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Appendix A

Glossary

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Table A-1. Glossary of terms for Seattle's Science Framework.

Term or phrase	Definition	Additional explanation
2-year flow event (Q_2)	A flow event with a recurrence interval of two-years.	On average, a flow of this magnitude will be equaled or exceeded once within 2 years. Higher values are associated with increased urbanization.
Adaptive Management	A process for incorporating management actions into science-based experiments and changing those actions based on the results.	Adaptive management is a widely embraced concept, which allows one to make management decisions in the light of uncertainty, while ensuring that learning from those actions will aid future decisions (Ralph and Poole 2003).
Aquatic health toxicity	A proposed secondary indicator that would be measured by toxicity tests that has not yet been determined, and may be different for each stream.	
Bank armoring	Bank hardening, with materials such as riprap, bulkheads, and revetments.	Measures percent of bank hardened or "armored". Bank armoring limits sediment recruitment and floodplain connections, and is often associated with fill. There is no identified threshold at which bank armoring becomes more or less problematic. In Portland's urban areas, bank armoring reaches 40 to 60% (Gregory et al. 2002).
Base flow	The portion of streamflow which comes from groundwater (Wisconsin Department of Natural Resources 1995).	
Benthic Indicator of Biological Integrity (B-IBI)	An indicator of benthic invertebrate abundance and diversity.	B-IBI scores range from 10 to 50; 10–16 (very poor), 18–26 (poor), 28–36 (fair), 38–44 (good), >44 (excellent).
Benthic invertebrates	Organisms (also known as benthos) that live on the bottom of a water body or in the sediment and have no backbone (Maryland Department of Natural Resources 2004). Benthic invertebrates include crustaceans and aquatic insects.	"Unlike fish, benthos cannot move around much so they are less able to escape the effects of sediment and other pollutants that diminish water quality. Therefore, benthos can give us reliable information on stream and lake water quality. Their long life cycles allow studies conducted by aquatic ecologists to determine any decline in environmental quality. Benthos represents an extremely diverse group of aquatic animals, and the large number of species possess a wide range of responses to stressors such as organic pollutants, sediments, and toxicants." (Maryland Department of Natural Resources 2004)
Cobble	Substrate particles that are smaller than boulders and are generally 64–256 mm in diameter. Can be further classified as small and large cobble.	
Combined sewer overflows	A combination of untreated wastewater and stormwater that can flow into a waterway when a combined sewer system reaches its capacity.	Storm events can cause large volumes of street, building, and parking lot runoff to overwhelm the drainage system. In areas where the wastewater and drainage systems are combined, the increased volume of stormwater runoff can lead to an overflow.

Term or phrase	Definition	Additional explanation
Conceptual model	A representation of a system's components and the relationships among all components. "Conceptual" refers to the model's focus on qualitative information.	Conceptual representations are simplifications. They commonly take the form of flowcharts or tables and are generally not quantitatively interactive.
Current conditions	A set of circumstances that describes the system as it exists presently.	Current conditions have been quantified by numerous indicators and metrics for Seattle's five primary streams.
Ecological goal	The desired end point for ecological system conditions.	Ecosystem management establishes measurable goals that specify future processes and outcomes necessary for sustainability (Christensen et al. 1996). The Science Framework serves as a scientific tool for setting ecological goals in Seattle's streams.
Ecological health framework	A structure or outline that resource managers can use to better understand ecological information and processes, leading to well informed resource management decisions. The structure gives order to information such as ecological indicators, hypotheses, and expected outcomes from improvement projects.	"Ecological health" is defined as "the occurrence of certain attributes that are deemed to be present in a healthy, sustainable resource, and the absence of conditions that result from known stresses or problems affecting the resource" (Government of British Columbia 2001).
Ecologically healthy stream	A stream that exhibits the necessary ecological functions and features supporting diverse, native, self-sustaining aquatic and riparian communities.	Because one of the focus species is salmonids, an ecologically healthy stream also includes the necessary functions that support successful spawning, incubation and rearing habitat for native fish, such as salmon and trout, and support a productive benthic community.
Effectiveness monitoring	Monitoring that evaluates the outcomes of specific restoration activities.	The effectiveness monitoring program results from an adaptive management process undertaken for each stream. This type of monitoring can reveal insights into cause-and-effect relationships, and otherwise provide information on project outcomes. It is a critical component of the overall effort to track changes associated with deliberate actions taken by the City and other agencies, groups, or individuals. Without a carefully designed monitoring program that examines relevant indicators, we learn little from success (or failure) of stream improvement investments. Often used synonymously with "cause-and-effect" and "evaluation" monitoring.
Evaluation cycle	A four step process in which organizations can create, develop, implement, and evaluate programs and projects that seek to restore and/or improve natural resource systems.	In practice, the *Evaluation Cycle* is an iterative and cyclic process of application, learning, and refinement occurring over many years. In effect, it should become woven into the institutional culture responsible for implementing any program that purports to have an environmental objective in mind.
Indicator	The quantity that can be described or measured either numerically or qualitatively.	Synonym: metric.
Indicator threshold	A numeric value of an indicator above or below which ecological health would be impaired.	

Term or phrase	Definition	Additional explanation
Infiltration	Movement of water from the land surface into the soil.	
Interacting factors	Ecosystem components that cannot be controlled within the watershed, yet still affect the watershed ecosystem.	Examples of interacting factors would be global climate change, or commercial ocean fishing.
Interstitial spaces	Pore spaces in between streambed particles.	These pore spaces provide important habitat for benthic invertebrates and ensure successful fish egg incubation.
Hydro-geomorphic system	The collection of hydrologic and geomorphic processes that are manifested in watershed attributes.	
Hyporheic flow	Percolating flow that mixes shallow groundwater and surface water.	Hyporheic flow is a smaller component of the hydrologic cycle, but can be important in surface and groundwater quality.
Large woody debris (LWD)	Logs or trunks with root structures that fall into a stream and create habitat.	LWD is often limiting in urban streams because wood supply is low, and what wood arrives is often removed to convey runoff more quickly.
Nonpoint source pollution	Pollution originating from runoff from diffuse areas that have no well-defined source (Gilliam et al. 1997).	Antonym is point source pollution, which is water pollution that is discharged from a discrete location such as a pipe, tank, pit, or ditch.(Gilliam et al. 1997).
Past conditions (also known historical or pre-development conditions)	A set of circumstances that describes the system as it existed prior to European settlement.	That Native Americans effectively managed natural resources is recognized; past or pre-development conditions include the results of their resource management.
Physiography	Physical surface features.	
Plane-bed habitat	Habitats characterized by relatively featureless gravel/cobble bed that encompasses channel units often termed glides, riffles, and rapids (Montgomery and Buffington 1998).	
Properly functioning conditions	"Concept originally created by the Bureau of Land Management to assess the natural habitat-forming processes of riparian and wetland areas" (Pritchard et al. 1993 as cited in Snake River Salmon Recovery Board 2005).	"When these processes are working properly, it can be assumed that environmental conditions are suitable to support productive populations of native anadromous and resident fish species. The notion of Properly Functioning Conditions for salmonid systems has also been advanced by the National Marine Fisheries Service (1996) in connection with recovery of species listed under the Endangered Species Act." (Snake River Salmon Recovery Board 2005)
Residual pool depth	RPD is the maximum depth of water that remains in a pool with no outflow over the downstream lip.	It is measured to define whether the area can be classified as a pool; it varies with pool area. For example, a reach with a bank full width of 10 to 15 m, and a residual pool depth of 0.3 m, would be classified as a pool (Snohomish County Surface Water Management 2001).
River Invertebrate Prediction and Classification System (RIVPACS)	Predictive model using the ratio of the set of native taxa expected at a site that are actually observed, to the set of native taxa expected at a site in the absence of human-caused stresses (Hawkins and Hafele 2003).	A measure of biological integrity using benthic invertebrates, similar to B-IBI.

Term or phrase	Definition	Additional explanation
Signal-to-noise ratio	"A comparative index between the uncertainty of a model and the change effects of scenario calculations which enables the modeler to objectively decide about suitability of a model to be applied in scenario analysis studies." (Bormann 2005)	Concept used to assess the relative utility of an indicator. "Noise" is loosely interpreted to refer to the indicator's variability; if the "signal" is sufficiently higher than the noise, then the ratio can detect change. Useful in differentiating inherent variability from that associated with a specific management action.
Status and trends monitoring	Monitoring designed to establish current conditions and track changes over many years, and to assess the cumulative net result of multiple management actions.	
$T_{Q\ mean}$	The proportion of time in a given water year that the hydrograph (based on any time step, such as daily or hourly) was above the year's average flow-rate (Konrad and Booth 2002).	Measures the frequency of high flows or "flashiness". Higher values are associated with streams with sustained storm-flow periods and gradual flow recession rates. Lower values are associated with brief but high flow periods and rapid recession rates. $T_{Q\ mean}$ values decrease with increasing effective and total impervious area (Konrad and Booth 2002).
Urban constraints	A specific set of interacting factors that are caused by to urbanization.	Examples of urban constraints are major arterial roads that transverse through the watershed.
Watercourse	Channels which may contain reaches of natural stream, but may also include sections of culverts, pipes, or other artificial structures to enclose or contain flow (as opposed to streams which are natural, unobstructed channels for flow).	
Water Quality Index (WQI)	A numerical description of water quality that includes temperature, pH, fecal coliform bacteria, dissolved oxygen, and nutrients nitrogen and phosphorus.	Metric developed by the Washington Department of Ecology.
W/d ratio	The relation between the bankfull width and the mean bankfull depth of a stream.	Relative index of channel shape that in a relative way helps to categorize how entrenched (i.e., incised) a stream channel is, which can be altered by management activities. Channels with high W/d ratios are shallow and wide whereas channels with low W/d ratios are narrow and deep. Context is important to using this measure appropriately.
Water quality standards	"The foundation of the water quality-based pollution control program mandated by the Clean Water Act." (EPA 2006)	These standards "define the goals for a waterbody by designating its uses, setting criteria to protect those uses, and establishing provisions to protect waterbodies from pollutants" (EPA 2006).
Watershed management actions	Actions that can be taken by landowners, stewards, and land use managers to minimize the effects of urbanization or other land use practices on stream health.	

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Appendix B

Memo: Similar "Framework" Programs in Other Cities

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Stillwater Sciences

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MEMO

DATE: 12 January 2007

TO: Julie Hall

COMPANY: Seattle Public Utilities

FROM: Steve Ralph

SUBJECT: Similar "Framework" programs in other cities

This memo completes Task 2 (Contract No. R00-34-18-02), in which we contacted other municipalities and reviewed their approaches to aquatic resource protection and desired future conditions. The scope of Task 2 was (1) to identify at least two municipalities employing plans or studies with an aquatic resource conservation component, and (2) to identify their respective approaches, paying particular attention to the development of desired future conditions or similar means, that define existing conditions and desired conservation endpoints.

The objective of this report is to determine whether other cities, counties, or water districts have already developed similar programs. Assuming such programs are being developed, a secondary objective is to identify important characteristics of the programs, such as structure and form of governing agency or body, the types of restoration or preservation projects envisioned in the program, and the criteria for measuring "ecological health" and for determining the success of any restoration or preservation projects.

SPU staff supplied several related documents and provided leads for beginning this investigation. An online literature search was also performed by Stillwater Sciences staff. Many of the studies reviewed described a specific aspect of watershed assessment or restoration, such as effects of impervious surfaces, or effects of stormwater management. We eventually narrowed our focus to programs attempting comprehensive watershed planning and management, with planning that extends beyond project implementation and into project evaluation (adaptive management). To evaluate the success of projects, these cities or counties would have established criteria by which to judge success; identifying these criteria (also called indicators or metrics) was another objective in our literature review.

The literature search identified two definitive documents that were frequently cited, but were not area specific:

McCammon, B., J. Rector, and K. Gebhardt. 1998. A framework for analyzing the hydrologic condition of watersheds. BLM Technical Note 405. USDA Forest Service and USDI Bureau of Land Management.

TNC (The Nature Conservancy). 2000. The five-S framework for site conservation. A practitioner's handbook for site conservation planning and measuring conservation success. Second edition.

Of the municipalities reviewed, five examples of watershed assessment and/or restoration programs were selected to illustrate various characteristics and approaches for aquatic resource protection and desired future condition goals. The examples are from:

- Greensboro, North Carolina
- Olympia, Washington
- Portland, Oregon
- Santa Clara, California
- San Francisco Bay Region 2 of the California Regional Water Quality Control Board, California

These programs are described in Tables 1–5 below.

Table 1. Summary description of the Ecosystem Enhancement Program, in Greensboro, North Carolina (Watershed Needs Assessment Team 2003).

Program characteristic	Description
Reasons for implementing program	Part of a larger program to "provide compensatory mitigation for the NC Department of Transportation."
Form or structure of entities governing the program	A team called the Watershed Needs Assessment Team, comprised of state and federal agency professionals, was formed. A Memorandum of Understanding was signed by three partnering agencies (the NC Department of Transportation, the NC Department of Environment and Natural Resources, and the US Army Corps of Engineers).
Types of projects planned, implemented, or constructed	Specific projects were not yet planned. "This should be a comprehensive list not limited to stream and wetlands restoration that meets requirements for compensatory mitigation; it should be inclusive of actions that can be taken to preserve areas where assets are predominant as well as solve problems that were described." Identifying projects was to be part of a Phase II.
Criteria for "success" or program endpoints	The watershed assessment methodology included a Phase III component, characterized by the subheading "How You Get There." However, the document did not describe "how you would know if you arrived."
Indicators and/or measures for monitoring success	The use of structural and surrogate indicators[1] was recommended, due to limited time and other resources (both scientific and economic). Specific measures were only given for hydrologic assessment[2]; the measures for other assessments (for water quality, biological resources, etc.) were given a more general treatment.
References	Watershed Needs Assessment Team. 2003. Report from the Watershed Needs Assessment Team to the Mitigation Coordination Group. October http://www.nceep.net/news/reports/WNAT%20Mit%20Group%20Final.pdf

[1] "Indicators may be of several types:

- functional indicators that directly assess a particular watershed function or process;
- structural indicators that do not assess function directly, but measure ecological structural characteristics of the system that are known to be or assumed to be closely tied to a specific function;
- surrogate indicators that measure watershed characteristics that do not assess a specific function, but that are associated with a number of functions or with watershed functioning in general."

[2] "The WNAT concluded that most of the individual hydrologic functions it identified were closely interconnected. Team members believed that developing indicators for specific functions was not practical, especially for the type of assessment that was to be conducted (as opposed to longer term research studies). The team therefore recommends that hydrologic functioning be assessed by using surrogate indicators that view the extent that hydrologic modifications have occurred in a watershed. Potential indicators of hydrologic change include:

- Presence of drainage districts
- Flood prevention projects
- Channel and stream bank modification
- Land use
- Impervious surface extent
- Storm sewer mileage
- Floodplain encroachment
- Repetitively flooded structures
- Impoundments
- Withdrawals
- Floodplain disconnected from the creek
- Instream habitat surveys

The WNAT recommends that growth and development trends (zoning, population) also be considered in evaluating watershed hydrologic condition. These factors will be especially important in evaluating the likely extent of future hydrologic change."

Table 2. Summary description of the Storm and Surface Water Plan in Olympia, Washington (City of Olympia 2003).

Program characteristic	Description
Reasons for implementing program	There were three main reasons why the City of Olympia generated this plan: (1) to replace the outdated basin plans in use for the past decade, (2) to respond to new regulatory requirements, and (3) to incorporate current technologies.
Form or structure of entities governing the program	The Public Works Department's Leadership Team was in charge of directing Utility staff who worked with the Utility Advisory Committee to develop the plan as well as a new financial structure for the purpose of guiding future services and funding.
Types of projects planned, implemented, or constructed	The objectives for the Plan were to: • Provide a management vision and approach that reflects community expectations for the Storm and Surface Water Utility's future. • Refine the understanding of current and potential flooding, water quality, and aquatic habitat problems faced by the Utility. • Propose actions that will comply with regional, State, and federal requirements for storm and surface water management. • Define services for flooding, water quality, and aquatic habitat management. • Identify appropriate and cost-effective solutions for accomplishing preferred services. • Include a process that enables the Plan to be regularly reviewed and revised in order to adapt to emerging information, problems, and regulations. • Provide a basis to obtain adequate long-term funding for the Utility. • Provide ongoing opportunities for internal and external customers to learn about stormwater issues, to participate in identifying problems and

Program characteristic	Description
	solutions, and to influence the future of the Utility.
Criteria for "success" or program endpoints	This plan outlines the principles of adaptive management, which requires Utility to conduct routine review of effectiveness and course correction as needed. Annual reports on Utility performance will be distributed to the Olympia community and elected officials and will create opportunities for people to participate in the adaptive management process.
Indicators and/or measures for monitoring success	A thorough summary of basin traits for Olympia's streams as well as a limiting factors analysis for salmonids is provided; however, specific indicators for monitoring are not discussed in detail. Based on current data, several recommendations for site-specific improvements are provided to increase stream health. The plan suggests that by employing adaptive management, specific indicators for monitoring success will become apparent over time.
References	City of Olympia. 2003. City of Olympia storm and surface water plan. City of Olympia, Water Resources Program, Olympia, Washington. http://www.olympiawa.gov/cityutilities/stormwater/policies/#StormAndSurfaceWaterPlan

Table 3. Summary description of the Framework for Integrated Management of Watershed Health in Portland, Oregon (City of Portland 2005).

