques to minimize impacts from new development are:

5. LID approach and techniques implemented as the primary/sole method of flow control in a new residential development not only meet Western Washington Stormwater Manual requirements for flow control but also a) maintain values of surface discharge volumes, durations, and peak flow rates observed in undisturbed Puget Sound lowland catchments of similar size and surficial geology; and b) achieve flow control performance superior to that measured on a similar size and type of project where ponds and/or vaults are used.
6. LID on infiltrative soils are more effective, and more cost-effective, at achieving measureable flow control and meeting flow control standards (relative to undeveloped conditions on the same soil) than LID on non-infiltrative soils.
7. LID techniques used for high-capacity roadways (*e.g.*, freeways) on favorable sites achieve water-quality and water-quantity of runoff superior to that provided by stormwater ponds and/or vaults, and groundwater quality is not measurably compromised.
8. Accumulation of metals in bioretention soils does not reach levels of concern after 10 years of use.

To test these hypotheses, at least six small-scale residential Low Impact Development (LID) projects (*i.e.*, 10 to 30 acres) will be constructed on undeveloped or minimally developed land within the drainage basins of 2nd or 3rd order streams and monitored to determine the effectiveness of LID as a stormwater management approach. LID stormwater treatment techniques for each project will be sized according to the appropriate flow control or water quality treatment requirements specified in the Stormwater Management Manual for Western Washington (or another Ecology-approved manual). Appendix III-C of the Stormwater Management Manual for Western Washington (Ecology 2005) provides limited guidance on modeling and design criteria for LID techniques. It is anticipated that these projects will employ one or more of the following LID treatment techniques: permeable pavement, bioretention areas (rain gardens), rainwater harvesting, and vegetated roofs.

To evaluate site specific influences on the performance of LID treatment techniques, site selection for these LID monitoring projects will take into account the predominate soil types in the Puget Sound region. Specifically, a minimum of three projects will be constructed on tills (class C) soils with relatively low permeability to represent a worst-case scenario for LID treatment performance. At least three projects will also be constructed on outwash (class A/B) soils with high permeability to represent a best-case scenario.

Following construction and a suitable period for site stabilization and vegetation establishment within the LID features, monitoring stations will be established in connection with each LID monitoring project at the following locations:

Outfall Stations: These stations will be established at all major stormwater outfalls from the project site to the stream.

Background Receiving Water Stations: These stations will be established within the stream at a location upstream of all stormwater outfalls from the project site, but downstream of outfalls for unrelated projects and/or known pollutant inputs. To the extent possible, these stations will also be established at locations that will not be influenced by shallow groundwater from the project site.

Downstream Receiving Water Stations: These stations will be established within the stream at a location downstream of all stormwater outfalls from the project site, but upstream of outfalls for unrelated projects and/or known pollutant inputs.

Figure F.1 shows an idealized layout for a LID monitoring project and location of each type of monitoring station described above.

In addition, groundwater monitoring stations will be established to intercept shallow groundwater flow immediately upgradient and downgradient of each project site. It is anticipated that between four and eight wells will be installed at each site for this purpose. Figure F.1 also shows the location of these monitoring stations within the idealized layout for a LID monitoring project. Groundwater will be monitored because of the concern that toxic chemicals will infiltrate the soil and create adverse impacts to groundwater quality in cases where standard LID techniques are used.

Monitoring will be performed in connection with each surface water and groundwater site to meet the following objectives:

- Determine if there are significant differences in water and sediment quality between the background and downstream receiving water stations due to stormwater discharges from the LID monitoring project.
- Determine if there are significant differences in hydrology between the background and downstream receiving water stations due to stormwater discharges from the LID monitoring project.
- Determine if there are significant differences in benthic macroinvertebrate community structure between the background and downstream receiving water stations due to stormwater discharges from the LID monitoring project.

