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For SWG discussion 9/29/09

A Stormwater Monitoring and Assessment Strategy for the Puget Sound Region

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How to Use this Document

This strategy document describes a framework for developing an integrated monitoring plan for stormwater in the Puget Sound region. An integrated plan means a diversity of people working together from a variety of perspectives, organizations and interests. As a consequence we expect the readers of this document to be diverse as well. A senior manager from the Department of Ecology might read to understand how this strategy informs NPDES permit requirements for stormwater. A resource manager from a county agency might read to discover which hypotheses their current programs already address. A representative from a business caucus might read to understand how we will test the effectiveness of new management actions.

Introductory sections connect this effort to related efforts in the Puget Sound region. The next sections describe the scientific framework and the types of monitoring designs that can be used to answer questions about stormwater. The last sections are more explicit and describe how the specific hypotheses will be tested.

Executive Summary

<*This section will use plain language to summarize technical detail. Parallel construction with main document, i.e., could be a stand alone document; look at similar SCCWRP and SFEI documents*>

- Goals; i.e., how will this strategy benefit Puget Sound?
- Current Situation/Problem statement
- Need
- Solution (i.e., this document)

Introduction: Background, Context, and Purpose

Project Goals

<Tie this section back to earlier work of consortium>

- To protect and restore Puget Sound and the rivers and streams that feed it.
- Create an integrated monitoring and assessment strategy to evaluate the effects of stormwater on receiving waters in the Puget Sound basin and the efficacy of management actions to prevent, reduce, or mitigate those effects
- Within the context of CWA goals: "Protect and maintain the physical chemical and biological integrity of the Nation's waters." Emphasize biota endpoints.
- Describe the broad context for the strategy (permits + TMDLs + biota…)
- Protect beneficial/designated uses for Washington

Current Situation

A lot of good work has been done to test what's in the water and to measure the problems caused by stormwater. Information is collected in different ways and by many agencies but is not coordinated or shared in a way that helps us make good decisions about what actions are the most important to protect and restore Puget Sound. Highlight SOPs, data base work and needs. We have learned from other programs around the country and around Puget Sound. Anchoring our effort in an Adaptive Management Framework.

Need/Problem Statement

A better system to test stormwater and share results in a way that helps us make better decisions. Our job is to create that system.

Current permit requirements contested; timeline driven by permits, but intent and scope not limited to permit and regulatory context. Broader mandate of CWA and Puget Sound recovery efforts

<*Description of past efforts*>

Solution: Process and Steps to Achieve Our Goals

- Create Stormwater Work Group
- Create a charter
- Assessment questions vetted by experts and stakeholders
- Sprint workshop of technical experts to translate assessment questions into hypotheses
- Small team to develop this document
- Peer review by outside experts and stakeholders
- Role of the Stormwater Work Group

- The dynamic process of integration: Oscillation from the small to the large; dynamic tension between structure and initiative; dynamic tension between process and content
- Mandates from PSP and Ecology: Status and trends, effectiveness, characterization of pollutant loadings
- Mandates from our partners: transparency, inclusive, specific, connection to permit, connection to other efforts, "accountable, credible, and builds trust," effective use of resources

<*Tie to ecosystem monitoring program, other work groups*>

Connection to Other Efforts

<Table of crosswalk between steps of Adaptive Management, Open Source, and CWA>

<Near term actions, Action Agenda indicators>

<Toxics work, ESA, others?>

<Caucuses>

Products of this Process

- Assessment questions
- Sprint document of hypotheses
- This document
- Implementation strategy (to follow)
- 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

Connecting Goals to a Monitoring Plan: the Assessment Questions

Comment [dbb1]: Note that I have taken this entire shaded text into my sections—the AQ's, and leska's table that follows, are in appendices and referenced; the "connecting" discussion now represents the organizational framework of page 17-28. I hope I've done it justice, and if so I suggest that this text can be deleted here.

The Role of Assessment Questions in the Integrated Strategy

Why and how AQ's were developed

Types of Assessment Questions and Monitoring Approaches

How is the resource doing? *Status assessment*

Is the resource changing? *Trend monitoring*

What's causing the resource to change? *Diagnostic monitoring, source identification, stressor identification and characterization*

What can we do to reverse changes? And can we make a difference? *Effectiveness monitoring*

Priority Assessment Questions

Overarching questions answered in part by the following sets of high-priority 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?

Translating the AQ's into Hypotheses

Suggested hypotheses from the Sprint Workshops.