Program characteristic	Description
Reasons for implementing program	Part of the City of Portland's River Renaissance vision involves a community-wide effort to revitalize the Willamette River. In addition, this framework allows compliance with federal regulatory requirements (i.e., Chinook salmon and steelhead listed under the Federal ESA) and regional requirements (i.e., Titles 3 and 13 of Metro's Urban Growth Functional Management Plan).
Form or structure of entities governing the program	The Framework states that the City of Portland will be responsible for implementation and that there will be coordination among various City bureaus and programs, but does not specifically describe entities or programs to execute the plan.
Types of projects planned, implemented, or constructed	Specific projects not yet planned. This approach involves "working toward a single set of watershed health goals and values; coordinating work plans and timelines across City bureaus; using commonly agreed-upon information and methods; and prioritizing actions to maximize success." The four steps in the process include defining goals and key issues, characterizing current watershed conditions[1], defining protection and restoration measures, and monitoring measures through adaptive management.
Criteria for "success" or program endpoints	The Framework details watershed-specific objectives consisting of measurable desired outcomes that the City will work towards to attain the defined watershed health objectives[2]. Success is defined as "achieving objectives, benchmarks and targets, not simply implementing actions. The outcome of actions—that is, actual change in environmental conditions—is what ultimately counts."
Indicators and/or measures for monitoring success	A set of environmental indicators and target values or desired conditions for each objective[2] will be established. Benchmarks will be used to attain target values or desired conditions and will direct the prioritization and timing of actions taken. In addition, the Framework provides a means for adaptive management to adjust watershed activities over time.

Program characteristic	Description
References	City of Portland. 2005. Framework for integrated management of watershed health. Endangered Species Act Program, Portland, Oregon. http://www.portlandonline.com/fish/index.cfm?c=33528

[1] Watershed conditions will be based on the following attributes:

- **Hydrology:**
  - Hydrograph alteration
  - Floodplain presence and connectivity
  - Groundwater
- **Physical Habitat**
  - Floodplain quality and connectivity
  - Riparian condition: width, composition and fragmentation
  - Stream connectivity
  - Habitat types
  - Bank erosion
  - Channel substrate (fine/coarse)
  - Refugia (depth, boulders, undercut banks, wood)
  - Large wood
  - Terrestrial habitat
  - Wetland habitat
- **Water Quality**
  - Water temperature
  - Dissolved oxygen
  - Nutrients and chlorophyll *a*
  - Total suspended solids
  - Toxic contamination of water, sediments and biota
  - Groundwater quality
  - Other 303(d)-listed TMDL parameters
  - Other parameters (as determined by weight of evidence)
- **Biological Communities**
  - Biotic integrity
  - Benthic communities
  - Salmonid population structure (abundance, productivity, spatial structure, diversity
  - Riparian wildlife
  - Terrestrial wildlife
  - Plant communities

[2] The four objectives are as follows:

1. Hydrology: Move toward normative flow conditions to protect and improve watershed and stream health, channel functions, and public health and safety.
2. Physical Habitat: Protect, enhance and restore aquatic and terrestrial habitat conditions to support key ecological functions and improved productivity, diversity, capacity and distribution of native fish and wildlife populations and biological communities.
3. Water Quality: Protect and improve surface water and groundwater quality to protect public health and support native fish and wildlife populations and biological communities.
4. Biological Communities: Protect, enhance, manage and restore native aquatic and terrestrial species and biological communities to improve and maintain biodiversity in Portland's watersheds.

Table 4. Summary description of the Framework for Conducting Watershed Assessment in Santa Clara, California (The Report Preparation Team and Watershed Assessment Consultant 2000).

Program characteristic	Description
Reasons for implementing program	The framework builds on previous work products developed by Santa Clara Counties' Watershed Management Initiative. The goal of the framework was to identify the condition of waterbodies in the basin to improve water resource management, and was designed to be consistent with federal and state water quality assessment methodologies to satisfy regional and federal regulations.
Form or structure of entities governing the program	The assessment will be performed by the Watershed Assessment Consultant with direction from a director designated from the Report Preparation Team. The Report Preparation Team, the Watershed Assessment Subgroup, and the Data Management Subgroup will be involved in providing input and reviewing products. The Watershed Assessment Subgroup recommended there be a "watershed captain" (i.e., a "person familiar with each watershed who would participate in the assessment process and work with the teams to provide a 'reality check' of the initial results").
Types of projects planned, implemented, or constructed	Specific projects not yet planned. The Watershed Assessment Subgroup reviewed Santa Clara Basin's designated beneficial uses for waterbodies to identify the primary beneficial uses and stakeholder interests. A list of data types or indicators was then identified for specified parameters that could be used to assess if a particular waterbody supported the designated beneficial uses/interest. A watershed assessment report will be performed using existing data to assess current conditions.
Criteria for "success" or program endpoints	A watershed assessment report will be produced to compile and summarize the most relevant information relating to the primary uses/interests. If a primary use/interest is not supported or only partially supported in a waterbody, a limiting factors analysis will be conducted, and the results will be summarized in annotated tables to including information pertaining to spatial and temporal variation when possible.
Indicators and/or measures for monitoring success	Assessment results will be programmatic due to the use of available data only, but can become refined if new data becomes available. Based on the primary uses, a list of data types or indicators was developed for selected parameters to evaluate whether a waterbody supports the beneficial uses/interests. Direct measures were selected instead of indirect measures because they were considered to be more conclusive and to provide a higher degree of confidence for examination of a waterbodies' fitness in relation to beneficial uses/interests over time. A detailed list of potentially applicable monitoring criteria is given in Part B, Tables 2A–2D of http://www.scbwmi.org/PDFs/Assessment%20Framework%20Final.pdf
References	The Report Preparation Team and Watershed Assessment Consultant. 2000. Framework for conducting watershed assessment (parts A and B). Final report. Santa Clara Basin Watershed Management Initiative. http://www.scbwmi.org/PDFs/Assessment%20Framework%20Final.pdf

Table 5. Summary description of the Stream and Wetlands System Protection Policy for the San Francisco Bay Region, California (San Francisco Bay Regional Water Quality Control Board 2006).

Program characteristic	Description
Reasons for implementing program	This policy was created to support the San Francisco Bay Region Water Quality Control Plan to protect stream and wetland systems by "restoring the physical characteristics of these systems, including their connectivity and natural hydrologic regimes, in order to protect beneficial uses."
Form or structure of entities governing the program	Staff of the San Francisco Bay Regional Water Quality Control Board will develop an amendment to the Water Quality Control Plan for the San Francisco Bay Region. Specific details on how this will be conducted were not given.
Types of projects planned, implemented, or constructed	The amendment (1) may establish new beneficial uses for the purposes of flood peak attenuation and water quality enhancement; (2) may establish new water quality objectives associated with protecting and managing a waterbodies' hydrological cycle, active channel, floodplain, riparian vegetation, and instream habitat; and (3) will include an implementation plan to protect stream and wetland systems in the San Francisco Bay Regions.
Criteria for "success" or program endpoints	The amendment will include an implementation plan detailing actions necessary to achieve water quality objectives associated with the described beneficial uses.
Indicators and/or measures for monitoring success	To be determined during production of the implementation plan.
References	San Francisco Bay Regional Water Quality Control Board. 2006. Stream and wetlands system protection policy. Summary of project scope. http://www.swrcb.ca.gov/rwqcb2/Stormwater/stream%20and%20wetlands/r2swsppscopesummary.pdf

Summary

After reviewing the efforts of other municipalities, we conclude that:

- Seattle's efforts are following trajectories and paths that are very similar to other municipalities. Other municipalities do not appear to be further along in the process, although the information from Santa Clara, California was dated 2000.
- Indicators lists from other municipalities were either too inclusive, or were still in planning stages and so not defined.
- Criteria by which to define success of the "framework" program, or even of individual improvement projects, were also in planning stages and so not defined.
- Adaptive management was cited as part of the process by two of the five municipalities, Portland and Olympia. The City of Santa Clara will use a watershed assessment and limiting factors approach; these procedures often tie into adaptive management programs.

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Appendix C

Descriptions of Seattle's Five Primary Streams

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This appendix describes Seattle's five primary streams. First, we describe stream conditions as they likely were prior to European settlement (pre-development conditions); second, we summarize existing stream conditions, including preliminary values for proposed indicators. Please refer to the *Seattle State of the Waters* report for more detailed information (SPU 2007 in prep.).

Pre-development Stream Conditions

Past stream conditions are defined here as conditions prior to European settlement. Stream conditions are primarily driven by the area's geology and hydrology, which in turn shape other physical and biological characteristics. The City of Seattle is located in the Puget Lowland hydro-geomorphic system; the characteristics of this Puget Lowland system govern the watershed level processes of Seattle streams.

Seattle watersheds are comprised of glacial till and outwash deposits of the Puget Lobe of the Cordilleran ice sheet, which completely receded as recently as 10,000 to 12,000 years ago. The ice sheet extended into and shaped the Puget Sound basin, and the present site of Seattle was covered in ice several thousand feet thick. Bedrock is absent from the streams (except for some outcrops in the headwaters of Taylor Creek). Where lack of bedrock is combined with the glacially shaped landscapes, the resulting stream longitudinal profile differs from "typical" mountain drainages of the west. Streams on the Puget Lowland plateau exhibit low gradient headwaters that are frequently marshy. Historically, small lakes and associated wetlands were present on the plateau. The headwater streams then transition to relatively narrow channels that are closely confined by valley walls composed of slide-prone glacial sediment. In these lowland streams, large boulders and cobble are infrequent and they do not create much habitat complexity (such as forming pools). As such, woody debris is a major component in forming complex habitat. Streams within the steep, narrow valleys then transition to short floodplain-type channels bounded at their outlets by small estuaries. The streams' substrates tend to be highly erodable, and as a result, these systems are prone to down-cutting, if they are not already at base level. Even without anthropogenic effects, these systems experience episodic and often profound landsliding and other erosional events, which strongly influence the stream's physical and ecological trajectory.

Hydrology is another component of the Puget Lowland's hydro-geomorphic system. Precipitation, which drives the hydrologic system, is the result of dominant regional climate patterns that shape seasonal weather. In the Puget Sound region, this pattern is characterized by long-duration precipitation from generally late fall through late spring. While the landscape's physiography is important, hydrology's influence on the landscape is what shapes the physical expression of landscape features, and what strongly influences the regional vegetation community. The historical vegetation community consisted of closed, old-growth stands of western hemlock, western red cedar, and Douglas fir, so interception would be an important hydrologic component (Trotter 2002). Native American gathering areas were frequently at large wetlands and bogs, where cranberries could be collected.

Due to the dense, old-growth stands and predominantly subsurface flow, stream temperatures would have been well-modulated and supportive of fish communities. On Piper's, Longfellow, and Fauntleroy creeks, which flow into Puget Sound, coho salmon and coastal cutthroat trout dominated (Trotter 2002). Steelhead returned to at least some of these streams (historical records note steelhead returns to Longfellow Creek), but their numbers were likely never large relative to coho and cutthroat. Chinook numbers would have been low (if not absent) due to the streams' small sizes. Other fish species included in historical accounts were sculpin, longnose dace, three-spine stickleback, western brook lamprey, and possibly Pacific lamprey.

Of the streams flowing to Lake Washington, which include Thornton and Taylor creeks, coho and cutthroat trout likely were the dominant species. Chinook and steelhead were noted historically on Thornton Creek (Trotter 2002). Whether anadromous sockeye salmon utilized Lake Washington and its tributary streams is in question, with historical accounts in disagreement. All historical accounts do agree on the presence of the "landlocked sockeye" or kokanee salmon in Lake Washington. In Thornton and Taylor creeks, non-salmonid fish species included peamouth and largescale sucker, longfin smelt, western brook and Pacific lamprey, redside shiner, dace, three-spine stickleback, and sculpin (Trotter 2002).

Existing Urban Stream Conditions

The boundaries of the City of Seattle encompass five primary streams: Fauntleroy, Longfellow, Piper's, Taylor and Thornton creeks (Figure 1-1). These streams have year-round flow and support salmon and trout. Numerous smaller streams are also within City boundaries, but they do not support salmon; these small streams include Mapes, Puget, Yesler, Fairmount, Madrona, Frink, Arboretum, Wolfe, Blue Ridge, Ravenna, and Schmitz creeks and Licton Springs (plus 25 un-named small stream systems). Seattle's streams receive their water not only from surface water runoff and groundwater, but also from drainage pipes that convey stormwater from impervious surfaces such as roads and parking lots.

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

The following sections describe Seattle's five primary streams in the context of the conceptual stream model presented in Appendix D. The descriptions are based on hydrologic, water quality, physical habitat, and biological information recently (1999–2005) available for the five streams (Tables C-1 through C-5). More detailed information about current stream conditions can be found in the *Seattle State of the Waters* report (SPU 2007, in prep.). Smaller streams, which have not been as extensively studied, likely have similar conditions to those found in the major streams. However, smaller streams are more likely to be found within culverts, and/or to be otherwise modified, due to their smaller size and more manageable stream flows.

Table C-1. Description of current conditions at Fauntleroy Creek.

Conceptual model component	Description
Hydrology	• 9 stormwater outfalls. • The 2-year storm flow is four times greater than that predicted during past (forested) conditions. • Stream experiences high and flashy flows.
Water quality	• Dissolved oxygen and water temperature levels generally meet standards. • Fecal coliform levels exceed standards, but have declined since 1988 • Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions. Total mercury is a parameter of concern. • Concentration of nutrients (total phosphorous) are low under non-storm conditions.
Instream habitat	• Within Fauntleroy Park, the stream has step-pool habitat, with active floodplain connections, instream wood and low banks. • Downstream of Fauntleroy Park, the stream has simple plane-bed habitat with riffles and few pools and little instream wood. Banks are heavily armored.
Riparian habitat	• Forested ravines and wide riparian areas contribute wood and leaf litter to the channel within Fauntleroy Park. Floodplain wetlands also add to diversity. • Downstream of Fauntleroy Park, riparian vegetation is dominated by landscaping, lawn, and invasive plants. Houses and other buildings encroach into the riparian zone and conditions are generally poor.
Biological communities	• Used by coho salmon for spawning. • 43% of potential anadromous fish habitat is accessible to anadromous fish. • Highest B-IBI scores[a] of Seattle's five major streams (range 20 to 36) but only 2 of 9 samples contained the minimum threshold of 400 macroinvertebrate individuals. • In 2000, 2001, and 2005, coho pre-spawning mortality was recorded as 25, 27, and 75%, respectively.

[a] The Benthic Index of Biotic Integrity (B-IBI) is a measure of the health of the stream invertebrate community. See the *State of the Waters* report (SPU 2007, in prep.) for details.

Table C-2. Description of current conditions at Longfellow Creek.

Conceptual model component	Description
Hydrology	• 64 stormwater outfalls. • Combined sewer overflows (CSO). • The 2-year storm event is five times greater than that predicted under past (forested) conditions. • Stream experiences high and flashy flows throughout the stream system.
Water quality	• Dissolved oxygen and water temperature levels do not meet criteria. • Fecal coliform levels do not meet criteria. • Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions, however, ammonia is a parameter of concern. • Concentration of nutrients (total phosphorous) frequently exceed established benchmarks.

Conceptual model component	Description
Instream habitat	• The stream is dominated by riffle habitat and a plane-bed channel type. • Over 50% of the stream is in culverts or armored, limiting floodplain connections. • Instream structure and complexity is lacking in most of stream. • Fine sediment is abundant, which decreases habitat complexity. • Habitat quality has increased through rehabilitation projects.
Riparian habitat	• Riparian habitat is highly fragmented due to encroachment by residential development. • Riparian vegetation is dominated by lawns, landscaping and non-native vegetation. • Riparian rehabilitation projects have helped create beneficial conditions in limited locations along the stream.
Biological communities	• Used by coho and chum salmon for spawning. • Poorest B-IBI scores[a] of Seattle's five major streams, with B-IBI ranging from 12 to 18, averaging 14.7, N= 22 at four locations. • From 1999 to 2005, coho pre-spawning mortality ranged from 54 to 82%, averaging 71%.

[a] The Benthic Index of Biotic Integrity (B-IBI) is a measure of the health of the stream invertebrate community. See the *State of the Waters* report (SPU 2007, in prep.) for details.

Table C-3. Description of current conditions at Piper's Creek.

Conceptual model component	Description
Hydrology	• 29 stormwater outfalls. • The 2-year storm event is five times greater than predicted under past (forested) conditions. • Stream experiences high and flashy flows throughout the stream system.
Water quality	• Dissolved oxygen and water temperature levels generally meet criteria. • Fecal coliform bacteria levels exceed criteria. • Concentrations of toxic materials (metals and ammonia) are moderate under storm flow conditions. Parameters of concern include dissolved lead, dissolved copper, and total mercury. • Concentrations of nutrients (total nitrogen and total phosphorous) frequently exceed established benchmarks.
Instream habitat	• Plane-bed and pool-riffle channel types in the stream are dominated by riffle habitat due to the lack of structure in the channel. There are few pools. • The main stream channel contains some floodplain connections, except where armored. • Sand deposits are abundant in the basin. • Upstream areas and tributaries tend to have more simplified habitat and high levels of encroachment. • Sediment storage rehabilitation projects have created some areas of good instream habitat.