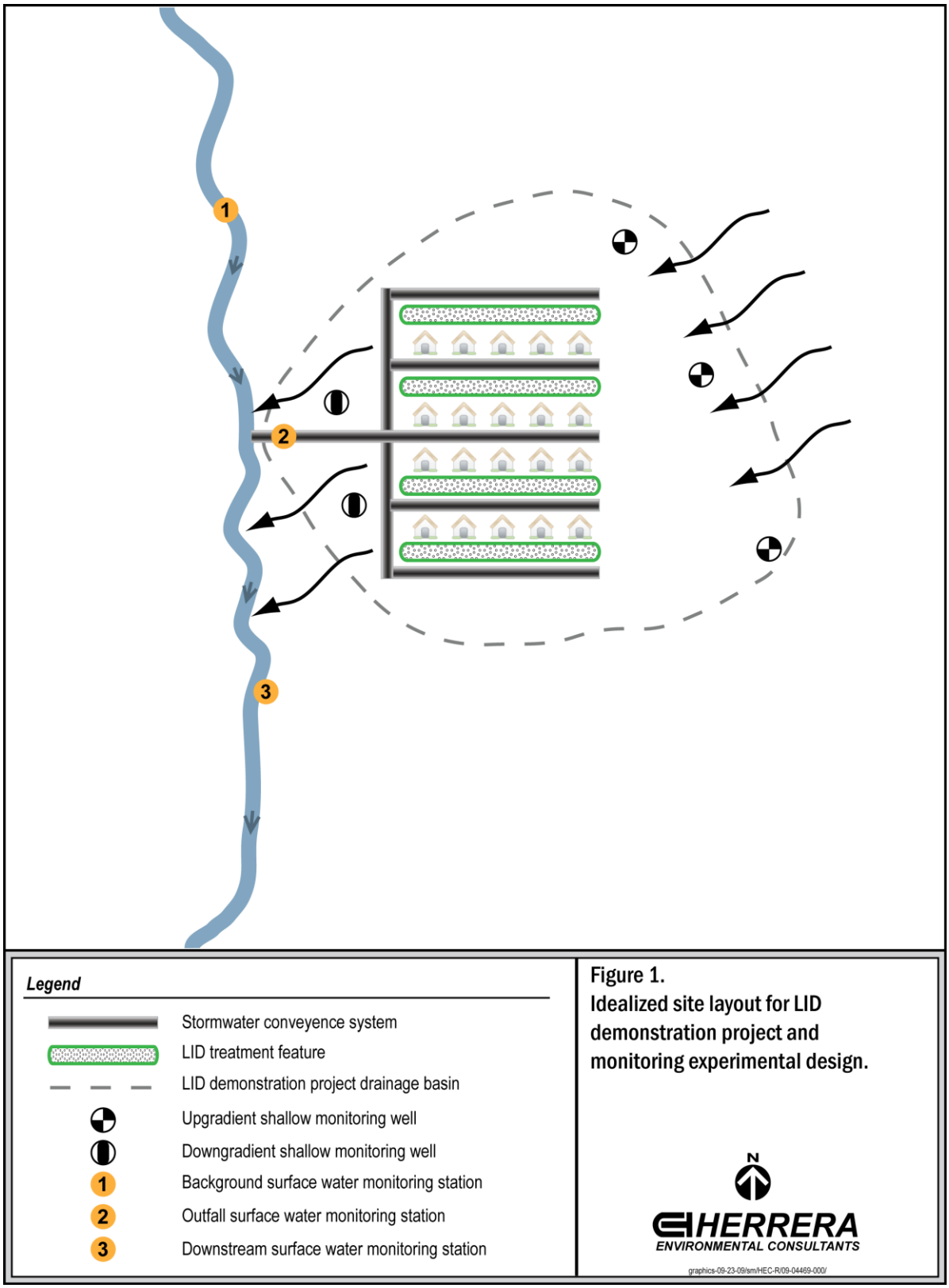

Figure F.1. Idealized site layout for LID demonstration project and monitoring experimental design.

- Determine if there are significant differences in toxicity between the background and downstream receiving water stations due to stormwater discharges from the LID monitoring project.

The following subsections provide more detailed information on specific elements of the experimental design for meeting these objectives.

F.1.1 Data Types and Indicators

A representative suite of indicators were selected for this monitoring to evaluate common impairments to beneficial uses in small streams and groundwater from residential stormwater. Included are indicators for water quality (*e.g.*; suspended sediment, heavy metals, nutrients, and petroleum hydrocarbons), hydrology, and biological integrity. The specific subsets of indicators will be used to evaluate impairment in surface and groundwater are identified in Tables F.1 and F.2, respectively. The rationale for each of the selected water quality parameters for surface water, groundwater, benthic invertebrate, and *in situ* salmonid embryo monitoring is provided below.

F.1.2 Surface Water Monitoring (Stormwater and Baseflow)

<u>Total suspended solids (TSS)</u>:

- Pollutant of concern from a variety of land uses including residential development (Ecology 2005)
- Key indicator used to measure the basic treatment effectiveness of a stormwater treatment technology
- Can reduce light penetration and lead to a smothering effect on fish spawning and benthic biota
- Associated with other pollutants that adsorb to particles such as nutrients, bacteria, metals, and organic compounds
- Inexpensive to monitor, minimal field and QA problems, reliable indicator

<u>Total phosphorus (TP)</u>:

- Nutrients are a pollutant of concern from residential development (Ecology 2005)
- High concentrations can lead to accelerated plant growth, algal blooms, low dissolved oxygen, decreases in aquatic diversity, and eutrophication in fresh water systems
- 31 lakes in the Puget Sound region are listed on Ecology's 303(d) list for TP under Category 5 (Polluted waters that require a TMDL)

<u>Total nitrogen (TN)</u>:

- Nutrients are a pollutant of concern from residential development (Ecology 2005)
- A concern in Puget Sound, since nitrogen is typically the limiting nutrient in marine systems

<u>Nitrate + nitrite nitrogen</u>:

- A concern in fresh water because it may contribute to an overabundant growth of aquatic plants and to a decline in diversity of the biological community

Table F.1. Data types and indicators for surface water monitoring stations to be established in conjunction with effectiveness monitoring hypotheses for LID in residential areas.

Indicators	Monitoring Stations	Monitoring Frequency	Monitoring Duration	Target Number of Samples per Station
Chemical Data				
Total suspended solids	1) Outfall stations 2) Background receiving water stations 3) Downstream receiving water stations	1) Monthly sampling during base flow; single grab sample collected during each event 2) Sampling during six storm events annually; up to eight timed-paced sequential samples collected during each event	Minimum of three years	36 base flow samples 144 storm flow samples 180 samples total
Total phosphorus				
Total nitrogen				
Nitrate + nitrite nitrogen				
Copper, total and dissolved				
Zinc, total and dissolved				
Hardness				
Total petroleum hydrocarbons				
Hydrologic Data				
Flow	1) Outfall stations 2) Background receiving water stations 3) Downstream receiving water stations	Continuous	Minimum of three years	NA

Precipitation	1) Outfall stations 2) Background receiving water stations 3) Downstream receiving water stations	Continuous	Minimum of three years	NA
Biological Data				
Benthic macroinvertebrates	1) Background receiving water stations 2) Downstream receiving water stations	Once annually	Minimum of five years	5 samples
In-situ salmonid embryo testing	1) Background receiving water stations 2) Downstream receiving water stations	Twice annually (spring and fall)	Minimum of five years	10 samples

Table F.2. Data types and indicators for groundwater water monitoring stations to be established in conjunction with effectiveness monitoring hypotheses for LID in residential areas.

Indicators	Monitoring Stations	Monitoring Frequency	Monitoring Duration	Target Number of Samples per Station
Chemical Data				
Nitrate + nitrite nitrogen	1).Upgradient monitoring wells 2) Downgradient monitoring wells	6 sampling events per year	Minimum of three years	18 samples
Ammonia nitrogen				
Copper, total and dissolved				
Zinc, total and dissolved				
Volatile Organic Compounds				
Hydrologic Data				
Groundwater elevation	1).Upgradient monitoring wells 2) Downgradient monitoring wells	Continuous	Minimum of three years	NA

Copper, total and dissolved:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)
- Washington state has a surface water quality standard for dissolved copper (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

Zinc, total and dissolved:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)
- Washington state has a surface water quality standard for dissolved zinc (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

Hardness:

- Contributes to toxicity of metals and required to calculate acute and chronic concentrations of dissolved copper and zinc

Total petroleum hydrocarbons (TPH):

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)
- TPH fractions, such as polycyclic aromatic hydrocarbons (PAHs), can accumulate in aquatic organisms and are known to be toxic at low concentrations
- TPH can persist in sediments for long periods, resulting in adverse impacts on benthic community diversity and abundance

Polycyclic aromatic hydrocarbons (PAH):

- Likely indicative of biological impacts

F.1.3 Sediment Monitoring

Semi-Volatile Organic Compounds:

- A broad indicator of pollution from urban development.
- Commonly detected in Puget Sound sediments, with some monitoring stations observing increases in concentrations over recent years (Ecology 2005b)

Heavy Metals (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Silver, and Zinc):

- A group of ecologically consequential heavy metals with defined sediment management standards in Washington

Organophosphorus Pesticides:

- Class of pesticides commonly identified in residential and agricultural runoff (Gilliom *et al*. 2007)

F.1.4 Groundwater Monitoring

Ammonia nitrogen:

- Potential toxicity to aquatic life in freshwater systems (toxicity increases when the pH or temperature of a water body decreases)

- Hatching, growth rate, and structural development of fish can all be affected by high levels of ammonia
- Human health can also be adversely affected by high levels of ammonia in aquatic systems

Nitrate + nitrite nitrogen:

- Washington state has a groundwater quality standard for nitrate+nitrite nitrogen (WAC 173-200-040)

Copper, total and dissolved:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)
- Washington state has a groundwater quality standard for total copper (WAC 173-200-040)
- Typically present primarily in the dissolved fraction in groundwater