Group[1]	#	Type/ scale	AQ_short	Hypotheses	WB	Land
E	1	Effect.	What specific retrofits or restoration are most effective in reducing pollutants, restoring hydrology and habitat? What are limits to	Retrofited wet ponds (media filters and remove dead storage) will improve smolt prod	Streams	urban
				Retrofited wet ponds will mimic natural hydrology	Streams	urban
				Physical limits exist to retrofitting capability	Streams	urban
				Retrofits improve water quality	Streams	urban

			restoration	Retrofits BMPs in urban improves beneficial use	Streams	urban
E	2	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
E	3	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
I	4	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
I	5	Status &	*Where* does stormwater impact water	Food fish impacted by PCB	All	all
				Biota affected by changes in flow	Streams	all

		trends	resources? What are impacts to biota? Where should target protection?	regime		
				Rural streams easier to restore	Streams	Ag, forest .
				Fecal coliforms from pets and birds	Streams	urban
				Fine sediment harms biota	Streams, nearshor e	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, nearshor e	urban
I	6	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
C	7	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
C	8	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
C	9	Source ID	What proportions of pollutants from air deposition and transport, spills, erosion and	Atmospheric dep from urban brings contaminants	Streams	urban
				Concentrations of pollutants decrease with source control	All	all

			resuspension?	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
				PAHS, metals vary by season	All	all
				Load and concentration is higher in wet season	All	all
C	10	Source ID	What are the seasonal variations and long term trends in pollutant loads and what influences them?	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

This Effort is Anchored in Adaptive Management

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

Purpose of this document as an adaptive management tool

This document articulates a recommended strategy for stormwater monitoring across the Puget Sound region. It explicitly invokes 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. This principal has been articulated in a variety of past ecosystem monitoring efforts, both regionally and nationally, and they provide worthwhile lessons for the current strategy. We have used these lessons to craft a robust conceptual framework in which to identify significant ecosystem threats from stormwater runoff; to stratify the landscape into discrete categories of land use and receiving water; and to articulate credible, testable hypotheses that can guide future monitoring efforts. In a later section of this document, a subset of these hypotheses have been translated into concrete monitoring plans 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 strategy for stormwater monitoring that will allow otherwise independent efforts or whole programs to contribute to our greater understanding and evaluation of progress.

Role of Monitoring in Adaptive Management at a Regional Scale

Land and water resource management agencies routinely make decisions that affect natural processes and ecological functions. These decisions are often made using fundamental assumptions and expectations that are based on incomplete or poorly understood knowledge. While uncertainties are often acknowledged, few land and water-resource management decisions are evaluated in an organized way that provides key feedback about their effectiveness. 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 past and present 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.

ecent 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. This proposed stormwater monitoring and assessment strategy for the Puget Sound region attempts to use the lessons articulated from comparable programs to frame a scientifically credible and useful approach based on the tenants of adaptive management and hypothesis-testing.

What *is* adaptive management?

Adaptive management, as first outlined by Holling (1978) and later revised, renamed, and recast by others (e.g., Walters 1986; Lee 1999), is a strategy for overcoming uncertain ecological outcomes associated with land-use and natural resource management actions by treating management activities as experimental components within the larger framework 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. Examples of both successes and failures of this approach are offered below.

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 monitoring framework 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 framework must explicitly tie stated hypotheses to the key ecological questions (Figure 2). 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, we have the water quality indicator, and we have a target value to judge acceptability. But, until recently, we lacked a comprehensive monitoring design that provided a statistically valid program to characterize water quality across state waters. Existing designs have also failed to provide clear insights into the ultimate and proximate causes when water-quality criteria are exceeded. Thus the management objectives are stated, but the underlying assumptions and hypotheses are neither articulated nor systematically tested.

Wagner (2006) asserts that [stormwater] regulatory programs often fail because they are designed in ways that ignore 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.

While science can provide defensible and replicable insights regarding the ecological outcomes of management prescriptions, 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 spatial, temporal, and technological limitations of the scientific process (Van Cleave et al. 2004). This is an uncomfortable truth for agency managers and elected officials to acknowledge, and it commonly results funding decisions and public pronouncements using the "language" of science but not its substance. This document seeks to avoid such a bifurcated outcome.

What is *not* adaptive management?

In natural resource management, the following process traditionally dominates: (1) a problem is identified 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); (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. A problem is not the same as a well-defined key question, and management prescriptions are not hypotheses; thus the framework breaks down at an early point and the resulting process is destined to be 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.

What we've learned from other programs around the country and around Puget Sound

Monitoring examples from around the nation

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. We have grouped these examples 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.

1. Large-scale ecosystem programs

- Chesapeake Bay Program (CBP). This program was established in 1983 and has evolved as a voluntary partnership between states, local and inter-state advisory and steering committees, and the USEPA 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 regaled for its successful "vertical and horizontal coordination and integration" of science (Van Cleave et al. 2004) and its effectiveness at maintaining 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). This institute 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.

- Louisiana Coastal Area Ecosystem Restoration. Ecosystem restoration efforts in this region 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 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. This program establishes 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 present document, 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.

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). This program 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 suggests 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. This 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 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).

3. Ecologically-Based Monitoring Programs in the Puget Sound Region

- Cooperative Monitoring Evaluation and Research Committee (CMER). CMER 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 the first quarter of 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 this 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. The Puget Sound Nearshore Ecosystem Restoration Project is a partnership between the U.S. Army Corps of Engineers (Corps), state, local, and federal government organizations, tribes, industries, and environmental organizations. Its 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, the Puget Sound Nearshore Ecosystem Restoration Project has accomplished a considerable amount, 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.