Conceptual model component	Description
Riparian habitat	• Carkeek Park has protected some of the riparian corridor from encroachment along the main stream. • The stream is sometimes covered by a mixed forest canopy, however, invasive plants are also present. • Encroachment by residential development is severe in the upstream portions of the watershed and lawns and landscaping dominate the stream banks.
Biological communities	• Used by coho and chum salmon for spawning. • 35% of potential anadromous fish habitat is accessible to anadromous fish. • B-IBI scores[a] indicate slightly better conditions at stations on "upper" Piper's Creek (average 19.7, N = 10), compared with those at "lower" Piper's Creek. (average of 15.5, N = 11). • From 1999 to 2005, coho pre-spawning mortality ranged from 18 to 100%, averaging 58%.

[a] The Benthic Index of Biotic Integrity (B-IBI) is a measure of the health of the stream invertebrate community. See the *State of the Waters* report (Seattle Public Utilities in prep.) for details.

Table C-4. Description of current conditions at Taylor Creek.

Conceptual model component	Description
Hydrology	• 18 stormwater outfalls. • The 2-year storm event is predicted to be five times greater than under past (forested) conditions. • Stream experiences high and flashy flows. • Flows are moderated by wetlands on the west fork.
Water quality	• Few data are available, but water quality is likely similar to Fauntleroy and Piper's creeks.
Instream habitat	• Within Deadhorse Canyon, there is a step-pool channel with some instream wood and pools, although pools and wood are small in size. • Erosion-resistant sediments in Deadhorse Canyon Park help to maintain stream gradient and habitat structure. • Downstream of the canyon, there is a riffle-dominate plane-bed channel. The banks are mostly armored and there is little diversity, instream wood or pools.
Riparian habitat	• The riparian forest in Deadhorse Canyon stretches over 200 feet laterally from the stream in some areas. • Downstream of the canyon, lawns and landscaping are the dominant stream-side vegetation. No shading or wood is contributed to the stream. Encroachment is very high and within 20 feet of the stream in many locations.
Biological communities	• Used by coho and chum salmon for spawning. • 16% of potential fish habitat is accessible to anadromous fish. • B-IBI scores range from 10 to 22 (average 18.9, N = 15 at three stations) indicating poor stream conditions. • Coho pre-spawning mortality not well assessed because few coho return to the stream.

[a] The Benthic Index of Biotic Integrity (B-IBI) is a measure of the health of the stream invertebrate community. See the *State of the Waters* report (SPU 2007, in prep.) for details.

Table C-5. Description of current conditions at Thornton Creek.

Conceptual model component	Description
Hydrology	• 216 stormwater outfalls. • The 2-year storm event has not increased over predicted forested conditions at the mouth due to flow bypass at Meadowbrook Pond. Upstream of the bypass, the north and south branches do exhibit flow magnitude increases in the 2-year storm event, compared to predicted past (forested) conditions. • Stream subject to frequent high flows.
Water quality	• Dissolved oxygen and water temperature levels frequently exceed criteria. • Fecal coliform levels frequently exceed criteria. • Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions. Parameters of concerns include dissolved lead and total mercury. • Concentration of nutrients (total nitrogen and total phosphorous) frequently exceed established benchmarks under non-storm conditions • Low levels of pesticides found in stormwater and sediment samples.
Instream habitat	• Most of the stream and tributaries contain plane-bed channels and riffle habitat and very few pools. Wood is generally unavailable to the stream. • Fine sediment is abundant but coarse sediment is limited. • Extensive filling and bank armoring has limited floodplain connections and stream meanders. • Habitat quality has increased through rehabilitation projects, but opportunities for improvement are limited; seasonal high flows tend to remove coarse sediment and woody debris.
Riparian habitat	• Residential and transportation encroachment occurs throughout the watershed, limiting the width of riparian zones. • Native riparian forests occur in patches along the stream, while most stream banks are dominated by non-native plants, lawns and landscaping. • The riparian corridor provides little shading, bank stability or woody debris to the stream.
Biological communities	• Used by Chinook, coho and sockeye salmon for spawning. • 30% of potential anadromous fish habitat is accessible to anadromous fish. • B-IBI scores[a] indicate very poor stream conditions on average. • 79% coho pre-spawning mortality; highest of Seattle's streams.

[a] The Benthic Index of Biotic Integrity (B-IBI) is a measure of the health of the stream invertebrate community. See the *State of the Waters* report (SPU 2007, in prep.) for details.

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Appendix D

Conceptual Stream Model and Stream Habitat and Channel Types

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Streams are shaped by physical, chemical, and biological processes that interact and continue over long time periods (Figure D-1). The interactions between processes are complex and not fully understood, so conceptual models such as the one presented here represent a simplification of these relationships. For example, watershed characteristics, processes, and impacts are not strictly linear, and important feedback loops and interactions were omitted so the graphic remains manageable and useful. The conceptual stream model provides a basis for the Science Framework, although it incompletely represents a real stream ecosystem. Table D-1 provides a summary of the major stream characteristics, influencing processes and their biological importance.

In understanding the present state of an urban stream, considering the myriad of factors that have interacted over the past, and continue to interact in the present, is vital. These interactions often occur in ways that are not predictable. The components of a stream ecosystem are linked in both time and space, and these interactions are in many dimensions (Figure D-1). Natural disturbances have and will continue to shape urban streams, but the magnitude and ecological significance of these changes are often more profound and lasting once the stream's natural resilience has been compromised by urban development. These cumulative effects need to be understood as one strives to define a long-term stream restoration strategy. Cumulative effects also impose significant challenges in terms of monitoring for long-term trends, as well as for monitoring the effectiveness of individual restoration actions. One must be able to distinguish between normal system variability and those changes that are attributable to direct application of restoration actions.

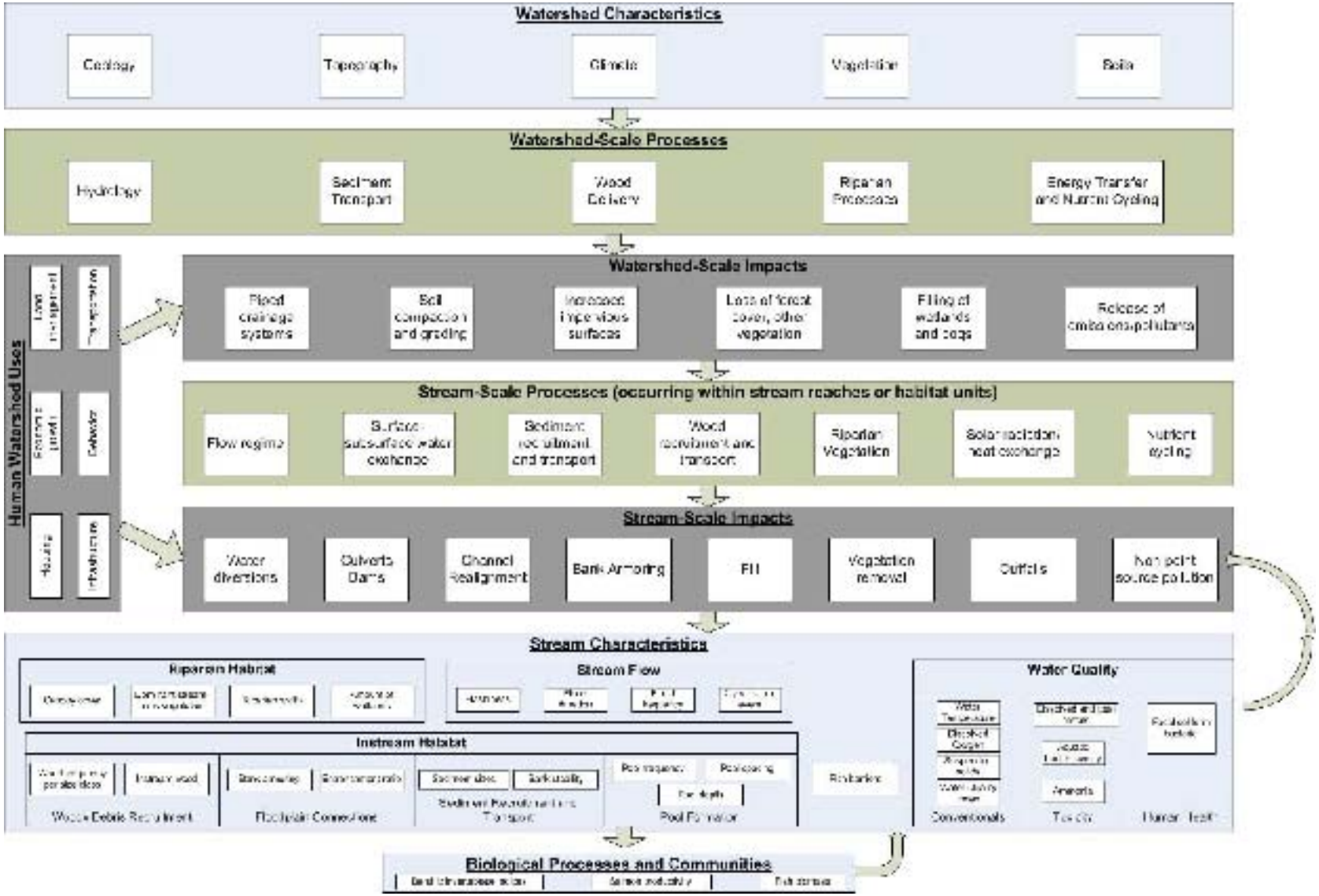


Figure D-1. A conceptual stream model. Note that this graphic is a simplification of stream processes and characteristics, without feedback loops and interactions illustrated.

Table D-1. Important watershed or stream characteristics, associated ecological processes, pre-development conditions, and their importance to biological communities.

Watershed or stream characteristic	Key associated ecological process	Pre-development condition	Ecological function and biological importance
Hydrology	Flow volume and timing	Moderated increases and decreases in flows during storm events that allow for instream habitat creation and maintenance (e.g., pools, undercut banks)	• Provides instream quality habitat for benthic invertebrates and fish • Provides a life necessity to all aquatic organisms
	Base flow volume and timing	Stable summer base flows that maintain adequate stream depths	• Allows for productive summer fish rearing in pools and riffles
Water quality	Water temperatures and dissolved oxygen levels	Moderated water temperatures and sufficiently high dissolved oxygen levels for aquatic life.	• Temperature drives aquatic metabolism/production in most aquatic organisms • Dissolved oxygen levels must be sufficient for organisms to survive, particularly fish
	Nutrient cycling	Regulated nutrient levels that are not excessive.	• Nutrients must be sufficient to allow for primary production, but not promote excessive algal growth
	Toxics	Water and sediment with low levels or no man-introduced metals and chemicals.	• Some metals and chemicals can be toxic to aquatic organisms and humans
Riparian habitat	Riparian Vegetation	A mature riparian zone dominated by coniferous and deciduous trees, with a native understory vegetation.	• Contributes wood to the stream for pool formation • Contributes leaf litter that drives secondary biotic productivity • Provides bank stability and can promote undercut bank refuge habitat for fish • Provides wildlife habitat
	Riparian wetlands	Wetlands that store and filter water with a diversity of native wetland plants	• Removes suspended sediments and some nutrients from surface runoff • Provides wildlife habitat
	Riparian canopy	A dense canopy provided over the stream that provides shading	• Moderates changes in water temperatures, which is especially important for keeping streams cool in warmer months

Watershed or stream characteristic	Key associated ecological process	Pre-development condition	Ecological function and biological importance
Instream habitat	Floodplain connections	Good connectivity between the stream and floodplain, allowing for complex surface-hyporheic-groundwater interactions, channel meanders, and wood and sediment storage and retrieval.	• Provide refuge habitat during flood events • Productive areas for primary production • Promotes habitat diversity and the resulting diversity of aquatic organisms
	LWD recruitment and function	Abundant instream wood promoting formation of a instream habitat. Wood in the stream is supplied by the surrounding riparian forest	• Promotes pools with serve as refuge habitat for juvenile fish and holding habitat for adult salmon • Promotes diverse habitats • Regulates stream gradient, increasing fish passage opportunities in steep areas
	Sediment supply and movement	Channel dominated by coarse sediments with controlled, episodic sediment inputs from upstream areas and canyon walls, with limited amounts of fine sediment deposited.	• Coarse sediment is productive for benthic invertebrates and as salmon spawning habitat • Fine sediment can clog interstitial spaces, limiting spawning success and invertebrate diversity

Stream habitats exhibit distinct characteristics such as depth, water turbulence, water velocity, and substrate; these characteristics change depending upon seasonal flow events. Stream habitat units include the following structures (Spence et al. 1996):

- Pools: Stream areas with reduced water velocities, greater stream depths, and typically a smooth surface.
- Riffles: Shallow stream areas with a rapid current, where the water surface is broken by stream bed sediments such as gravel, cobbles or boulders.
- Glide: Stream segments with intermediate, uniform depths and moderate water velocities with very little surface turbulence. Also called a run.
- Cascade: Stream segments high in gradient with exposed rocks and boulders forming drops in the stream. Cascades have high currents and turbulence.
- Steps: Isolated small falls over boulders or large wood in steep and shallow areas. Steeper gradients and shallower water than in cascade areas.

Combinations of stream habitat units have been used to classify stream channels into reach types (Montgomery and Buffington 1998). While these types were first used to characterize mountain stream reaches, the lower gradient reaches are applicable to Seattle streams (Montgomery et al. 2004). Generally, these stream types are (from higher to lower gradient), cascade, step-pool, plane-bed, pool-riffle and regime (Figures D-2 and D-3). Cascade channels are in steep areas (8 to 30% gradient), where the channel is confined by valley walls and contains mostly large boulder substrate. Step-pool channels are found when the gradient is from 4 to 8%, with a moderate amount of confinement from valley walls around the stream. Step-pool channels have limited floodplains, if any, and the channel itself typically contains cobbles, boulders, and large woody debris. Plane-bed channels develop in lower gradient areas (1 to 4%) and the channel adopts a rather uniform appearance of riffle and glide habitat with gravel and cobble substrate. Plane-bed channels may or may not have a developed floodplain. Pool-riffle channels develop in unconfined, low gradient areas (0.1 to 2%) where the creek can interact with the surrounding floodplain and in-channel woody debris. In some cases, the channel oscillates between pool and riffle areas with some gravel bars, providing diverse habitat. Regime channels exist in flat, unconfined areas (<0.1% gradient) with primarily sand substrate. Typically, the channel is rather sinuous, with sand bars and potential for multiple stream channels (Montgomery and Buffington 1997).