Zinc, total and dissolved:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)
- Washington state has a groundwater quality standard for total zinc (WAC 173-200-040)
- Typically present primarily in the dissolved fraction in groundwater

Volatile Organic Compounds (VOCs):

- Generated from automobile use, lawnmower use, and pesticide/herbicide application in residential areas
- Most mobile fraction of organic compounds in groundwater
- Washington state has groundwater quality standards for several VOCs that are carcinogens (WAC 173-200-040)

F.1.5 Benthic Invertebrate Monitoring

- Integrates a number a habitat perturbations including channel modification and sediment loading
- Provides an overall assessment of whether beneficial uses are improving or declining

F.1.6 *In Situ* Salmonid Embryo Monitoring

- Reflects cumulative longer-term impacts of a variety of co-occurring contaminants

F.1.7 Monitoring Frequency and Duration

Water quality sampling will be performed at the background, downstream, and outfall monitoring stations during base and storm flow to obtain data for the chemical indicators identified in Table F.1. Sampling during base flow will be performed on a monthly basis whereas sampling during storm flow will occur during a minimum of six events annually. During the storm flow sampling, up to eight separate samples will be collected at each water quality monitoring station (see Section F.1.8 *Sampling Procedures*, below) and analyzed separately. This sampling will be performed over at least a three year period at

each LID monitoring project to account for climatic variability in the results. Based on this design, the target number of samples that will be collected in connection with each LID monitoring project is summarized in Table F.1.

Statistical power calculations determine the target number of samples to be collected. Based on an existing data set of concentrations at similar sites, the expected standard deviation of concentrations is used to determine the number of samples necessary to obtain a power of 90% when performing paired tests of differences between background and downstream or downgradient concentrations and loads. Prior transformation of data to normality is required in order to perform the calculations. In addition, nonparametric power calculations will be performed to directly estimate the numbers of samples required for the sign and/or signed-rank tests (see Section F.1.9 *Data Analysis Procedures*, below). These power calculations are described in Noether (1987). A power of 90% provides a 90% probability that a given difference in concentrations will be detected for the sample sizes obtained.

Sediment sampling for the chemical indicators identified in Table F.1 will be performed annually at the background, downstream, and outfall monitoring stations. This monitoring will be performed over at least a five year period at each LID monitoring project.

Hydrologic indicators identified in Table F.1 will be measured continuously at the background, downstream, and outfall monitoring stations stations using automated equipment (see Section F.1.8 *Sampling Procedures*, below). This monitoring will be performed over at least a three year period at each LID monitoring project.

Biological indicators identified in Table F.1 will be measured at the background and downstream, monitoring station on an annual basis. This monitoring will be performed over at least a five year period at each LID monitoring project. Based on this design, the target number of samples that will be collected in connection with each LID monitoring project is summarized in Table F.1.

Sampling for chemical indicators identified in Table F.2 will be performed six times annually (October through March) at each groundwater monitoring stations. This monitoring will be performed over at least a three year period at each LID project. Based on this design, the target number of samples that will be collected in connection with each LID monitoring project is summarized in Table F.1.

F.1.8 Sampling Procedures

Water quality samples will be collected during base and storm flow and analyzed for the chemical indicators identified in Table F.1. Samples collected during base flow will consist of single grab samples that are collected at each surface water quality monitoring station after a suitable antecedent dry period. Samples collected during storm flow will consist of time-paced sequential grabs that are collected at each surface water quality monitoring station using automated samplers. Each automated sampler will collect eight separate samples over the course of discrete storm events. These samples will be analyzed separately in order to evaluate variations in pollutant concentrations over different portions of the hydrograph (*e.g.*, rising limb versus falling limb). The resultant

data will also be used to develop regression equations for predicting pollutant loads as a function of discharge (see Section F.1.9 *Data Analysis Procedures*).

To facilitate monitoring for the hydrologic indicators indentified in Table F.1, automated equipment will be installed in connection with each surface water monitoring station. It is anticipated that this will include at a minimum a water level sensor (*e.g.*, pressure transducer), rain gauge, and data logger. Water level measurements at each station will be converted to estimates of discharge using a control structure (for outfall stations) or rating curve (for stream stations). This equipment will be used to continuously monitor precipitation and discharge at each station with a five-minute logging interval.

Sediment sampling procedures will be adopted from procedures developed for King County's stream sediment monitoring program. Because contaminants are more likely to be concentrated in fine sediments with high organic matter content, sampling locations will be selected where fines are present. If no such locations are found, a location with the smallest grain size observed will be sampled. Samples will be collected using a pre-cleaned PVC core tubes to penetrate to a depth of five to ten centimeters. The sediment in the tube will then be transferred to a compositing container. This process will then be repeated a minimum of five times to acquire the appropriate volume of material for the analyses specified in Table F.1. Sediment samples will be sieved prior to analysis to normalize concentrations for grain size. Grain size will also be measured in the composite sediment samples as an additional explanatory variable.