The Nearshore Restoration Project 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 the Nearshore Partnership, 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 (CBP), the Comprehensive Everglades Restoration Plan (CERP), the California Bay-Delta Authority (CALFED), the Glen Canyon Adaptive Management Program (GCAMP), and the Louisiana Coastal Areas Ecosystem Restoration Program (LCA). Many of those findings are already included in the previous discussions. 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 Steering Committee and Management Committee. 2008. Keys to a Successful Monitoring Program: Lessons Learned by the Puget Sound Assessment and Monitoring Program).

This report's purpose is well-aligned with the intention of the present document's, 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) In keeping with the objective of the present document, that of providing a scientific framework for the stormwater monitoring program, the following subset of their recommendations are repeated 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

f. An adaptive management framework that targets restoration and conservation activities which improve environmental condition

The PSAMP program 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.

A summary of "lessons learned" from around the region, and around the nation

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.

An Adaptive Management Program for Stormwater Management in the Puget Sound Region

1. Why Monitor?

Monitoring is a presumptive element of most stormwater management programs. It can demonstrate compliance with regulations, it can identify sources of pollutants and characterize their effects in receiving waters, it can evaluate the effectiveness of stormwater control measures, and it can provide feedback to managers and the public about whether ecosystem improvements are occurring. 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). The adaptive management framework presented below does not purport to describe every such type of stormwater monitoring, because some have existing statutorily requirements and others are responding to very local or site-specific needs. Ideally, however, this framework should provide guidance on how even those proscribed or localized 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.

Comment [KD2]: This is a good reference point, I'd also like to see something here about a broader framework than the permits, i.e., the permits are a tool for implementation, they don't have to and ideally should not drive the strategy

The goal of this program is thus to guide, through existing and future monitoring programs, effective management of stormwater across the Puget Sound region. It will achieve this by addressing three broadly recognized needs: (1) guidance on the allocation of resources amongst different types of stormwater management practices in different locations across the landscape, (2) detailed feedback on the effectiveness of widely used practices, and (3) unbiased assessment of whether our actions are resulting in genuine progress towards regional conservation targets. This goal requires a robust scientific framework to ensure that the work does not duplicate past efforts (i.e., monitoring for outcomes that are already well known), nor target issues of secondary importance while those of known (or at least strongly suspected) major influence languish for lack of resources.

2. Conceptual Framework

The scientific framework for understanding 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, National Research Council 2009). They are summarized by the following cartoon (Figure 2), which characterizes the types of "threats" that should be considered, the pathways by which those threats are transmitted, and how the outcomes of our management efforts should be assessed.

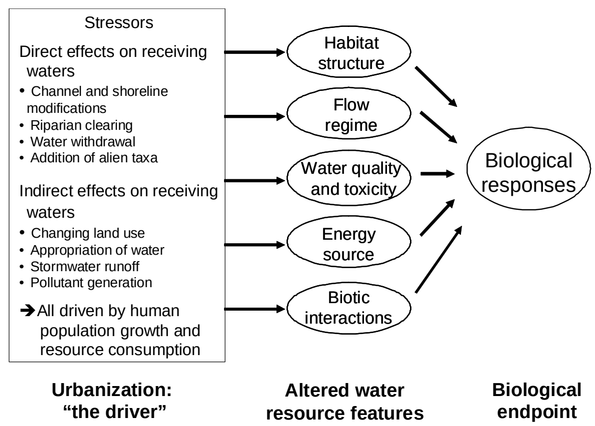

Figure 2. Conceptual model of the varied stressors resulting from human actions that alter biological conditions (modified from Booth et al. 2004 and Karr and Yoder 2004).

Management actions that seek to minimize or eliminate the effects of stormwater on downstream systems are addressing (whether knowingly or implicitly) the linkage(s) between urbanization 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 place(s) 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 their accuracy should be tested through monitoring and modified, if/as needed.

Similarly, 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 plan for Puget Sound's recovery; they would occupy the same conceptual position in this framework.

Within this broad conceptual framework, each element can be further deconstructed. "Urbanization" itself is multidimensional, and it has been defined in many different ways (McIntyre et al., 2000). It may constitute industrial, retail, or housing developments; 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. "Forestry" is not included in this discussion, not because it isn't also a land-use category but because the hydrologic response of a forested catchment does not typically include a significant component of what is commonly considered "stormwater."[1]

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.

Just as urbanization has multiple facets, so "water features" comprise a wide range 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 are divided 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 A).

Whereas Table A outlines the 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, it suggests some of the most pervasive impacts and most threatened resources, offering a framework in which to prioritize management (and monitoring) efforts. It also can readily admit new information or evaluation efforts as they emerge, even though there is no effort to include them all here.