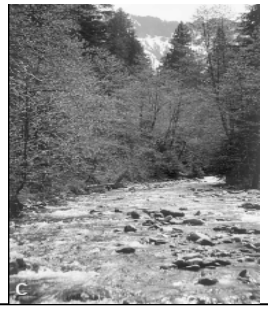
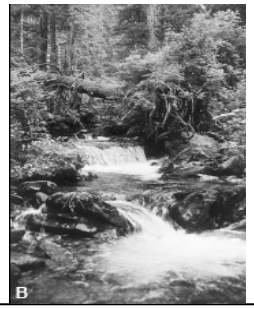
	Regime	Pool-riffle	Plane-bed	Step-pool	Cascade
Typical slope	<0.1%	0.1-2%	1-4%	4-8%	8-30%
Confine-ment	Unconfined	Unconfined	Variable	Moderately confined	Strongly confined
Instream structure	Sinuosity, bedforms, banks	Bedforms, co/bo, LWD, banks	Boulders, cobble, banks	Bedforms, boulders, LWD, banks	Boulders, banks
Typical substrate	Sand	Gravel	Gravel, cobble	Cobble, boulders	Boulder
Sediment sources	Channel, banks, inactive channels	Same as regime + debris flows	Channel, banks, debris flows	Channel, hillslope, debris flows	Channel, hillslope, debris flows
Example picture					

Figure D-2. Stream channel types and their associated characteristics (Montgomery and Buffington 1997). Seattle streams exhibit characteristics that "fit" within some of these categories. LWD = large woody debris, co = cobble, bo = boulders

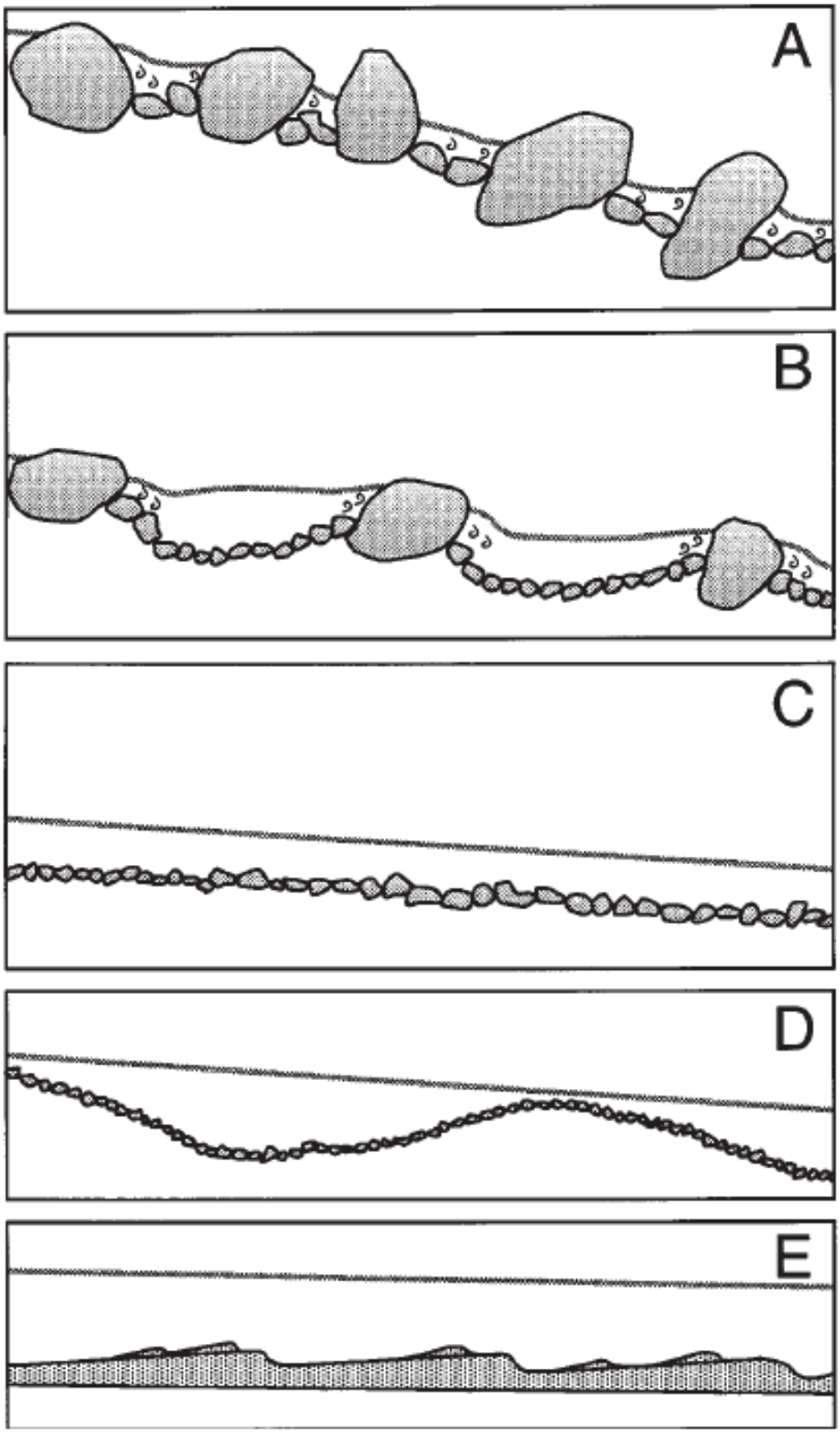


Figure D-3. Schematic longitudinal profiles of alluvial channel morphologies at low flow: (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; and (E) dune ripple. Used with permission, excerpted from: Montgomery, D.R. and J.M. Buffington 1997.

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Appendix E

Initial List of 30 Indicators

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An initial list of 30 indicators of stream ecological health, as compiled from the recommendations of workshop participants, appeared in a draft of the Framework document (Table E-1). The initial list was reviewed by five peer reviewers and several SPU staff; their comments were tabulated (Table E-2) and are discussed briefly below.

Some reviewers were concerned about the feasibility of measuring indicators, suggesting that five or six indicators be chosen, considering the likely financial constraints of City of Seattle agencies. The indicators measuring woody debris and pools were the ones that generated the most comments, and would be the ones most likely to be dropped altogether, or at least moved to the secondary indicators list. The woody debris indicator was kept primarily because woody debris restoration projects have occurred on many of Seattle's streams. Pool indicators were kept because pools are important components of instream habitat that supports native fish; pools are rare in Seattle streams. If pools are defined as depressions in the bed surface that have a residual depth of >0.3 m (1 ft) in urban streams, then changes in pools may become evident in the short-term. Recognizing that pool formation will be partially constrained by stream channelization (flow, sediment supply and woody debris are other interacting factors), bank armoring has also been selected as a primary indicator.

Workshop attendees and the technical reviewers generally agreed that an index of macroinvertebrate community condition is a useful and direct indicator of a biotic endpoint of "healthy" streams. However, which macroinvertebrate index to use was widely discussed. The two indices that were most frequently considered as indicators were B-IBI and RIVPACS (River Invertebrate Prediction and Classification System). One reviewer stated, "[the] application of RIVPACS results are [*sic*] important for use in general assessment and also for evaluation of stormwater permit compliance. Phase I permits require use of the RIVPACS indicator and this would be a good measure to retain for tracking cumulative impacts. The B-IBI (or multi-metric index) is a good biological indicator, but requires a greater burden of proof for use in monitoring programs where required data submittal to a regulatory agency is involved" (Plotnikoff, TetraTech, pers. comm., 2006). Both indices can be applied to Seattle's streams because: 1) for the RIVPACS model, reference streams have been identified, and 2) for the B-IBI method, macroinvertebrate data from all five streams have already been handled by the B-IBI method. The B-IBI method was selected as an indicator, primarily due to the SPU staff's familiarity with the index and its wide use within the Puget Sound area. We note that field data collected for either index are the same, and either index could be calculated with the same data, so that inclusion of both will require only additional analysis, not data collection and sample processing.

The initial table of indicators (Table E-1) includes "ecological health thresholds." Thresholds were based on best scientific judgment about what is needed to sustain benthic communities and salmon spawning and rearing. The spatial and temporal extents to which hydrologic, water quality, physical habitat, and biological processes must work together, and at what recommended level or thresholds, are uncertain; thresholds will likely be extremely site specific. Therefore, these thresholds are put forward as goals to guide study designs and management actions. Threshold values will be revised as knowledge is gained through observation and monitoring.

Table E-1. Initial list of 30 indicators as recommended by workshop participants, and as presented in the draft Science Framework document.

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
Watershed-Scale Indicators				
Hydrology	$T_{Q\ mean}$	Flashiness	Higher $T_{Q\ mean}$ values are associated with streams exhibiting sustained storm flow periods and gradual flow recession rates. Lower $T_{Q\ mean}$ values are associated with brief but high peak flow periods and rapid recession rates. $T_{Q\ mean}$ values decrease with increasing effective and total impervious area (Konrad and Booth 2002). In general, values above 0.3 are associated with greater B-IBI scores (>30), and presumably greater stream health.	>0.3
	$T_{0.5\ yr}$	Flood Duration	Measures the fraction of time that a stream channel is exposed to flows whose magnitude exceeds a more significant, less common flow (Booth et al. 2004).The "half-year flood" is associated with streambed sediment transport and occurs often enough to exert persistent effects on stream biota (Booth et al. 2004). This metric is evaluated on a log scale, with increased values associated with higher B-IBI scores. A $T_{0.5\ yr}$ threshold for urban vs. suburban stream is 0.01 (Konrad 2000). In general, values above 0.01 are also associated with higher B-IBI scores (>30) (Booth et al. 2004).	>0.01
	High pulse count	Flood Frequency	Measures the number of times the daily hydrograph rises above the high-flow threshold (200% of the average flow rate under forested conditions). Higher pulse counts are associated with greater urbanization. High pulse counts below 10 appear associated with higher B-IBI scores (>30), but variation in the relationship is high (see Cassin et al. 2005, Figure 10).	<10 events
	Q_2	2-year storm event flows	Measures flow at a two-year return period. Higher Q_2 values are associated with increased urbanization. A decreasing trend, moving toward forested Q_2 values, would improve stream health. A 75% decrease toward forested values is assumed to be beneficial.	$0.75 \times Q_{2forested}$

[1] Thresholds were based on best scientific judgment about what is needed to sustain benthic communities and salmon spawning and rearing. The spatial and temporal extents to which hydrologic, water quality, physical habitat, and biological processes must work together, and at what recommended level or thresholds, are uncertain; thresholds will likely be extremely site specific. Therefore, these thresholds are put forward as goals to guide study designs and management actions. Threshold values will be revised as knowledge is gained through observation and monitoring.

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
Water quality *Conventional parameters*	Maximum daily temperature (7-day average)	High temperature	Measures the moving average of 7-day maximums (June through September). High water temperatures during the summer increase fish metabolism and induce stress. High temperatures >22 °C can become lethal. Preferred temperatures for salmonids generally range between 12 and 14 °C (Spence et al. 1996). Temperatures between 10 and 17 °C are common for acceptable summer habitat use (Poole et al. 2001). Washington State criteria (proposed) for salmon and trout spawning, core rearing, and migration is 16 °C (60.8°F).	<16 °C
	Instantaneous rate of change in stream temperature	Rate of temperature change	Measures the rate of change in water temperature as one more indicator of how sensitive stream is to solar radiation input or other factors (such as reduced flows) that affect stream temperatures. Useful in tracking improvements over time from riparian shade and low-flow restoration strategies	<0.5 °C/hr
	Dissolved oxygen	Dissolved oxygen	Measures dissolved oxygen (DO) concentration in mg/L. The solubility of oxygen in water varies with temperature and salinity. In urban streams, DO is also affected by the amount of pollution present, particularly nutrients, wastewater, some inorganic chemicals, and organic matter that can stimulate biological growth, which uses up oxygen. DO concentrations below 6.5 to 7.0 mg/L greatly impaired adult salmon performance (regardless of temperature) (Spence et al. 1996). DO levels must average greater than 8.0 mg/L for embryos and alevins to survive. For Class AA streams, Washington State criteria include DO >9.5 mg/L (criteria under revision).	DO >9.5 mg/L
	Specific metric to be determined	Suspended solids	Suspended solids and turbidity can provide insight into full complement of transported fines within the stream water column. Deposition of larger fraction of fines (Suttle et.al. 2004) can affect benthic invertebrates and fish spawning areas. Potential pollutants can also attach suspended solids, leading to accumulation in watercourses. Specific metrics to measure suspended solids could include suspended sediment concentrations, total suspended solids or turbidity. Criteria are based on storm flows, and are a maximum increase over background levels. Usually measured during high runoff events. Interpretation of full meaning of SS data needs refinement through correlation and experience.	<water quality criteria under Washington State WQ Standards (currently in revision)
	Water Quality index	Water quality	Index based on composite values for temperature, dissolved oxygen, pH, fecal coliform bacteria, total nitrogen, total phosphorus, total suspended sediment, and turbidity. Values range from 1 to 100, with higher scores indicating better water quality. For Washington State Department of Ecology, scores >80 are of "lowest concern," scores 40 to 80 indicate "marginal concern," scores below 40 are of "highest concern." This	>60

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
			index may not be a good fit for urban streams, where fecal bacteria , TN and TP can drive low scores, even though TN and TP values are not problematic. Could be modified to work better in Seattle's urban environment and be responsive to management actions.	
Water quality *Toxicity*	Dissolved metals (Cu, Pb, Zn)		Dissolved metals that affect aquatic life include arsenic, cadmium, chromium III and IV, copper , mercury , nickel, selenium, and zinc. Water quality criteria are developed to protect aquatic life. The effect of dissolved metal concentrations is hardness-dependent. Copper (Cu), lead (Pb), and zinc (Zn) are the pollutants most commonly associated with urban runoff.	<water quality standard
	Aquatic health toxicity		Toxic pollutants in the water column or stream sediments, such as metals, PCBs, and pesticides, can affect the survival and growth of aquatic organisms. Methods to evaluate this could include whole effluent toxicity tests, sediment bioassays with *chironomids* or *Hyallela* exposed to stream sediments, or in-situ trout egg incubation boxes to look for normal development and survival to emergence.	<water quality standard
Water quality *Human health*	Fecal coliform (or other human health indicator)	Human health – contact recreation	Measures the number of fecal coliform colonies per 100 mL of water. Fecal coliform bacteria are indicator organisms that are used to evaluate the present of pathogenic organisms that may make people sick. State water quality standards have been established for extraordinary primary contact, primary contact, and secondary contact recreation. Seattle urban streams are classified for use as extraordinary primary or primary contact recreation. For extraordinary primary contact, fecal coliform levels cannot exceed a geometric mean value of 50 cfu/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 cfu /100 mL. Standards for primary contact recreation are 100 cfu/100 mL geometric mean with a percentage threshold of 200 cfu/100 mL. Seattle streams all exceed standards for primary recreation, with pets and urban wildlife (rodents, birds) being the most significant sources.	<water quality standard

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
Stream-Scale Indicators (customized according to stream channel type and surrounding land uses)				
Instream habitat *Sediment recruitment and transport*	Bed surface particle size distribution	Sizes of gravels on streambed	Streambed gravels provide important structural elements of aquatic habitats and are used by primary and secondary producers, stream insects and related invertebrates and provide spawning substrate for adult fish and amphibians and hiding places for juvenile fish and amphibians. Being able to efficiently characterize bed substrate in a way that is repeatable will provide a reliable means to track status and trends in this key habitat component over time. A simple technique, referred to as Wolman (1954) pebble counts is used to determine D_{50} and D_{85} particle size (the intermediate diameter of the median and 85th-percentile clast in a randomly selected population of streambed sediment particles) at reference locations for each stream. These size fractions of streams can then be assessed in terms of those sizes known to be suitable for spawning and rearing (see Kondolf and Wolman 1993, Suttle et al. 2004). Ranges of expected values are a function of both localized geology (source characteristics) and the frequency of flows of a sufficient magnitude to transport bed particles downstream. Instream channel roughness elements such as wood and boulders can help retain substrates by minimizing localized sheer forces associated with flood flows. Expections for predominant substrates in Puget Sound lowland streams can be generally characaterized as follows: In low gradient headwaters/wetlands – predominantly sand/fines In low gradient floodplain reaches <2% – predominantly gravel In higher gradient reaches >2% – predominantly gravel and cobble Decreasing trend over time in % fines (grain size <0.85 mm); ideally <10% in low gradient riffles; median D50 grain size in spawning habitats ~ range established in literature. See (Kondolf and Wolman 1993; Chapman 1988; Bunte and Abt 2001)	Decreasing trend over time in % fines, at locales where it is deemed to be a problem. In addition, want to see increasing input and retention of coarse sediments of suitable size distribution to satisfy life history requirements of native fishes for spawning and rearing refuge habitats. Where input sources are limited or non-existent, may want to test effectiveness of gravel replacement.
	Bank stability index	NA	Captures the relative stability of stream banks in terms of erosion state. Application in urban streams must be tempered with an understanding of the influence and spatial extent of bank armoring, which nominally limits erosion, as well as the positive role bank erosion may play in terms of providing much needed coarse gravels to a given stream.	>50%

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
			Bank stability indices specifically for urban streams have been published by the US Geological Survey's NAWQA program (Adolphson et al., 2002). These expectations need to be refined for each stream of interest to reflect present state and what might be attainable.	
Instream habitat *Floodplain connections*	Bank armoring (%)	Bank armoring	Measures percent of bank hardened or "armored". Bank armoring limits sediment recruitment and floodplain connections, and is often associated with fill. There is no identified threshold at which bank armoring becomes more or less problematic. Same as bank stability description above.	<10% of entire length of stream
	W/d ratio	Width : depth	Measures the channel width to depth ratio and tracks changes over time. Ratio scaled to localized channel gradient and confinement. No recommended range given because channel measurements must be specifically defined. Urban streams present challenges to making appropriate expectations in that width is often artificially constrained by bank armoring, which under highly altered flood flow regimes, can precipitate bed scour and channel incision. This measurement repeated over time at fixed locations provides a highly reliable indicator of those changes. Measurement can be done as part of a long-term monitoring program that includes several fixed-station channel cross sections and a longitudinal profile survey, performed every few years (see discussion in Bauer and Ralph 1999 p. 44).	highly variable; can be inferred from regional indices of channel geometry derived from relationship of basin area to channel dimensions; but these are highly modified in urban streams; calibrate to stream of interest
Instream habitat *Woody debris recruitment*	Frequency of woody debris	LWD (large woody debris)	Measures the frequency of woody debris in the stream, per size class (# per 100m; size classes as small, medium and large). Piece size should be scaled to channel dimensions, but generally of sufficient size to remain stable under typical Q_2 flow events. LWD per 100 m ranges from 26 (25th Q), to 29 (median), to 38 (75th Q) (Fox et al. 2003).	29 to 38+ LWD/100m Increasing trend in larger size classes
	Instream wood (%)	Location within channel	Measures the position of wood in the active channel to assess interaction with low flow wetted width (%) and subsequent contribution to summer pools. >50% of pieces within wetted width during summer low flow period source (Ralph et al. 1994; Fox 2002)	>50%