Benthic marcoinvertebrate samples will be collected at each surface water quality monitoring station in the late summer or early fall (August through October). Sampling within this time window is intended to provide adequate time for the instream environment to stabilize following natural disturbances (*e.g.*, spring floods). In addition, representation of benthic macroinvertebrate species typically reaches a maximum during this period. The actual procedures used for benthic macroinvertebrate collection, processing, and analysis will follow Washington State Department of Ecology protocols for instream biological assessment (Publication #94-113).

In situ salmonid embryo testing will be conducted at each surface water quality monitoring station in the spring and the fall. These two time windows cover the periods when salmonids typically spawn. The length of the testing period (from eyed eggs through swim-up fry stage) is dependent on temperature, but usually lasts for approximately three weeks, which should provide enough time for multiple storm exposures.

To facilitate monitoring for the groundwater indicators indentified in Table F.2, dedicated shallow monitoring wells will be installed in the upgradient and downgradient groundwater monitoring stations. Each well will be equipped with equipment to facilitate continuous monitoring of water elevations within each well and the collection of groundwater water samples.

F.1.9 Data Analysis Procedures

The following data analyses will be performed in conjunction with this monitoring to meet the monitoring objectives described above:

Loading Calculations: Samples collected during base and storm flow will be used to estimate continuous loadings at each surface water monitoring station for the water quality indicators identified in Table F.1. These loading estimates will be derived using a "rating curve" method, as described in Helsel and Hirch (2002). This method involves the development of regression equations to predict mean loadings for short periods of time as a function of discharge. These mean loadings are subsequently summed to estimate loadings over longer time periods. Because the regression equations are typically derived based on log transformed data, a nonparametric correction factor, or "smearing estimate", will be applied in these calculations to account for transformation bias in the results (Duan 1983). A regression approach to load estimation has been documented and used by many others, including evaluations by Cohn *et al*. (1992), Gilroy *et al*. (1990), and Cohn *et al*. (1989).

Statistical Comparisons of Loadings: Loadings for water quality indicators measured at the background and downstream surface water monitoring stations (Table F.1) will be compared to determine if there are significant differences due to stormwater discharges from the LID demonstration project. To perform these comparisons, monthly loading estimates for each water quality indicator will be calculated using the method described above. The monthly loading estimates for the background and downstream stations will then be paired and evaluated using a one-tailed non parametric matched pair test (*e.g.*, sign test or Wilcoxon signed rank test) to determine if there is a significant increase in loadings at the downstream station relative to the background station. In all cases, statistical significance will be evaluated based on a significance level (α) of 0.05.

Statistical Comparisons of Concentrations: Concentrations of water quality indicators (Table F.1) that are measured at the background and downstream surface water monitoring stations will also be compared to determine if there are significant differences due to stormwater discharges from the LID demonstration project. In addition, concentrations measured in the upgradient and downgradient monitoring wells will also be compared for the same purpose. Concentrations measured on the same date will be paired and then evaluated using a one-tailed non parametric matched pair test (*i.e.*, sign test or Wilcoxon signed rank test) to determine if there is a significant increase in concentration at the downstream station relative to the background station. In all cases, statistical significance will be evaluated based on a significance level (α) of 0.05.

Statistical Comparisons of Biological Data: Biological indicators that are measured at the background and downstream surface water monitoring stations (Table F.1) will also be compared to determine if there are significant differences due to stormwater discharges from the LID demonstration project. To perform these comparisons, data measured on the same year will be paired and then evaluated using a non parametric matched pair test (*i.e.*, sign test or Wilcoxon signed rank test) to determine if there are significant differences between the downstream and background stations. These tests will only be performed at the end of the monitoring program when sufficient quantities of data are available to make these comparisons. In all cases, statistical significance will be evaluated based on a significance level (α) of 0.10.

Analysis of Hydrologic Performance: The hydrologic performance of LID demonstration project will be assessed by comparing measured flows from outfall locations to modeled

outputs for the basin under historic forested conditions. The flows for forested conditions will be modeled in Hydrologic Simulation Program–FORTRAN (HSPF) or the Western Washington Hydrology Model, an HSPF derivative. If there is a gauged and undisturbed forested small watershed near any of the LID sites, the forested watershed could be used to calibrate the HSPF model for local conditions. If there is no suitable calibration watershed, regional parameters would have to be used for the forested conditions model. The peak flows, total volumes, and flow durations of modeled forest flows and measured LID flows will be compared to determine whether LID results in values for these parameters that are similar to the forested condition.