Table A. A summary of the most common stormwater impacts to beneficial uses, categorized by receiving water and major land-use category (based on existing information, a presumed lower level of impact for a given combination of land use and receiving water is indicated by smaller font).

[1] From NRC (2009): "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…From a regulatory perspective, stormwater must pass through some sort of engineered conveyance, be it a gutter, a pipe, or a concrete canal." (p. 14) As with the NRC report, the attention of this document "…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 ('urban stormwater')."

	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	• contact recreation • eutrophication • benthic invertebrates	• toxics accumulation in food chain • contact recreation • eutrophication • benthic invertebrates • drinking water		
Groundwater	• drinking water	• drinking water	• drinking water	• drinking water
Wetlands	• physical habitat	• physical habitat	• physical habitat	• physical habitat

3. Planning a Stormwater Monitoring Program for the Puget Sound Region

3.1 Assessment Questions

In the first half of 2009, a series of meetings and workshops articulated a set of overarching "assessment questions" that reflect the collective judgment of what this monitoring program should answer. They are attached in full to the end of this document (<*Section xxx*>); in summary they are:

1. Where should the greatest attention be focused for managing stormwater?
2. What is the effectiveness of specific stormwater control measures, either individually or in combination? What is the most effective balance of stormwater-management efforts between areas of existing development and new development? Between programmatic and structural measures?
3. Are we making progress in protecting or improving beneficial uses and biological resources from the impacts of stormwater runoff?

The basic nature of these questions suggests that any scientific foundation for the region's stormwater management strategy continues to have significant uncertainty. Fortunately, both regional understanding and scientific literature suggest that we are not completely without prior guidance, or that existing efforts have been utterly misguided. Clearly articulating any continued uncertainties, however, should result in a much better targeted monitoring effort that provides genuine guidance for the region's stormwater management.

We acknowledge that those assessment questions in <Section xxx> that deal strictly with "characterization" of flows, pollutant loadings, and pollutant concentrations are not included in this synopsis. There may be particular site-specific regulatory or research-oriented reasons for pursuing such issues, but in general we consider characterization as an appropriate focus of an adaptive management program only to the extent that it supports specific hypotheses and can lead to tangible management actions. As such, it is incorporated into various other elements of this recommended strategy.

3.2 Translating Assessment Questions into Monitoring Categories

Answering these assessment questions requires interrelated categories of monitoring, a division that is commonly expressed by other ecosystem monitoring programs (see <*Section xxx*> for a more complete description of these categories):

1. <u>Source identification</u>, by which we mean the determination of what specific stressors (be they physical, chemical, or biological; see Figure 2), emanating from which element(s) of what specific land use(s), and affecting what specific types of receiving waters, are causing significant impacts (see Assessment Question #1, above);
2. <u>Effectiveness</u>, 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 (see AQ #2); and
3. <u>Status and trends</u>, by which we mean an integrative assessment of whether our "endpoint" indicators (biological or other) are showing any consistent, statistically significant change over time (see AQ #3).

In consort with the omission or reorganization of particular assessment questions in this framework, two of the five monitoring types listed at the beginning of this section are not included here, specifically the "identification of illicit discharges" and "characterization monitoring." The former is omitted because it is very site-specific, and the management response to any positive monitoring results is quite straightforward (i.e., stop the discharge). However, illicit-discharge monitoring could reasonably be included as part of an adaptive management framework if the accumulation of many such discharges was hypothesized to cause a regionally significant (and measureable) impact to receiving waters.

"Characterization monitoring" *per se* is not further considered on its own because, by definition, it has no basis in either hypothesis-testing or management adaptation. Of course, "characterizing" the condition of a waterbody or an outflow discharge at a particular time and place is the product of any kind of monitoring—but once a purpose for the data has been articulated then the activity transcends such a simple description. Until that time, however, the activity serves no articulated function and in fact the data may not be useful for any future (but as-yet unidentified) use. For this reason, this framework strongly discourages any "characterization" or "ambient" monitoring efforts that have no clearly articulated role in either hypothesis-testing or systematic trend evaluation. As noted by NRC (2009, p. 508), "…monitoring under all three [NPDES] stormwater permits [municipal, industrial, and construction] 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."

3.3 Applying Monitoring Categories to the Stormwater Management Landscape

As guiding hypotheses are developed, we suggest that they be aligned 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? We note that some aspects of the science of stormwater remain uncertain, and that monitoring could also help inform a research agenda to identify heretofore unrecognized stormwater impacts. This type of monitoring can have great value but is explicitly not included in the current strategy.