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
Instream habitat *Pool formation*	Pool frequency		Habitat complexity is measured by the relative number and location of pools within a given stream. Pools provide critical rearing and holding habitats for native fish, especially juvenile salmon and trout. Pool habitat is generally considered to be lost as urbanization increases over time. Therefore, some measure of pools seems appropriate. In this instance, measure the # of pools (>0.5 m depth) per unit length of stream channel. Pool frequency depends on channel type and needs to be scaled to the relative gradient and confinement of a given stream reach.	Increasing trend
	Pool spacing		The distance between pools is a critical feature that directly affects overall stream productivity. Streams with too few pools, spaced too far apart will fail to support many juvenile salmon and trout. A simple measure of the number of pools per channel width can be inferred from a longitudinal profile as part of a long term monitoring program. See Montgomery et al. 2003	>2 to >4 pools/ channel width
	Residual pool depth		Pool depth is a critical factor in determining relative quality of aquatic habitat and is positively correlated with large wood within the channel. Pools of sufficient depth must be maintained or enhanced to support a sustainable population of native fishes. Residual pool depths sufficient for migrating adult salmon (>0.7 ft) and rearing juveniles (>2.0 ft; Bjornn and Reiser 1991, Ralph et al. 1994).	Increasing trend
Instream habitat *Longitudinal connectivity*	Fish barriers		Physical barriers to upstream migration interrupt the free flow of organisms throughout a stream channel. Identification and eventually elimination of all possible barriers to fish migration is part of the overall restoration strategy of all streams, not just those in urban environments. A simple stream specific inventory of the number of full and partial man-made barriers will be completed for each stream within Seattle. Tracking improvements over time is an important factor to ensure progress and accountability.	0

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
Riparian habitat	Canopy cover		Loss of shade from denuded riparian zones allows increased solar radiation to warm stream temperatures, especially during critical summer months when juvenile fish are rearing. Simple measures of view to sky or, conversely percent shade will provide an indirect measurement of solar input levels. Various techniques are available, some more accurate than others. The specific method and locations at which measures will be made will be defined during the design phase of the extensive monitoring program. Baseline measurements for each stream will allow progress in reducing shade to occur through directed restoration.	>80% canopy cover throughout a give stream course; may not be attainable in some reaches of urban streams due to hard constraints
	Dominant stream bank vegetation		The dominate canopy species are important for providing canopy cover and woody debris to the stream, while understory species can either support or limit future tree regeneration. Mixed hardwood-conifer forest numerically dominated by hardwoods (red alder, big leaf maple, cottonwood, willow, vine maple). Biomass dominated by a mix of hardwoods and conifers, mostly cedar, sitka spruce, Douglas fir and hemlock.	Canopy: Native conifer/ mixed Understory: native shrubs/ groundcover
	Average riparian width and standard deviation		Measures the width of the riparian zone, perpendicular to the stream channel. An intact riparian corridor is important for protecting instream habitat and supporting adequate riparian functions and processes. Riparian widths can vary by surrounding landform (e.g., canyon versus valley). Generally, recommended riparian widths range between 50 and 200 feet to maintain stream water quality for salmonids, provide LWD recruitment, maintain stream temperatures, and benthic communities (City of Seattle 2005). Wildlife habitat is provided when riparian widths range from 100 ft to over 300 ft.	Park lands: >200 ft Other lands: >75 ft
	Riparian wetland area		Measured in acres, relative to appropriate channel types. Riparian wetlands are important for filtering surface runoff, storing water, and providing habitat diversity for aquatic and terrestrial species.	Increasing trend
Biological communities *Benthic Invertebrates*	B-IBI		B-IBI scores indicate the degree of human impact on streams, calibrated for the Puget Sound lowland. Scores ranges from 10 to 50 and are categorized as very poor (10-16), poor (18-26), fair (28-36), good (37-44) and excellent (>44). Used to compare locally.	Park lands: >36 Other lands: >30
	RIVPACS		Multivariate approach that compares the observed (sampled) benthic macroinvertebrate community to that of a reference collection collected in a minimally disturbed site. The value produced is expressed O/E, (observed over expected.) A relatively pristine site might score a 1.0 or higher, where a degraded site would score much lower. A reference collection for Western Washington streams has been developed, and data can be entered and calculated using University of Utah's RIVPACS software. Other	>0.8

Key ecological process	Indicator metric	Popular term for indicator	Anticipated ranges of indicator values	Ecological health threshold[1]
			metrics (% filterers, temperature preference, fines indicators, tolerance metrics) also available. Used to compare regionally.	
Biological communities	Salmon productivity		Measures the ratio of redds to the summer standing juvenile salmon stock. Different from usual salmon productivity measures because we are concerned with the ability of salmon to withstand winter and spring high flow events once out of the gravel. Ranges for expectations of productivity will need to be established from reference streams and tempered by actual data collected over the first few years of a monitoring program specific to each stream.	Increasing trend
Fish	Fish Biomass		Routine fish sampling surveys done periodically as part of the extensive monitoring program will establish year to year estimates of distribution, abundance and growth for both native and non-native fish within Seattle urban streams. Tracking this over time will provide evidence of increasing or decreasing trends in overall condition of native salmon and trout, and overall species composition of the stream community.	Increasing trend over time indicating improving habitat conditions overall

Table E-2. Comments on indicators by Science Framework reviewers, and indicator assignment after review.

Indicator	Derek Booth	Rob Plotnikoff	Scott Tobiason	George Pess	Jean Jacoby	Indicator assignment and rationale
$T_{Q\ mean}$						Primary. Frequently used in Puget Sound, and SPU staff have found it is responsive to watershed changes
$T_{0.5\ yr}$	Omit, see above					Dropped. R redundant with $T_{Q\ mean}$
High pulse count						Dropped. Redundant with $T_{Q\ mean}$
Q_2	Omit if can't accept decades-long timeframe					Dropped. Measurable change would require too long of a time.
Maximum temperature (7-day average)			Inherent variability argues for continuous monitoring			Primary. High biological relevance and relatively easy to measure
Instantaneous rate of change in stream temperature			See above			Dropped. No information readily available on acceptable rate of increase
Dissolved oxygen			See above. Try luminescent DO sensors			Primary. High biological relevance although dependent upon temperature
Specific metric to be determined (SS)	Don't set criteria		Use turbidity, again continuous monitoring			Secondary. For reliable information, need to measure continuously, probes often become clogged with sediment, maintenance very labor intensive
Water quality index	Omit for reasons already given	Good reporting tool for non-tech groups	Nutrients—no. WQI, no.		Nutrients—no.	Dropped. Index is not sensitive enough to urban water quality concerns

Indicator	Derek Booth	Rob Plotnikoff	Scott Tobiason	George Pess	Jean Jacoby	Indicator assignment and rationale
Dissolved metals		Review 303(d) list, past pesticide studies, review Nat Scholz NOAA-Fisheries studies.	No, except where adapt mgt indicates particular need. A variety of sampling and analysis problems		Remove ref to synthetic organics, not metals. Specify if thresholds are acute or chronic levels	Dropped. Variety of sampling and analysis problems.
Aquatic health toxicity			Use tox invest and eval (TIE) and tox reduction eval (TRE) techniques for cause/effect monitoring			Secondary. An indicator that would point to water and sediment quality problems is important, especially when status and trend monitoring parameters do not include major toxics. Added coho pre-spawning mortality as a measure of toxicity, although there is uncertainty around the cause.
Fecal coliform (or other human health indicator)			No, too variable and uncertain. Use microbial source tracking (MST) DNA fingerprinting method		Use E. coli even though WA has not switched, despite US EPA recommendations	Dropped. Fecal coliform bacteria levels can be highly variable and do not directly measure the presence of pathogens that affect human health. Other biological tests, such as E. coli, should be considered.
Bed surface particle size distribution						Secondary. Important issue for urban streams, but not best technique if primary interest is in elevated fine materials clogging gravels. Suggested for index at spawning sites only.
Bank stability index	Threshold value unsubstantiated					Dropped. Highly subjective measure, use bank armoring as a surrogate
Bank armoring (%)				Need more than just this		Primary. Used as a surrogate for floodplain connectivity and bank condition.

Indicator	Derek Booth	Rob Plotnikoff	Scott Tobiason	George Pess	Jean Jacoby	Indicator assignment and rationale
Entrenchment ratio	Omit, does not apply to urban streams			Need more than just this. Suggest floodplain to mainstem channel ratio, and wetland habitat assoc w/ floodplain channel		Secondary. Floodplain connectivity is an important feature lacking in urban streams, however, metrics to evaluate are imperfect. W:D has been used in the past, although still problematic.
Frequency of woody debris	Why not just combine these two—"frequency of in-channel (or influential) wood"	Omit LWD, not a good indicator on urban or suburban streams.				Primary. Important issue for urban streams, easy and quick to collect data.
Instream wood (%)	See above	See above				See above
Pool frequency		Slow to change, omit or measure less frequently		What about other species that don't require pools?		Primary. Seattle's streams lack adequate pool habitat.
Pool spacing	1 pool per 2 to 4 channel widths	See above		See above		Primary. See above
Residual pool depth	Goal not a threshold	See above				Primary. See above
Artificial Fish barriers						Primary. Limits habitat access, easy to inventory or update existing records.
Canopy cover	Omit ref to attainability					Primary. Lack of riparian trees a large problem in non-park land. Remote sensing data should allow for easy data collection.
Dominant stream bank vegetation						Dropped. Shading is most important.
Average riparian width and standard deviation	Threshold values should be reversed					Dropped. Difficult to measure reliably, can approximate with canopy cover.

Indicator	Derek Booth	Rob Plotnikoff	Scott Tobiason	George Pess	Jean Jacoby	Indicator assignment and rationale
Riparian wetland area						Dropped. Not common and unlikely to show substantial changes through time.
B-IBI		Requires a "greater burden of proof" than RIVPACS. Omit.	Disadvantage: for tox assessment, too infrequent. OK to complement channel habitat indicators			Primary. Used frequently in Puget Sound area.
RIVPACS		Do this, and already required for Phase I permits				Dropped. Redundant with B-IBI.
Salmon productivity		Review recent NOAA Fish limiting factors analysis, so the framework is convergent with salmon rec plans		Must estimate standing crop by season—critical, combine w/ redd counts		Dropped. Extremely difficult to measure with any accuracy.
Fish Biomass				See above		Primary. Even though time consuming to measure, provides a snapshot of fish communities
General comments on Table 5	Omit thresholds column. Give column for sensitivity, measurement freq, etc.	S&Ttrends monitoring and Cause/Effect monitoring are embedded within each other. Argues for both. Need to consider sensitivity to disturbance, time	Estimated costs provided. Add illicit discharge detection and elimination (IDDE) as a mgt tool; it is required of the "MS4 NPDES permit"	Pre-spawn mortality analysis is critical.		

Indicator	Derek Booth	Rob Plotnikoff	Scott Tobiason	George Pess	Jean Jacoby	Indicator assignment and rationale
		to detect change, volume data needed to "see" anything, collaboration with others collecting data				

[1] "Core" terminology suggested by R. Plotnikoff
[2] No comments specifically on indicators.

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Appendix G

Stream-Specific Improvement Recommendations

Seattle's major streams and their watersheds differ from one another based on historical physical characteristics and existing conditions. Watershed-based illustrations of historical and current conditions for Fauntleroy, Longfellow, Piper's, Taylor and Thornton creeks, and improvement recommendations for the five streams are presented (Figures G-1 to G-15) (Herrera Environmental Consulting of Seattle, Washington). For other Seattle streams, non-specific recommendations are illustrated (Figure 3-5).

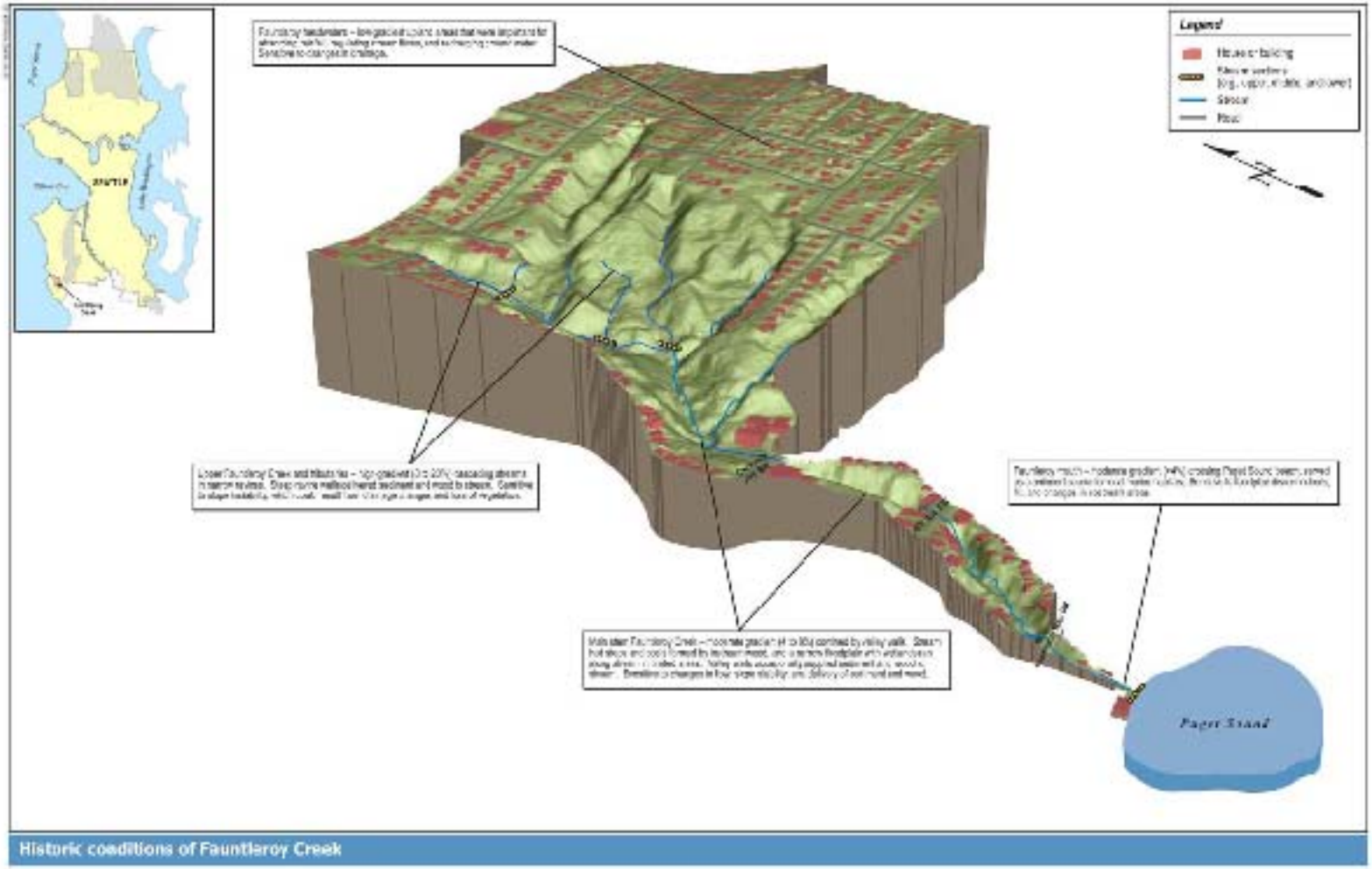

Figure G-1. Historical conditions at Fauntleroy Creek. Roads and buildings are shown for spatial reference. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

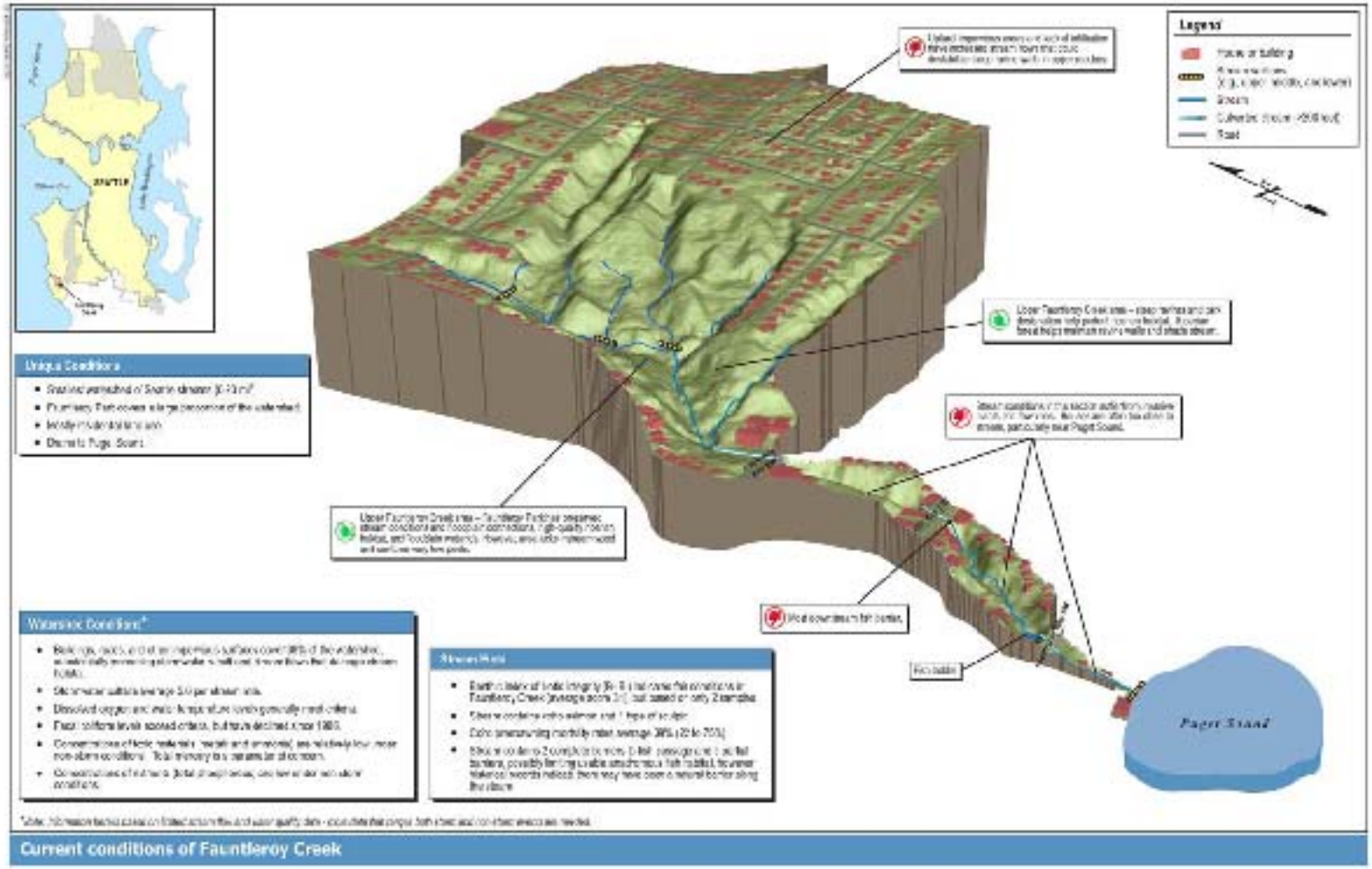

Figure G-2. Current conditions at Fauntleroy Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