Comparison to Basic Treatment Water Quality Performance: To evaluate the water quality performance of the LID sites relative to basic treatment facilities, performance data will be obtained from the International Stormwater Best Management Practice database (ISBMPD) (ASCE 2009). Basic treatment facilities that will be evaluated include, but are not limited to the following: biofiltration systems (*e.g.*, grass strips and grass swales), media filters (*e.g.*, sand filters, peat mixed with sand, StormFilter), retention ponds (*e.g.*, surface wet ponds with a permanent pool), and retention underground vaults or pipes (*e.g.*, surface tanks with impervious liners).

F.1.10 Reporting Procedures

Results from each individual LID demonstration project should be summarized on an annual basis, with a final project report prepared upon cessation of all monitoring activities that integrates all the compiled monitoring data.

F.1.11 Expected Challenges and Outcomes

It is recognized that the primary challenge of this proposed monitoring will be the identification of suitable sites for the LID demonstration projects. To be successful, candidate demonstration projects for this monitoring will need to be identified early on the permitting process so that design modifications can be made, as necessary, to conform to this study design. Overcoming this challenge will likely require some type of partnership between regional monitoring authorities, local governments, and the home building business community. This partnership would work proactively to identify suitable sites and potentially enter into cost sharing arrangements to ensure the associated projects are constructed in a manner that will facilitate this monitoring.

The expected outcome of this project will be the acquisition of data on the aggregate benefits of LID treatment techniques for protecting beneficial uses in small streams. This is in contrast to plot scale studies that generally examine only the flow control and/or pollutant reduction potential of individual LID treatment techniques, without making any direct connection to actual receiving water conditions.

F.2 Effectiveness of a Pollutant Source Control Program at Industrial Sites

One of the proposed priority hypotheses articulated in Section 2.6.2 for testing the effectiveness of operational and programmatic approaches used in stormwater programs is:

15. Intensive pollutant source control programs at industrial sites achieve long-term reductions in pollutants and meet water quality standards at the point of discharge.

To test this hypothesis, water quality will be monitored in stormwater outfall pipes from industrial facilities. The monitoring design will evaluate the water quality benefits due to intensive implementation (*i.e.*, 6 or more) of the following recommended source control BMPs (Ecology 2008):

- Cover outdoor materials storage and handling areas
- Cover outdoor operations
- Cover galvanized surfaces to prevent exposure to water
- Load and unload bulk materials only at designated loading areas
- Replace galvanized items (*e.g.*, roofs, ductwork, turbines, equipment boxes, downspouts, gutters, light poles, bay doors, steps, etc.)
- Replace galvanized chain-link fences with aluminum chain-link fences on paved surfaces
- Paint galvanized surfaces as an alternative to replacing them
- Place chain-link fence on vegetated, not paved areas
- Use a vacuum sweeper to remove coarse and fine solid particles
- Use forklift tires made from non-rubber materials (*e.g.*, polyurethane)
- Do not use paints containing zinc oxide or zinc-rich paints intended to provide galvanic protection
- Do not use a moss remover containing zinc
- Avoid the application of fertilizers that contain zinc.

In order to evaluate the differences between intensive pollutant source control practices compared to standard source control practices at an industrial facility, two outfalls from the industrial facility will be evaluated. In the test basin, intensive pollutant source control practices will be implemented. In the control basin, minimal pollutant source control practices will be implemented. Monitoring stations will be established at the outfalls from each basin.

Figure F.2 shows an idealized layout for the industrial source control BMP study and provides the locations of each monitoring station.

Monitoring will be performed in connection with each study site to meet the following objectives:

- Indicate if the outfall is in compliance with state and federal water quality standards
- Indicate that the facility is in compliance with the General Industrial Stormwater Permit requirements