As with most other programs, these perspectives suggest multiple, nested scales of monitoring, and thus of the hypotheses that will guide their implementation. The finest scale is that of *source identification*: what parts of the landscape generate stormwater and their associated impacts, be they direct (i.e., chemical or physical) or indirect (i.e., biological and human health and well-being)? The existing science of stormwater provides much guidance (NRC 2009), and it suggests particular focus in all land uses on areas of well-connected impervious area (NRC 2009, p. 120, 231, 232), high vehicular traffic (NRC 2009, p. 232), and exposure to toxic chemicals (NRC 2009, p. 330). More specific contaminants associated with particular land uses (or specific high-risk activities within particular land uses), such as pesticides draining off of agricultural lands, are also recognized problems even if their contribution to stormwater impacts may primarily be local. Such concerns do not receive equal attention in this strategy document, but their inclusion in the recommended framework could readily occur at any future time.

The guidance from source identification in turn can inform a second (and also relatively site-specific) scale, 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, exactly this organizational approach ha been successfully taken by the Nationwide Stormwater Quality Database. It 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 final, and broadest, scale of monitoring is that of the integrated effect of stormwater impacts, and stormwater management, on receiving waters. This follows the second dimension of Table 1, recognizing that impacts will differ by waterbody but in all cases 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. As with the other scales of monitoring, however, the tremendous number of individual waterbodies in the Puget Sound region defies any strategy based on comprehensive sampling. In addition, the mere fact of collecting data does not require (and typically does not elicit) any management response. Thus an adaptive management framework is critical for this scale of monitoring as well.

3.4 Identifying Hypotheses for the Management (and Monitoring) of Stormwater

Key elements of any adaptive management strategy are the 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 framing them in this structure at all—they should already be incorporated into existing management programs.

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 framework must be that it is **actionable**—that different outcomes, as revealed by monitoring, will result in different management responses. If no difference occurs, then clearly there is no purpose to having made the effort in the first place.

Thus, we suggest that hypotheses used to guide the adaptive management strategy must be credible (though not already known with virtual certainty), testable, and actionable. These criteria are applied in the following section to develop an initial set of hypotheses for more rigorous development.

3.5 Narrowing the Universe (a): Selecting High-Priority Hypotheses for Implementing Source Identification and Effectiveness Monitoring

"Sources" could be investigated literally everywhere in the developed landscape; similarly, the "effectiveness" of every implemented stormwater control measure could be tested at every location at which it occurred. Clearly, this is neither feasible nor rational. Instead, we recommend a targeted, hypothesis-driven effort based on the extent and severity of impacts suggested by the last several decades of study in the Puget Sound region, on the assumption that focusing on likely problems and their solutions will achieve more direct benefits to the region than a thinly spread effort with insufficient resources to justify any change in management approach. We have begun this process through a largely unsorted list of hypotheses, grouped by their corresponding Assessment Question (<*Section xxx*>), that reflects broad input from the stormwater professionals of the region. They are tabulated in <*Section xxx*>. In total, they are probably not a tractable list of tasks, and they have not all been critically evaluated under the three criteria listed above. But they do provide a useful starting point for identifying the major concerns and needs of the region's stormwater community.

We suggest the following steps to narrow the list of hypotheses to identify some initial, high-priority monitoring efforts:

- Discriminate the list by land use (see Table 1), and focus on those land uses of greatest significance. *Residential* land use is suggested by the sheer area of the Puget Sound landscape that has been so affected and by the findings of a recent study on the sources of pollutants into Puget Sound (EnviroVision et al. 2008). *Industrial* land use is also indicated by virtue of the potential severity of acute impacts, particularly those unique to this land use (including the regulatory impact of NPDES industrial permits). Other land uses are certainly relevant and specific monitoring efforts could readily be developed within this overall framework, but they are not part of this recommendation for program initiation.
- Within these two focus land uses, target those hypotheses that address receiving-water impacts (Table 1) for which the nexus with stormwater effects is best established. *Small streams* (hereafter, "*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 other aquatic organisms. 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.

3.6 Narrowing the Universe(b): Selecting High-Priority Hypotheses for Implementing Status-and-Trends Monitoring

"Biological 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 of initial approach 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 (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 (e.g., <*Section xxx*>). 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. We have incorporated these issues into the list or recommendations that follows.

3.7 Towards a Set of Credible, Testable, and Actionable Hypotheses for Adaptive Management

With this guidance, a recommended set of hypotheses—the first of a prioritized, sequenced implementation plan to guide Puget Sound stormwater monitoring—is as follows. This is not meant to be an exhaustive list, but it does seek to conform to the principles and priorities outlined above. We note that the full implementation of even this limited list, however, might stretch the stormwater-monitoring resources of the region for some time to come.

SOURCE IDENTIFICATION

1. The impact of residential neighborhoods on small streams is most strongly determined by the fraction of connected impervious surface and is largely expressed through physical flow alterations rather than changes in water chemistry.
2. Toxic 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.
3. 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.

Comment [dbb3]: Note that with few exceptions, none of these hypotheses specifically call out their scientific underpinnings ("credible"), whether and how they could be tested ("testable"), and what management responses (including the appropriate administrative or regulatory mechanism) might be ("actionable"). THESE COULD BE ADDED (particularly the first, and a pointer for the third)--but not for this draft.