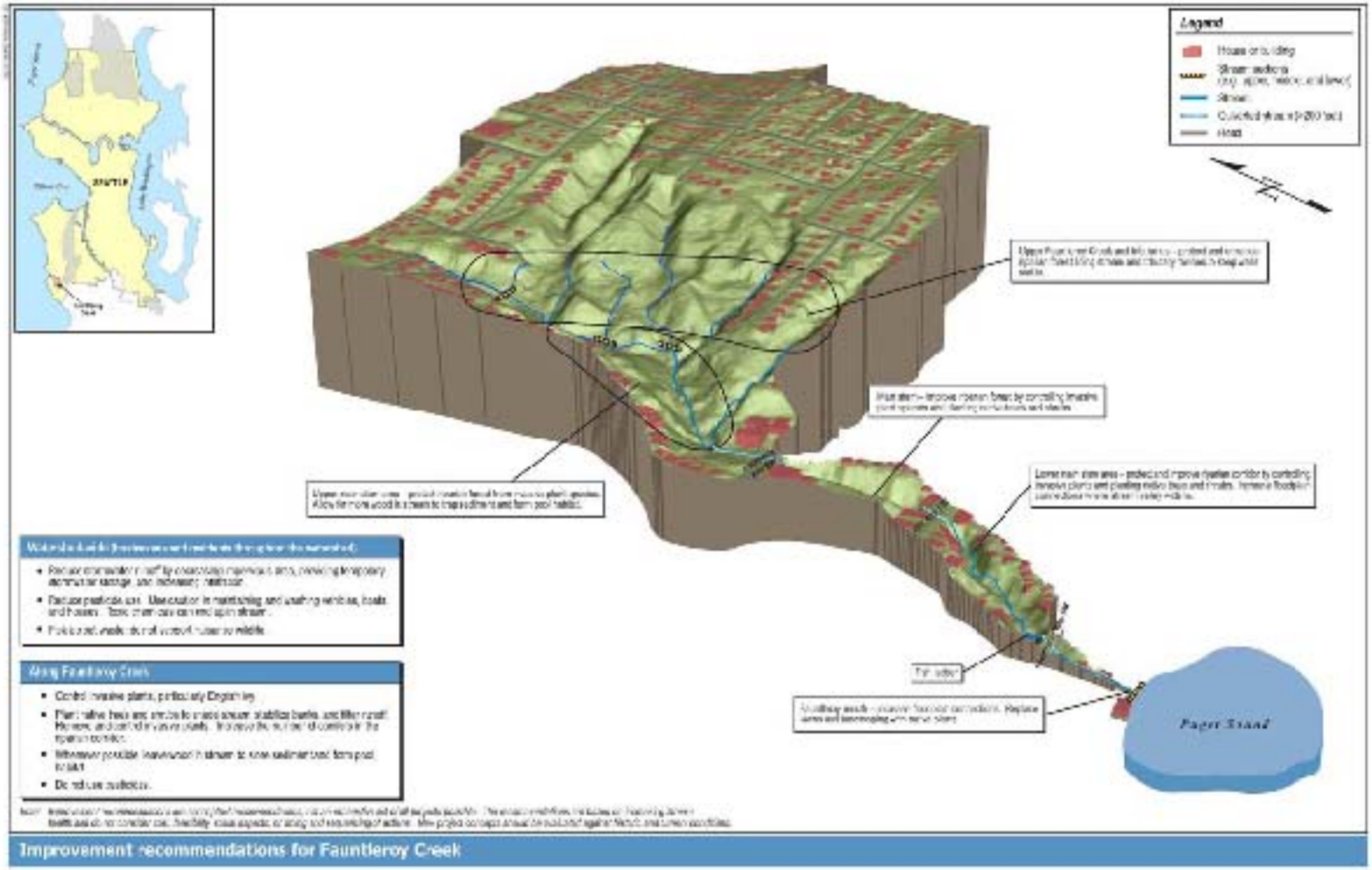

Figure G-3. Improvement recommendations for Fauntleroy Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

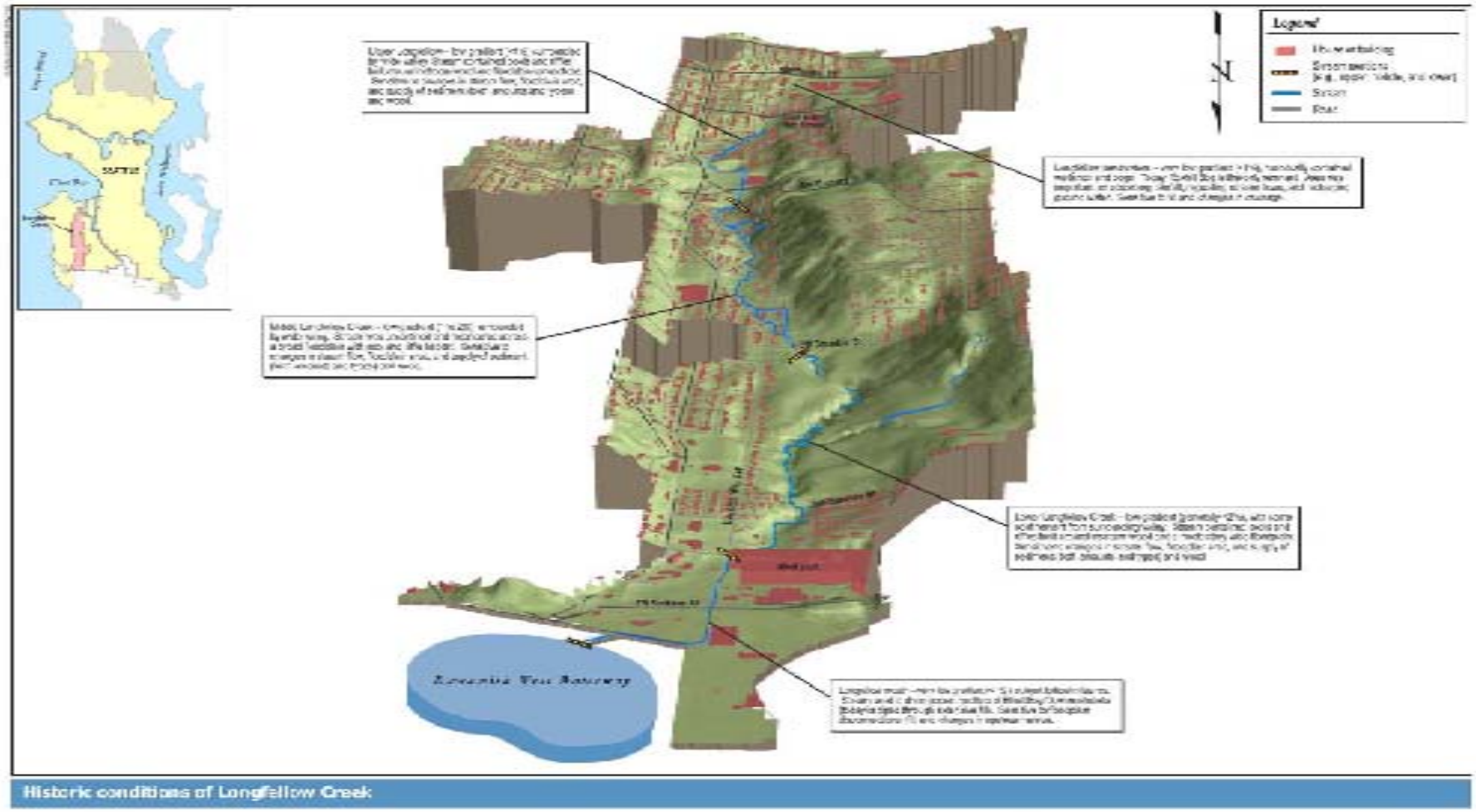

Figure G-4. Historical conditions at Longfellow Creek. Roads and buildings are shown for spatial reference. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

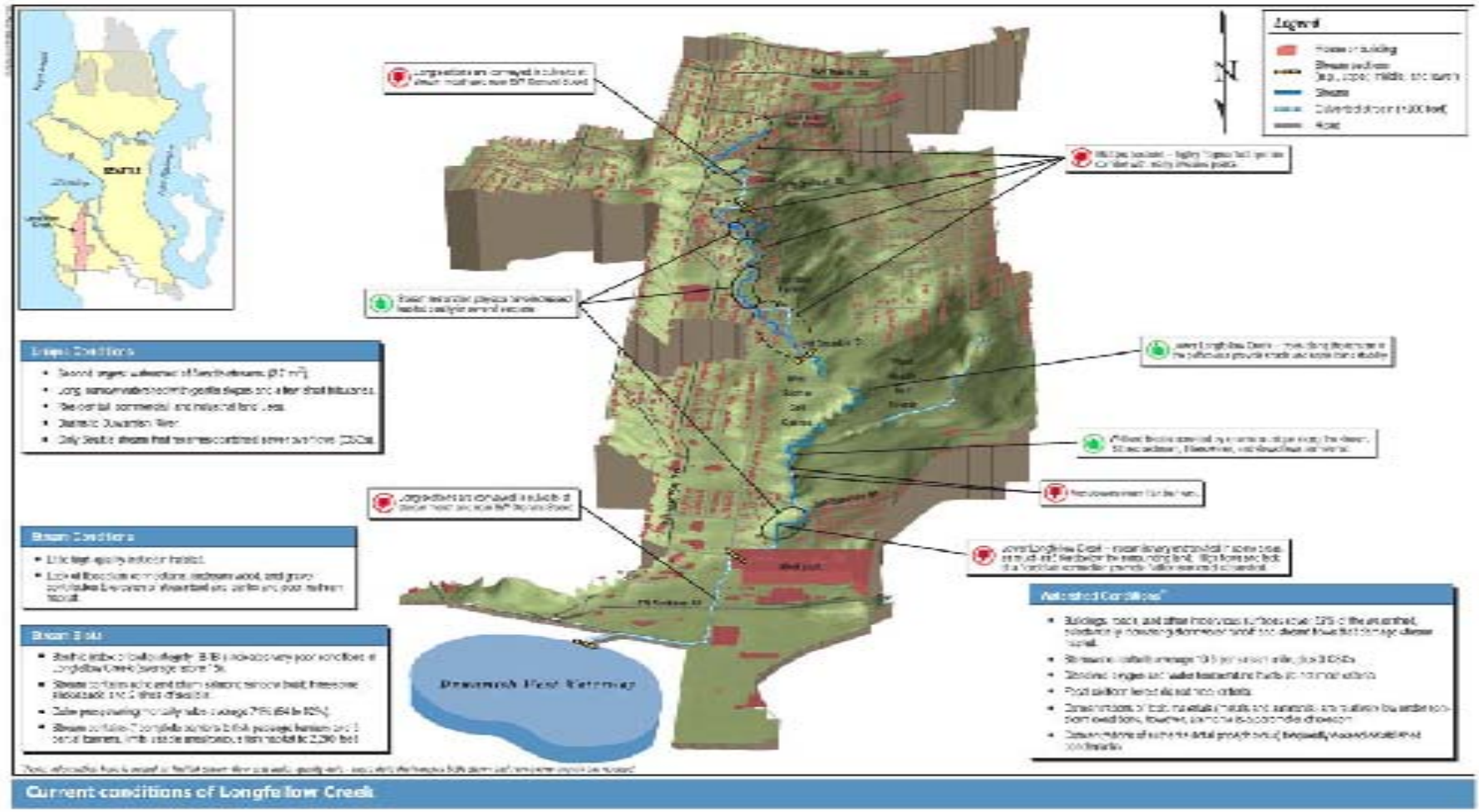

Figure G-5. Current conditions at Longfellow Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

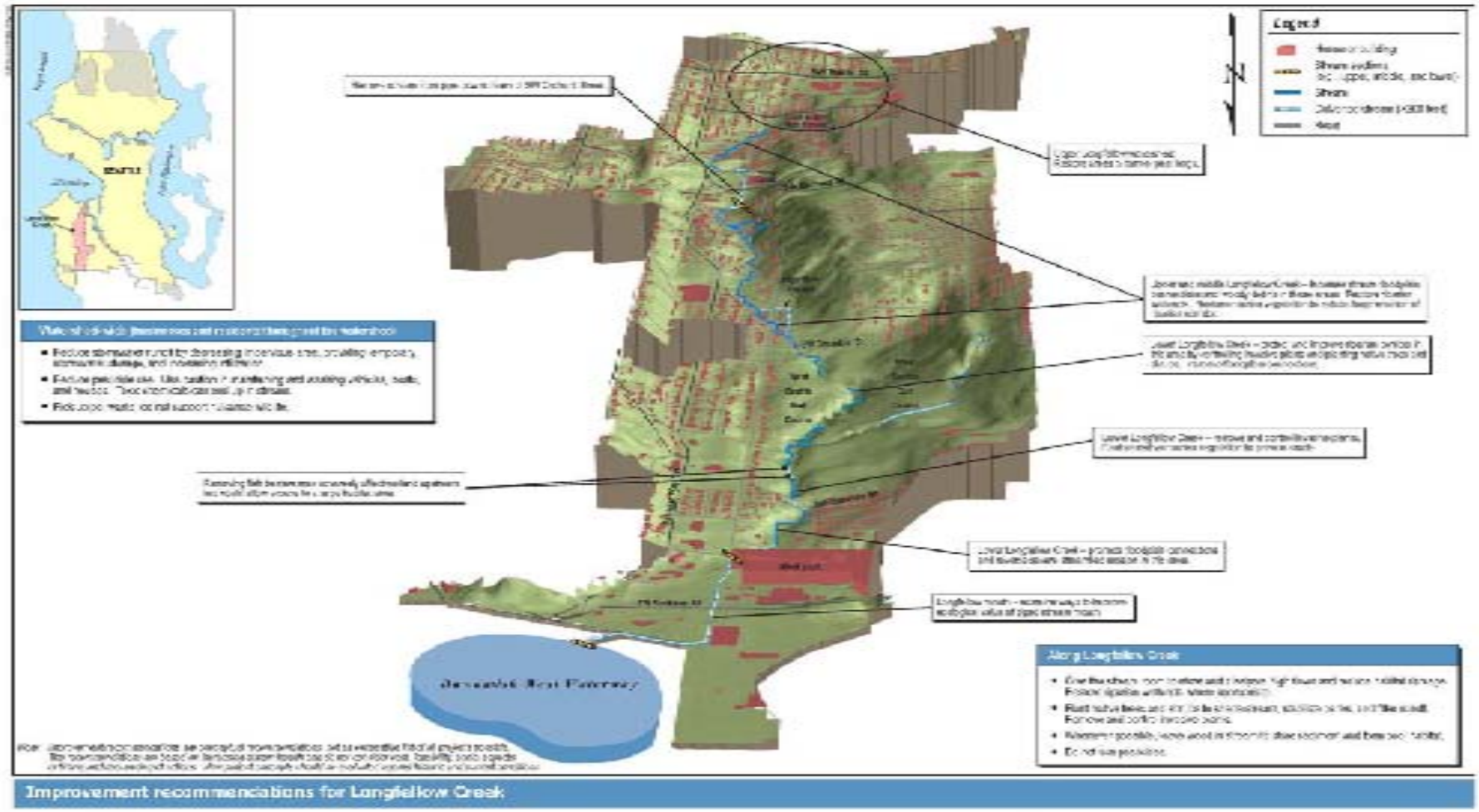

Figure G-6. Improvement recommendations for Longfellow Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