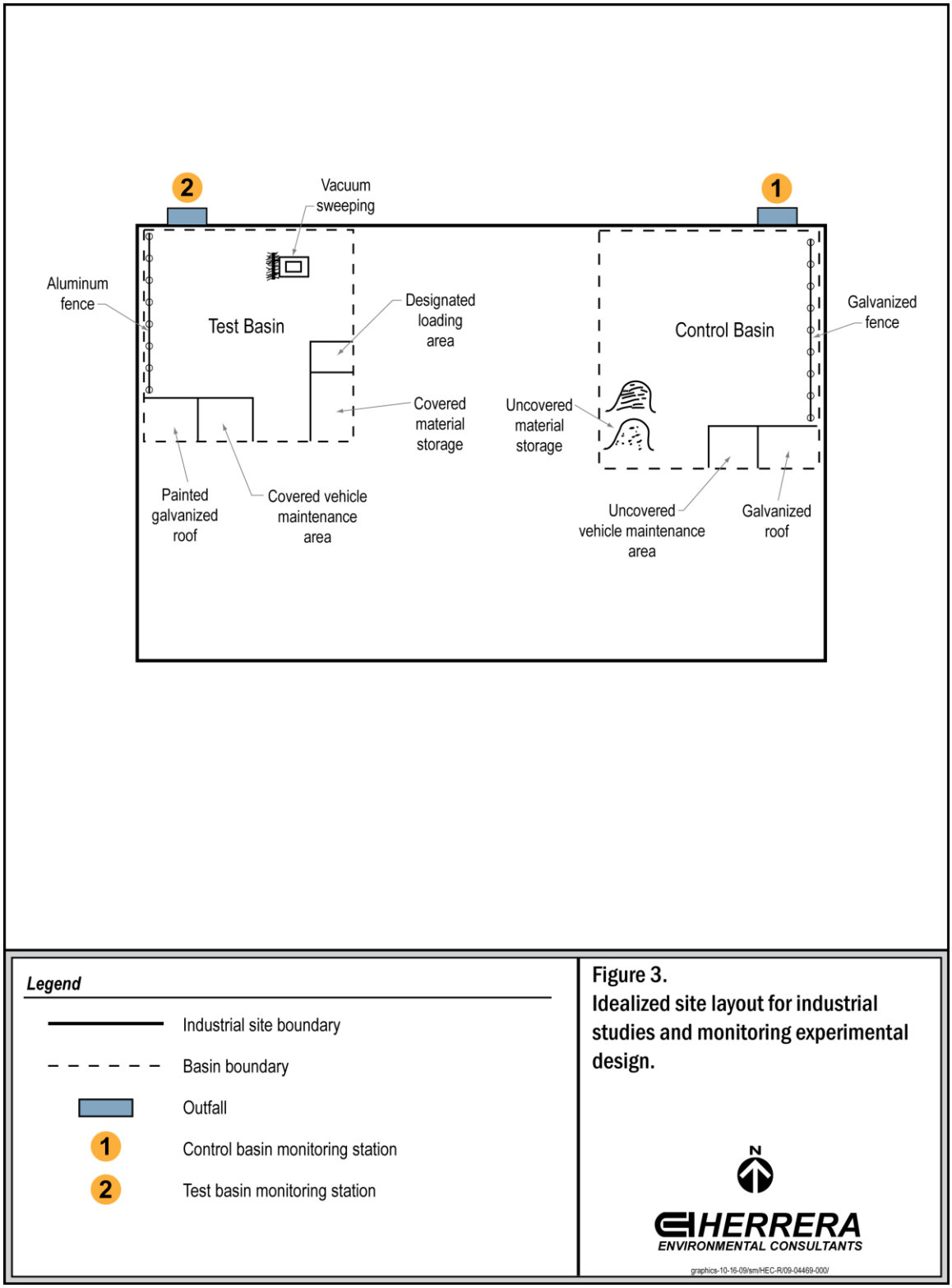

Figure F.2. Idealized site layout for industrial studies and monitoring experimental design.

- Determine the effectiveness of intensive source control BMP implementation on minimizing water quality impacts to waterbodies adjacent to industrial operations.

The following subsections provide more detailed information on specific elements of the experimental design for meeting these objectives.

F.2.1 Data Types and Indicators

A representative suite of indicators were selected for this monitoring to evaluate common impairments to beneficial uses in waterbodies from industrial operations. Included are indicators for water quality (*e.g.*, suspended sediment, metals, and petroleum hydrocarbons). The specific subsets of indicators will be used to evaluate impairment in surface water are identified in Table F.3. The rationale for each of the selected water quality parameters are provided below.

<u>Total suspended solids (TSS)</u>:

- Pollutant of concern from a variety of land uses including residential development (Ecology 2005a)
- Key indicator used to measure the basic treatment effectiveness of a stormwater treatment technology
- Can reduce light penetration and lead to a smothering effect on fish spawning and benthic biota
- Associated with other pollutants that adsorb to particles such as nutrients, bacteria, metals, and organic compounds
- Inexpensive to monitor, minimal field and QA problems, reliable indicator

<u>Copper, total and dissolved</u>:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- Washington state has a surface water quality standard for dissolved copper (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

<u>Zinc, total and dissolved</u>:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- Washington state has a surface water quality standard for dissolved zinc (WAC 173-201A-240) based on water hardness
- Heavy metals contribute to toxic effects on aquatic life (bioaccumulation in fish and shellfish) and impact the beneficial uses of a water body