EFFECTIVENESS MONITORING

4. "LID" stormwater control measures 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 achieve a range of target values for ecohydrologic metrics (e.g., high-pulse counts, rate of change) that match the value of such parameters from undisturbed Puget Lowland catchments of similar size.
5. LID on infiltrative soils are more effective, and more cost-effective, at achieving measureable flow control (relative to undeveloped conditions on the same soil) than LID on non-infiltrative soils.
6. Infiltrative stormwater control measures for high-capacity roadways (e.g., freeways) on favorable sites achieve water-quality and water-quantity

performance superior to that provided by stormwater ponds and/or vaults, and groundwater quality is not measurably compromised.

7. Existing residential neighborhoods receiving intensive public educational outreach discharge significantly reduced levels of nutrients, fecal coliforms, and pesticides relative to what control and/or literature (or existing ambient) data would otherwise suggest.
8. Enhanced enforcement of "good-housekeeping" practices at industrial sites achieves significant reduction in pollutant releases.
9. Proprietary runoff-treatment systems achieve long-term reductions in pollutants commensurate with laboratory tests and presumptive regulatory performance.

STATUS AND TRENDS MONITORING

10. Proximal land use is the strongest determinant of shellfish bed closures, whether due to toxic accumulations or fecal coliforms.
11. Instream biological metrics (e.g., B-IBI) show statistically significant trends in streams draining established residential land-use areas in Phase I jurisdictions with established public education programs.
12. "Flagship species" with life histories closely tied to stormwater-affected systems (small streams, nearshore) show improving population trends in consort with increased stormwater-management efforts.

Type of Monitoring Questions

In keeping with the adaptive management framework that underlies this regional stormwater and assessment strategy, four distinct categories of monitoring will be performed to guide stormwater management efforts for Puget Sound; Effectiveness, Status and Trends, Source Identification, and Research. Each category and example hypotheses are described in the following subsections.

Articulate the connection from Sprint and Assessment Questions to hypotheses included in the strategy. Perhaps use Leska's document presented at 9/17 subgroup meeting.

Effectiveness Monitoring

The objective of this monitoring is to evaluate the effectiveness of specific management actions in reducing known stormwater impacts to beneficial uses in receiving waters. To be successful, effectiveness monitoring must be performed using clearly defined hypotheses that link the anticipated benefit from a management action to appropriate indicators for the stormwater impact. This monitoring must also be performed over a 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". The linkage to land uses is important because stormwater management actions are typically very different for different land use types. For example, a management action to mitigate stormwater impacts from residential land use would likely be inappropriate (or less effective) at mitigating stormwater impacts from agricultural land use. The linkage to outcomes is important because goals for stormwater management actions are typically different for new and existing land use. For example, the desired outcome for a management action that is applied to new land use would be to prevent any change relative to baseline conditions. In contrast, the desired outcome for a management action that is applied to existing land use would be to reduce existing stormwater impacts to the extent possible.

The ultimate goal of this monitoring will be to identify the most cost effective management actions for specific land use and outcome combinations. This information will then be used to inform decision making processes within the following frameworks:

- Regional stormwater management policy and strategies
- Municipal stormwater permit requirements
- State and local stormwater design manual guidance
- Local capital improvement project funding priorities

Through these initiatives, the management actions that are most effective will be broadly implemented over the coming years. Through time, the effectiveness of these management actions at a regional scale will be assessed via the status and trends monitoring program.

Specific hypotheses for stormwater management actions are presented in the following sections. The hypotheses have been selected to target different land use types including; existing residential development, new residential development, high density urban, agricultural area, industrial area and transportation networks. Each hypothesis section begins with a general overview of the experimental design that will be used to test the hypothesis. Separate subsections then provide more detailed information on the following elements of the experimental design:

- Data types and indicators
- Monitoring procedures
- Monitoring frequency and duration
- Data analysis procedures
- Reporting procedures
- Cost
- Expected challenges and outcomes.

Status and Trend Monitoring

This monitoring will be performed to meet the following objectives:

- Characterize existing conditions
- Detect changes and trends in key indicators for stormwater impacts over time

<*Highlight the long-term nature of this investment in monitoring*>

The ultimate goal of this monitoring is to determine whether the component efforts at stormwater management are actually achieving the desired level of resource protection. This monitoring is underlain by the fundamental hypothesis that our various management actions are “enough” to produce measurable ecosystem improvement (or avoid measurable ecosystem degradation). Because of the integrative level at which these measurements commonly occur and the complexity of the ecological system, it is rare that a direct diagnosis of cause-and-effect can occur from this level of monitoring alone. However, this monitoring will serve to identify broad trends in key indicators for stormwater impacts. This information will then be used within the overarching adaptive management framework to determine if existing management actions are ineffective or insufficiently implemented to produce a measureable response.