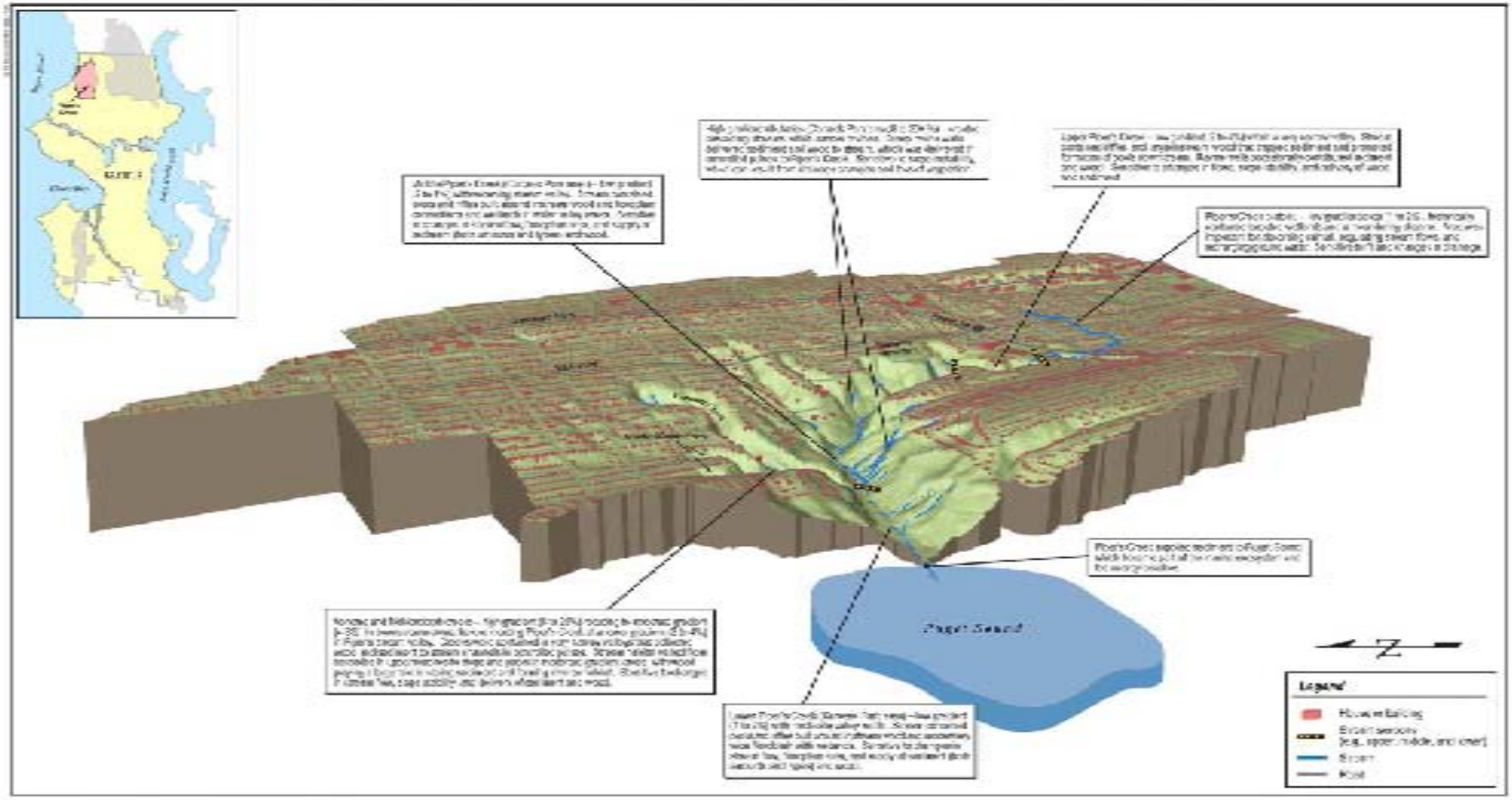

Figure G-7. Historical conditions at Piper's Creek. Roads and buildings are shown for spatial reference. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

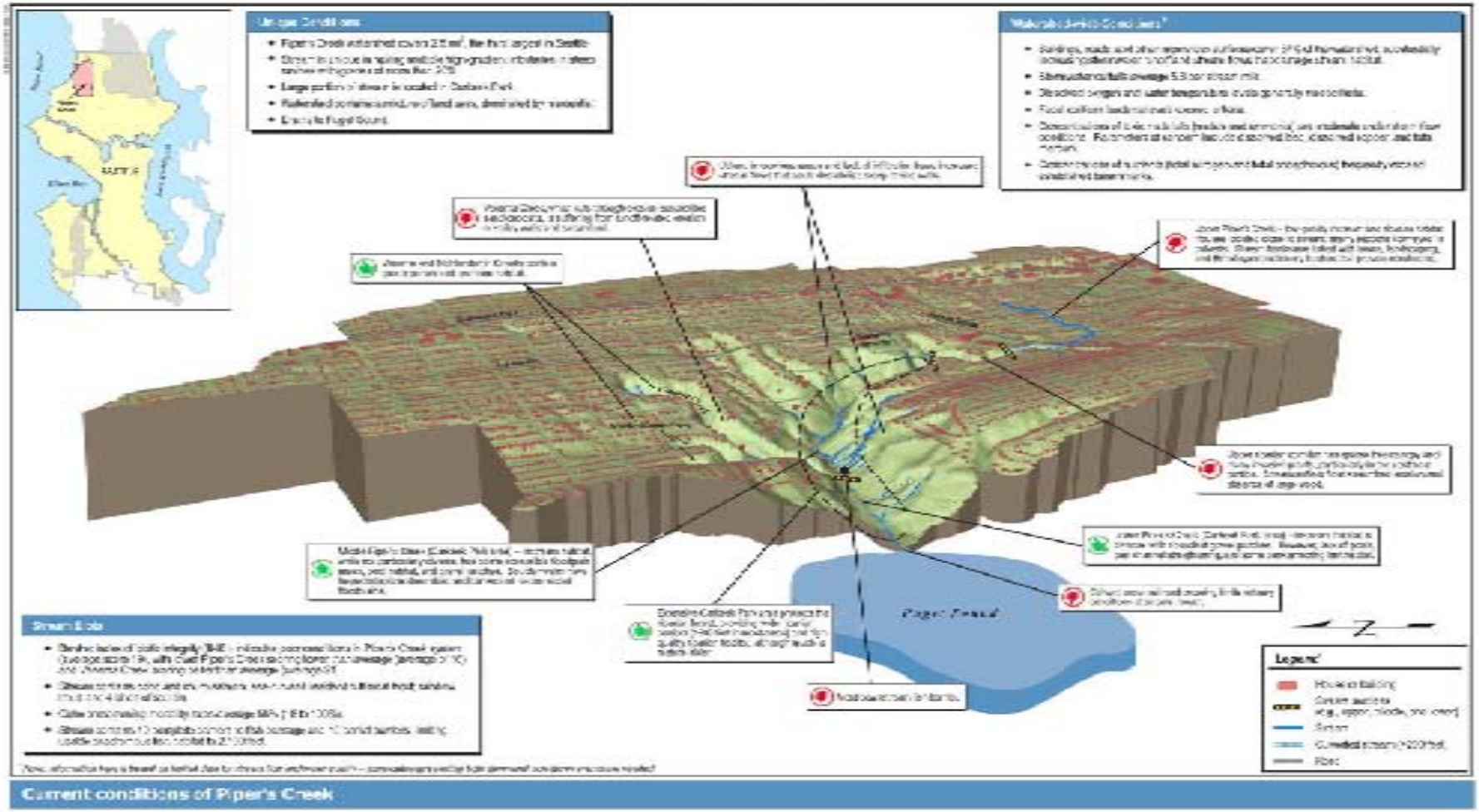

Figure G-8. Current conditions at Piper's Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

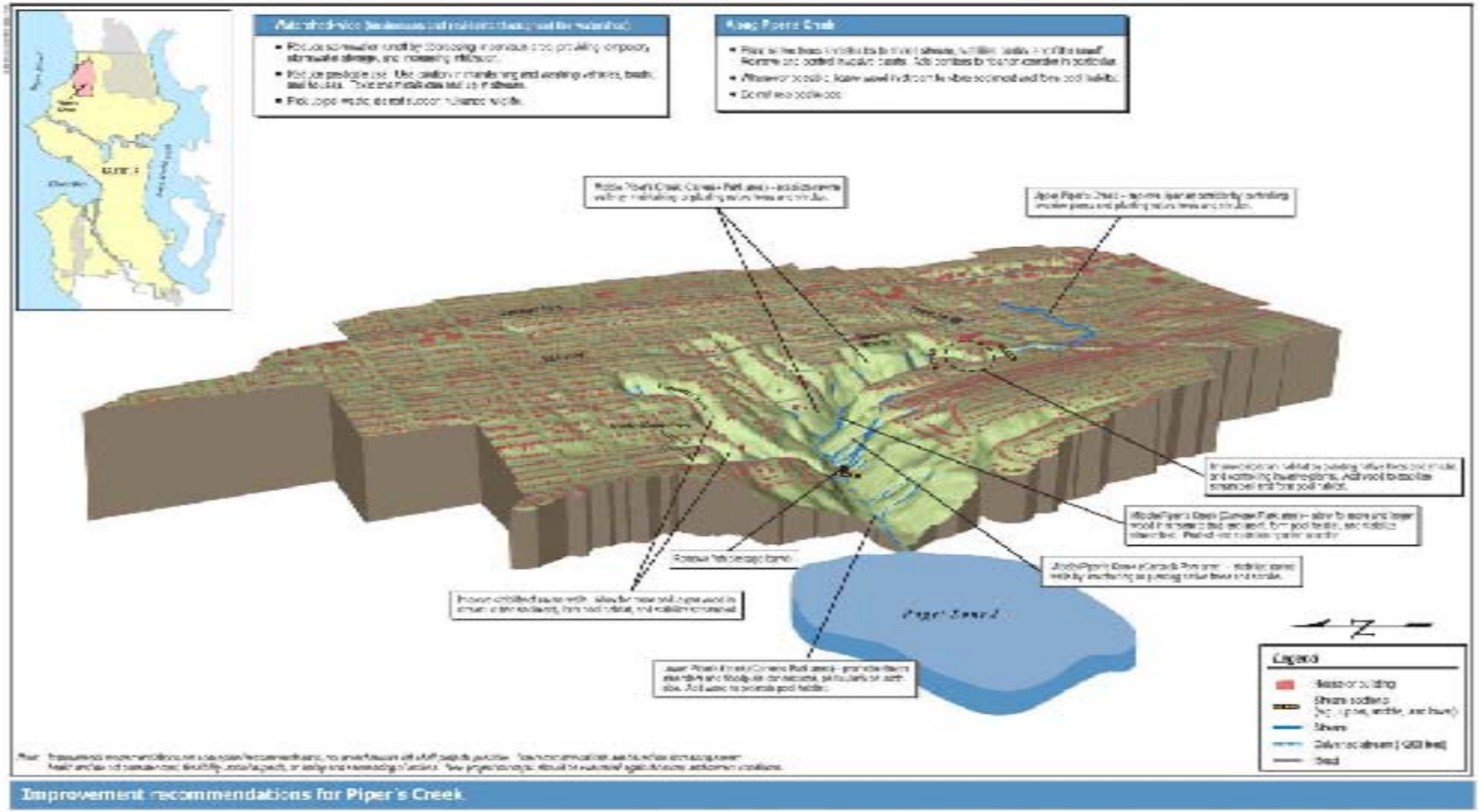

Figure G-9. Improvement recommendations for Piper's Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

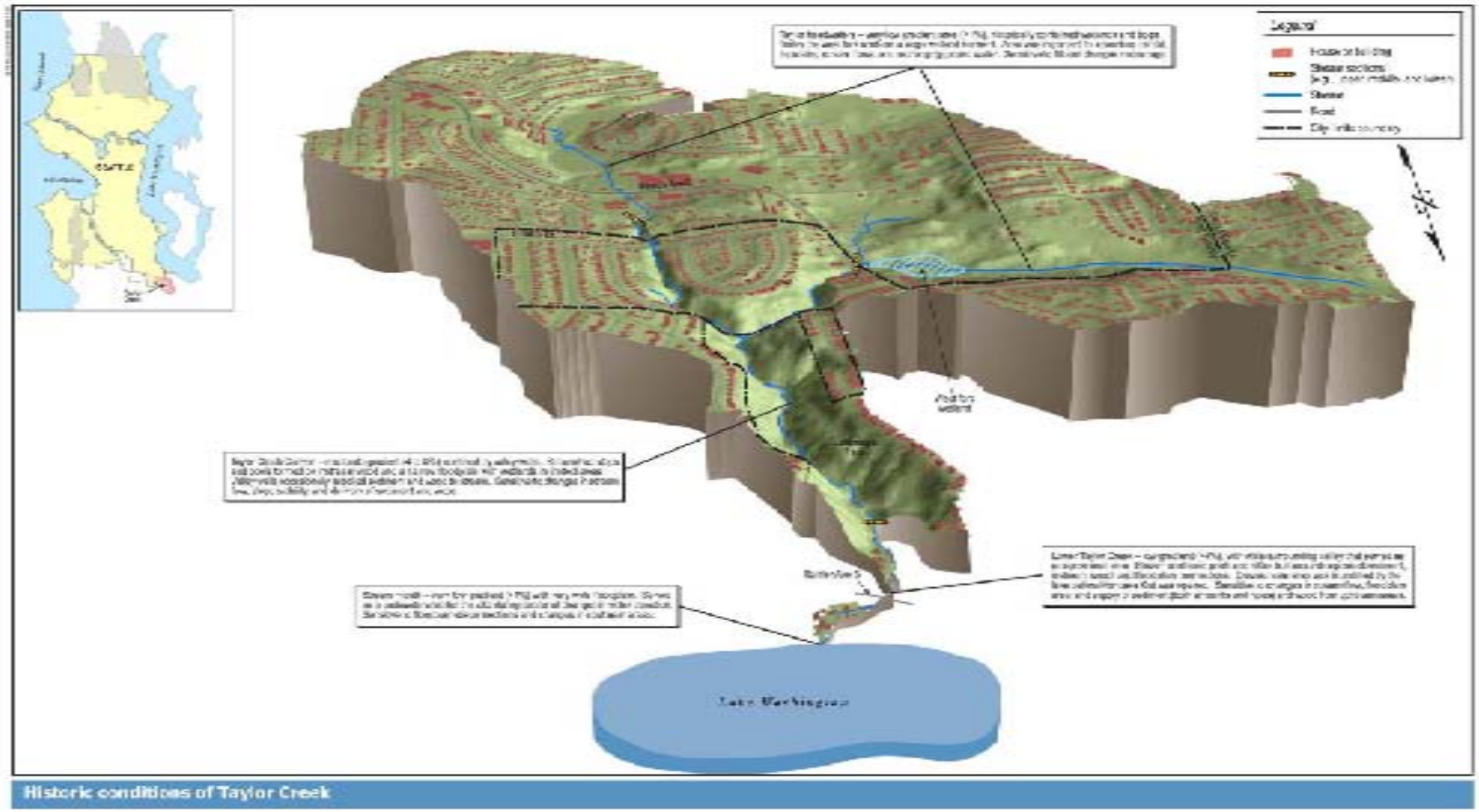

Figure G-10. Historical conditions at Taylor Creek. Roads and buildings are shown for spatial reference. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

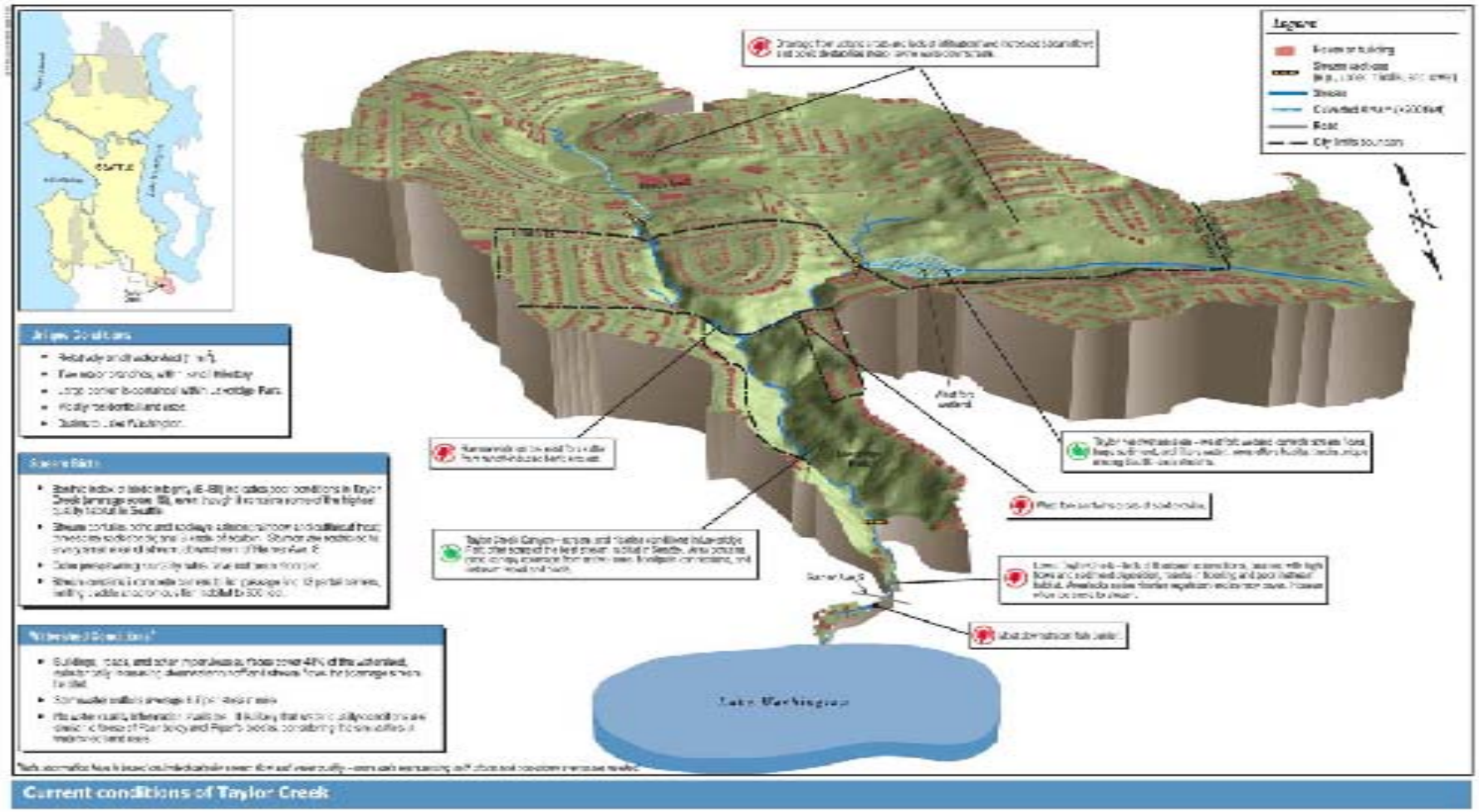

Figure G-11. Current conditions at Taylor Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