<u>Hardness:</u>

- A factor in determining the toxicity of metals and required to calculate acute and chronic concentrations of dissolved copper and zinc

Table F.3. Data types and indicators for monitoring stations to be established in conjunction with this effectiveness monitoring hypothesis

Indicators	Monitoring Stations	Monitoring Frequency	Monitoring Duration	Target Number of Samples per Station
Chemical Data				
Total suspended solids	1) Control outfalls 2) Test outfalls	1) Monthly sampling during base flow; single grab sample collected during each event 2) Sampling during six storm events annually; one flow-weighted composite sample collected during each event	Minimum of three years	36 base flow samples 18 storm flow samples 54 samples total
Copper, total and dissolved				
Zinc, total and dissolved				
Hardness				
Total petroleum hydrocarbons				

Total petroleum hydrocarbons (TPH):

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005a)
- TPH fractions, such as polycyclic aromatic hydrocarbons (PAHs), can accumulate in aquatic organisms and are known to be toxic at low concentrations
- TPH can persist in sediments for long periods, resulting in adverse impacts on benthic community diversity and abundance

Polycyclic aromatic hydrocarbons (PAHs):

- A broad indicator of pollution from urban development
- Indicate likely biological impacts
- Commonly detected in Puget Sound sediments, with some monitoring stations observing increases in concentrations over recent years (Ecology 2005b)

F.2.2 Monitoring Frequency and Duration

Sampling will be performed at outfall monitoring stations during base and storm flow to obtain data for the chemical indicators identified in Table F.3. Sampling during base flow will be performed on a monthly basis whereas sampling during storm flow will occur during a minimum of six events annually. During the storm flow sampling, a single composite sample will be collected at each outfall monitoring station (see Section F.2.3 *Sampling Procedures*, below). This sampling will be performed over at least a three year period to account for climatic variability in the results. Based on this design,

the target number of samples that will be collected in connection with each outfall monitoring station is summarized in Table F.3.

Statistical power calculations determine the target number of samples to be collected. Based on an existing data set of concentrations at similar sites, the expected standard deviation of concentrations is used to determine the number of samples necessary to obtain a power of 90% when performing paired tests of differences between background and downstream or downgradient concentrations and loads. Prior transformation of data to normality is required in order to perform the calculations. In addition, nonparametric power calculations will be performed to directly estimate the numbers of samples required for the sign and/or signed-rank tests (see Data Analysis section below). These power calculations are described in Noether (1987). A power of 90% provides a 90% probability that a given difference in concentrations will be detected for the sample sizes obtained.

F.2.3 Sampling Procedures

Water quality samples will be collected during base and storm flow and analyzed for the chemical indicators identified in Table F.3. Samples collected during base flow will consist of single grab samples that are collected at each surface water quality monitoring station after a suitable antecedent dry period. Samples collected during storm flow will consist of flow-paced composite samples that are collected at each surface water quality monitoring station using automated samplers. Grab samples during storm events will also be collected for total petroleum hydrocarbons (TPH) and visual observations will be made for presence/absence of visible oil sheen.

F.2.4 Data Analysis Procedures

To meet the monitoring objectives described above, concentrations of water quality indicators (Table F.3) that are measured at the control and test monitoring stations will be compared to determine if there are significant differences due to implementation of intensive source control BMPs. Concentrations measured on the same date will be paired and then evaluated using a one-tailed non parametric matched pair test (*i.e.*, sign test or Wilcoxon signed rank test) to determine if there is a significant increase in concentration at the test station relative to the control station. In all cases, statistical significance will be evaluated based on a significance level (α) of 0.05.

F.2.5 Reporting Procedures

Results from this monitoring should be summarized on an annual basis, with a final project report prepared upon cessation of all monitoring activities that integrates and summarizes all compiled data.

F.2.6 Expected Challenges and Outcomes

It is recognized that the primary challenge of this proposed monitoring will be the identification of suitable sites for implementing the monitoring described herein. Overcoming this challenge will likely require some type of partnership between regional

monitoring authorities, local governments, and the business community. This partnership would work proactively to identify suitable sites and potentially enter into cost sharing arrangements for the required BMP installations.

The expected outcome of this project will be to determine the effectiveness of intensive source control BMP implementation on minimizing water quality impacts to waterbodies adjacent to industrial operations.

Dear Readers: Outfall monitoring can be expensive and difficult to implement. A proposal to substitute sampling street and surface dirt during dry conditions has been brought to our attention that appears to offer an easier and less costly approach (see *Minton_Research_R51Final.doc*, the second document posted at http://sites.google.com/site/pugetsoundstormwaterworkgroup/home/resources). Do you believe such an alternative approach could provide sufficiently reliable information to evaluate stormwater management practices? Which practices?