To be comprehensive the status and trend monitoring program must address all receiving waters; streams, rivers , lakes, groundwater, and marine (including marine nearshore). Furthermore, this monitoring must be implemented on regional scale to provide an integrated assessment of trends across multiple watershed and jurisdictional boundaries. Finally, the indicators for this monitoring must be carefully selected based on their sensitivity for detecting change in each respective type of receiving water.

Overarching Objective: Determine whether key ecosystem indicators are improving, or if we are preventing further degradation.

Objectives: Evaluate trends status and trends in small streams, lakes, and marine nearshore that receive stormwater, and in rivers, groundwater, and open marine areas

Example Ho's for small streams:

- Pollutant concentrations are no different during baseflow conditions than during storm events in urban catchments
- Pollutant loads/yield are no different during baseflow conditions than during storm events in urban catchments
- Hydrologic response to storm events is similar between streams draining urban catchments and those draining control areas
- Pollutant concentrations are no different during baseflow conditions than during storm events in agricultural catchments
- Pollutant concentrations/loads/yields/hydrologic metrics in 2020 are no different than during 2010 …

<Need a reference to Leska's table here – connection back to AQ's>

Research

<Articulate ongoing need to improve our understanding of how the ecosystem works and cause-effect relationships>

Source Identification Monitoring

<Link to current framework for diagnostic monitoring: municipal IDDE programs, 303(d) list and TMDLs, others>

<Consider recent work by Gary Minton>

Connecting Assessment Questions to Specific Hypotheses: the Scientific Framework

<Candidate headings to organize this section:>

- Categories of monitoring: Overarching (Status and Trend), Effectiveness, Characterization/Source ID, and Research
- Beneficial/Designated uses: aquatic life use, i.e., benthic invertebrates, shellfish, drinking water, toxics accumulation, acute toxicity, contact recreations, physical habitat, other water uses, e.g. industrial, agricultural, eutrophication, flooding and its prevention,
- 10 known impacts to beneficial uses: Aquatic life use support, Shellfish, Drinking water, Toxics accumulation, Acute toxicity, Contact recreation, Physical habitat, Other water uses, Eutrophication, Flooding and prevention
- Land use: Residential, Commercial, Industrial, Agricultural, Forestry, Transportation
- Purpose driven question headers

Description of Monitoring Plan for Priority Hypotheses

Describe overall experimental design framework to address the group's charge: impacts, effectiveness, and loads. *(Organize by one candidate heading above or some other depending on hypotheses)*

Connecting Hypotheses to Data Collection: the Experimental Design

Hypothesis to be Tested

Experimental Design

Section will provide a general narrative of experimental for testing the hypothesis (e.g.; paired watershed monitoring, long-term trend monitoring).

Data Types and Indicators

- Section will identify data types required to test hypothesis (e.g.; chemical, biological, GIS, survey/pole, model output).
- In selecting data types and indicators, the following factors may be considered:
- sensitivity
- repeatability
- relevance

- feasibility
- cost
- Where possible, recommendations will be provided for appropriate analytical methods and detection limits. These recommendations may be provided in a generalized form and referenced as appropriate for specific hypotheses.

Sampling Methods

- Section will identify sampling method required to test hypothesis (e.g.; grab versus flow-weighted composite, polling).

Sampling Frequency

- Section will provide recommendations for a sampling frequency required to test hypothesis. In selecting a sampling frequency, the following factors may be considered:
- Cost
- Anticipated uncertainty
- To guide decision making related to sampling frequency, generic power curves may be developed for representative parameters showing minimum detectable difference as function of sample size. Power curves would be generated based on compiled regional monitoring data.

Sampling Duration

- Section will identify a reasonable sampling duration to test hypothesis (e.g.; permanent, permanent rotating, permanent periodic, temporary, short-term).

Number Sampling Locations

- Section will identify a reasonable number sampling locations required to test hypothesis and describe possible strategy(s) or criteria to be used for their selection (e.g.; random, stratified random selection). However, it unlikely that specific sampling locations will be identified through this effort.

Data Analysis

- This section with provide recommendations for appropriate data analyses that could be used to test the hypothesis.

Reporting

- Section will identify the frequency and timing of reporting and the primary audience (public, policy-makers, regulated community, agencies).

Range of costs

- Section will presented planning level costs for required monitoring. Costs assumptions may be broken down as follows:
- Approximate cost per station or test area (w/ parameter assumptions)
- Approximate cost per event (w/station and parameter assumptions)
- As necessary, special considerations and/or assumptions for costs will be presented.

Anticipated results

Example experimental study design to test one hypothesis – for SWG discussion 9/29/09

Effectiveness Monitoring Hypothesis #1:

New residential developments that employ LID stormwater treatment techniques will have no significant impact on receiving water beneficial uses when compared to baseline (pre-developed) conditions.

To test this hypothesis, small-scale residential LID demonstration projects (i.e., 10 to 30 acres) will be constructed on undeveloped or minimally developed land within the drainage basins of 2^{nd} or 3^{rd} order streams. 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 demonstration 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 demonstration 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, surface water monitoring stations will be established in connection with each demonstration 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 1 shows an idealized layout for a LID demonstration 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 1 also shows the location of these monitoring stations within the idealized layout for a LID demonstration project.

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

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

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 1 and 2, respectively. The rationale for each of the selected water quality parameters for surface water, groundwater, benthic invertebrate, and *in situ* trout embryo monitoring is provided below.

Surface Water Monitoring (Stormwater and Baseflow)

Total suspended solids (TSS):

- 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
- Monitored as part of the existing National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit requirements (Ecology 2007)
- 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 2005)
- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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 Total Maximum Daily Load [TMDL])

Total nitrogen (TN):

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

Nitrate + nitrite nitrogen:

- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- Nitrate+nitrite nitrogen is 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

Copper, total and dissolved:

- Pollutant of concern from a variety of land uses including residential collector streets (Ecology 2005)

- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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)
- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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:

- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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)
- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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

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)
- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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)
- Monitored as part of the existing NPDES Phase I Municipal Stormwater Permit requirements
- 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)

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

In Situ Trout Embryo Monitoring

- Dissolved metals, primarily copper, can cause sublethal olfactory or behavioral impacts on salmonids
- Reflects cumulative longer-term impacts of a variety of co-occurring contaminants

Monitoring Frequency and Duration

Sampling will be performed at surface water monitoring stations during base and storm flow to obtain data for the chemical indicators identified in Table 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 monitoring procedures in next subsection) and analyzed separately. This sampling will be performed over at least a three year period at each LID demonstration 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 demonstration project is summarized in Table 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 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.

Hydrologic indicators identified in Table 1 will be measured continuously at surface water monitoring stations using automated equipment (see monitoring procedures in next subsection). This monitoring will be performed over at least a three year period at each LID demonstration project.

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

Sampling for chemical indicator identified in Table 2 will be performed on a monthly basis at each groundwater monitoring stations. This monitoring will be performed over at least a three year period at each LID demonstration project. Based on this design, the target number of samples that will be collected in connection with each LID demonstration project is summarized in Table 1.

Monitoring Procedures

Water quality samples will be collected during base and storm flow and analyzed for the chemical indicators identified in Table 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 Data Analysis Procedures).

To facilitate monitoring for the hydrologic indicators indentified in Table 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.

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 trout 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 2, dedicated shallow monitoring wells will be installed in the upgradient and downgradient groundwater monitoring stations. Each well will be equipped with an automated equipment to facilitate continuous monitoring of water elevations within each well. Dedicated sample tubing will also be installed in each well to facilitate the collection of monthly groundwater water samples using low flow procedures.

Data Analysis Procedures

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

<u>Loading Calculations</u>: 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 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).

<u>Statistical Comparisons of Loadings</u>: Loadings for water quality indicators measured at the background and downstream surface water monitoring stations (Table 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 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 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 forested condition.

Reporting Procedures

<To be developed.>

Cost

Table 3x provides planning level costs for effectiveness monitoring hypothesis #1.

Table 3x. Planning level cost estimate for effectiveness monitoring hypothesis #1.

Task	**Planning Level Cost**
1.0 – Equipment Purchase and Installation	$100,000-150,000
2.0 – Stormwater Monitoring	$160,000-200,000
3.0 – Baseflow Monitoring	$90,000-140,000

4.0 – Groundwater Monitoring	$80,000-120,000
5.0 – Benthic Macroinvertebrate Monitoring	$20,000
6.0 – *In Situ* Trout Embryo Testing	$160,000-200,000
7.0 – Flow Monitoring	$50,000
8.0 – Quality Assurance/Quality Control	$60,000-70,000
9.0 – Project Management	$30,000-50,000
Total Cost	**$750,000-$1,000,000**

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.

Table 1x. Data types and indicators for surface water monitoring stations to be established in conjunction with effectiveness monitoring hypothesis #1.

Indicators	Monitoring Stations	Monitoring Frequency	Monitoring Duration	Target Number of Samples per Station
Chemical Data				
Total suspended solids Total phosphorus Total nitrogen Nitrate + nitrite nitrogen Copper, total and dissolved Zinc, total and dissolved Total petroleum hydrocarbons	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
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 trout embryo testing	1) Background receiving water stations 2) Downstream receiving water stations	Once annually	Minimum of five years	5 samples

Table 2x. Data types and indicators for groundwater water monitoring stations to be established in conjunction with effectiveness monitoring hypothesis #1.

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	Monthly	Minimum of three years	36 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

Effectiveness Monitoring Hypothesis #2: (To be Developed)

Effectiveness Monitoring Hypothesis #3: (To be Developed)

Etc.

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Appendices:

Summary of knowledge and current efforts

<Literature review – purpose driven to answer question, what do we already know? Or could we do this as a group exercise or survey?>

Recommendations for Implementation Plan

Recommendations for data collection and data management

Related ongoing efforts

Sampling relevant to municipal and other permit requirements

Connect data needs to partners and describe how the data will be used