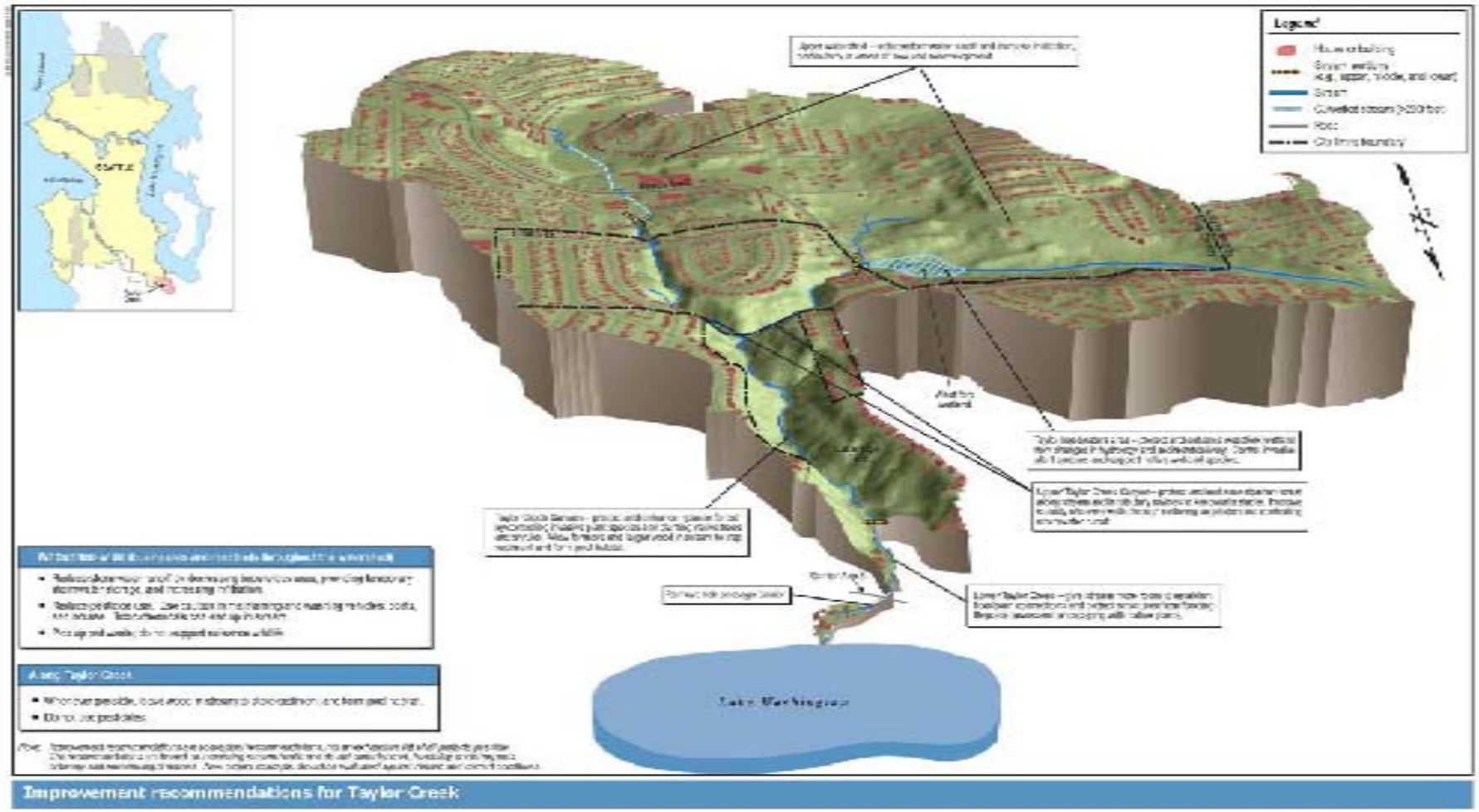

Figure G-12. Improvement recommendations for Taylor Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

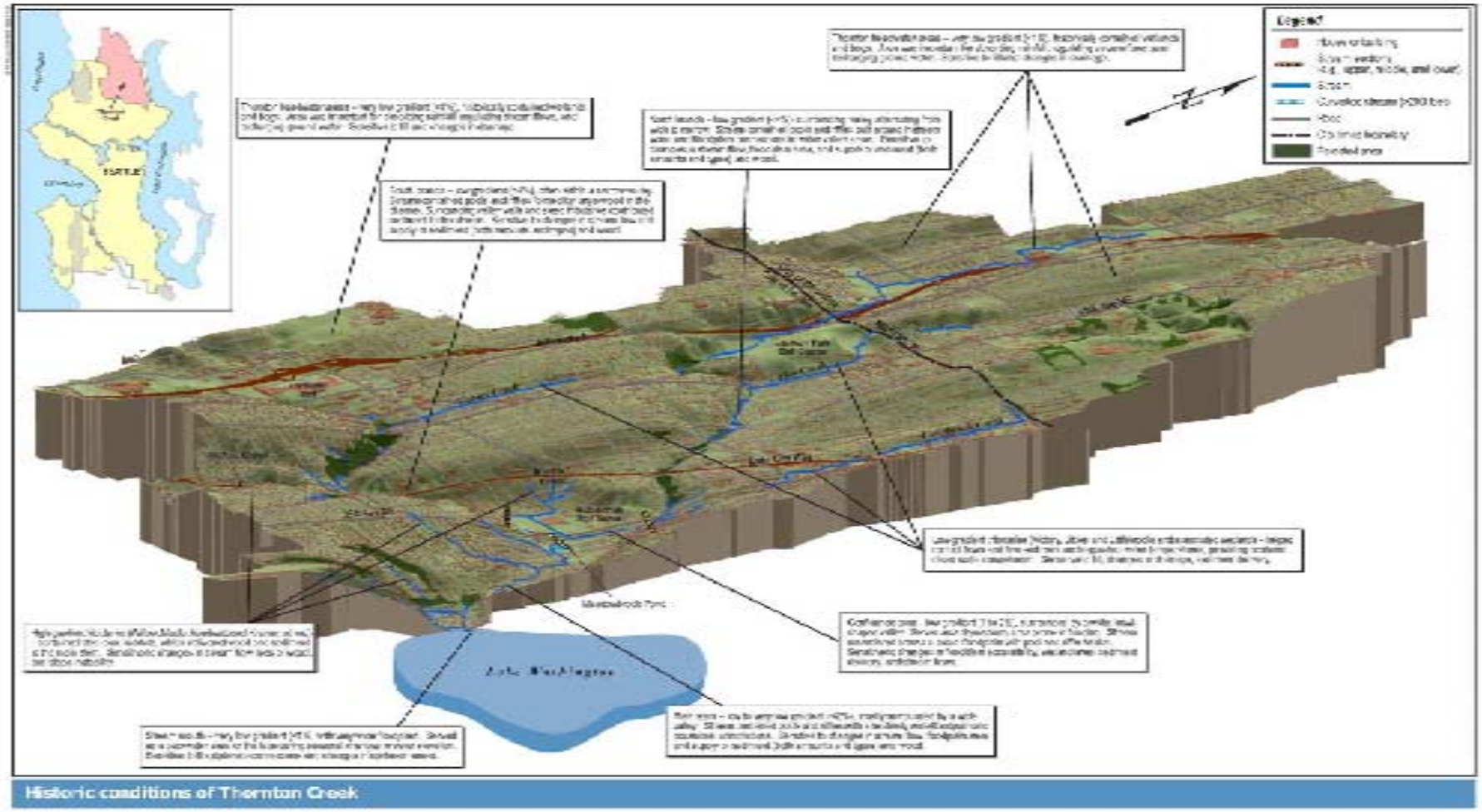

Figure G-13. Historical conditions at Thornton Creek. Roads and buildings are shown for spatial reference. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

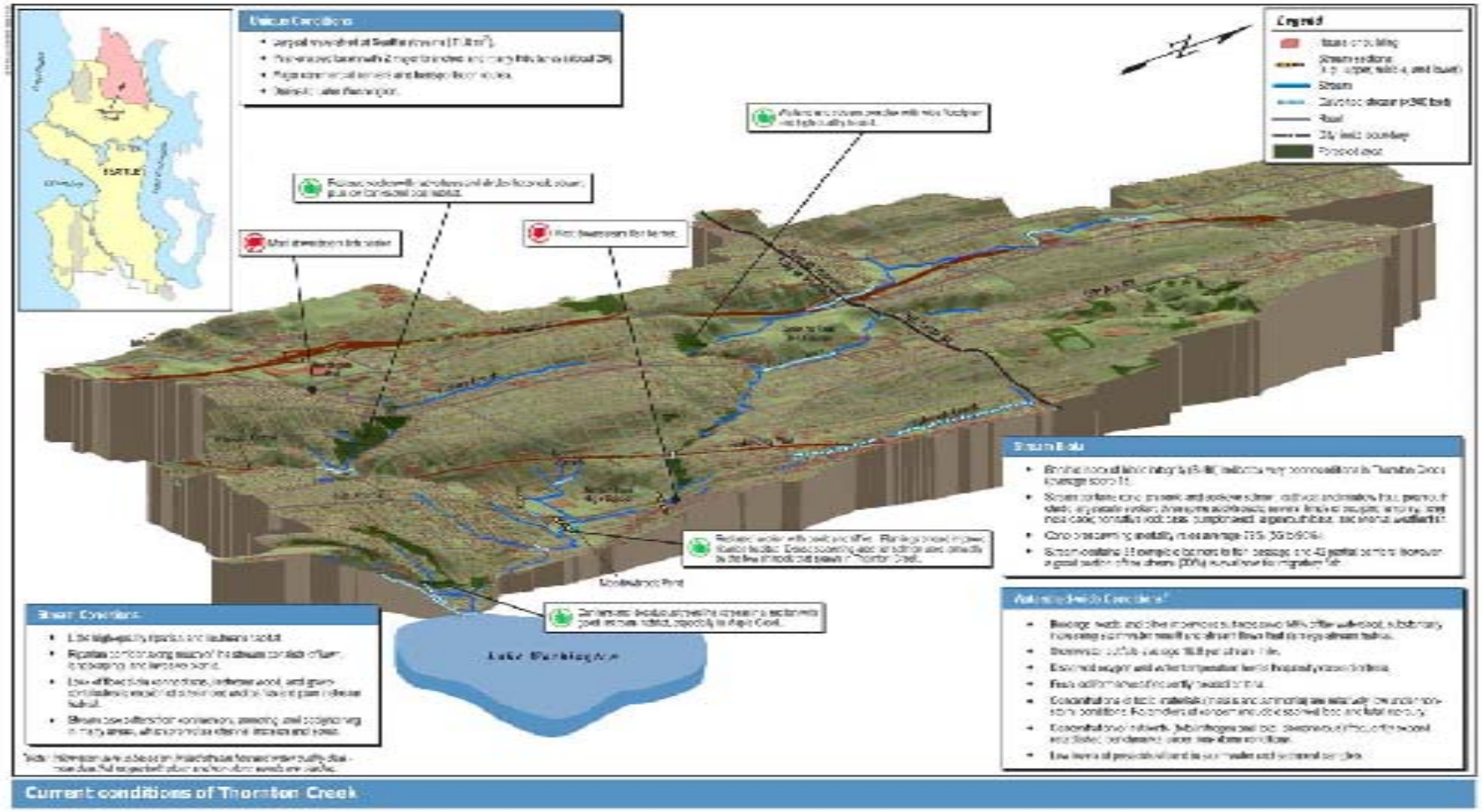

Figure G-14. Current conditions at Thornton Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

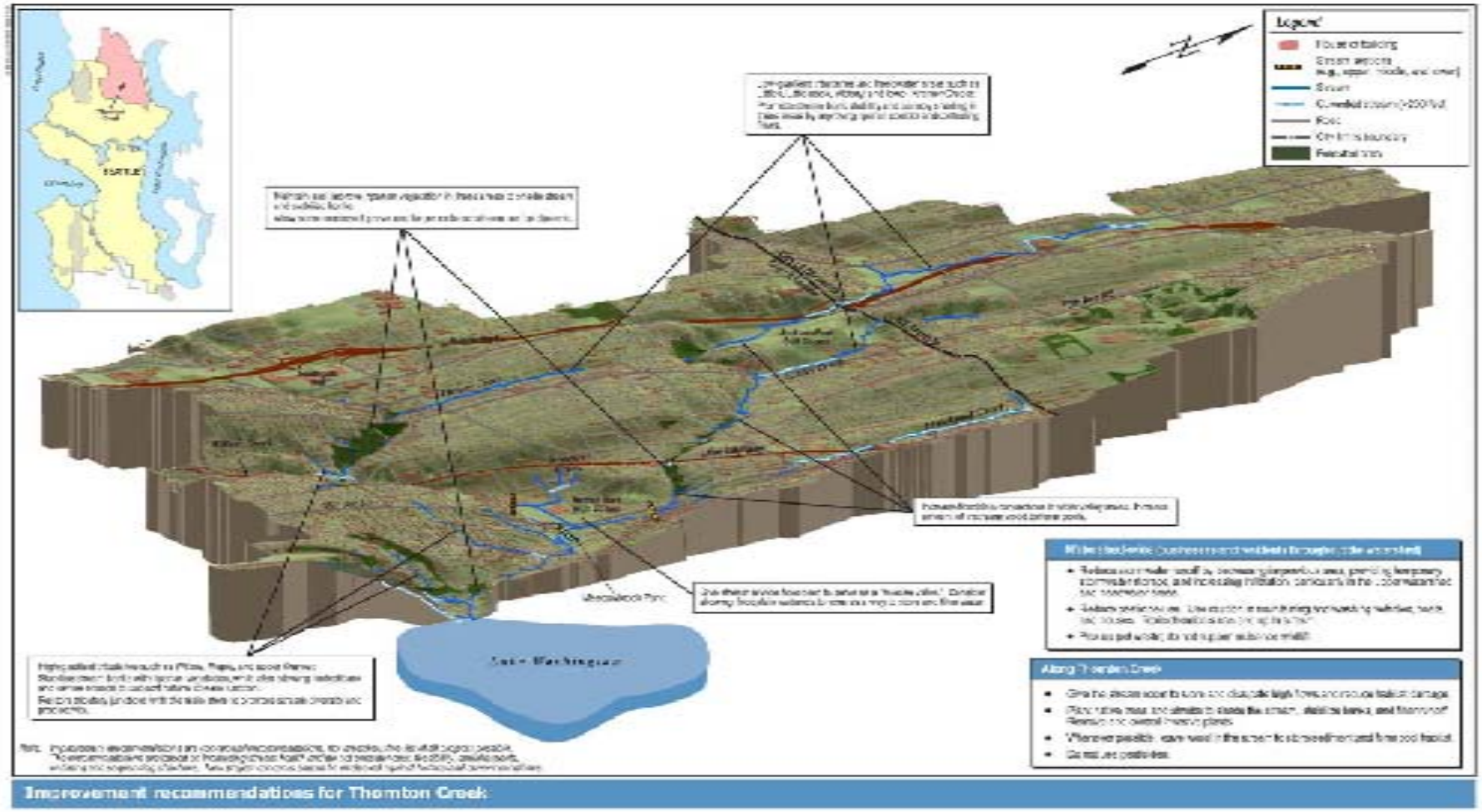

Figure G-15. Improvement recommendations for Thornton Creek. Graphic provided by Herrera Environmental Consultants, Seattle, Washington.

Appendix H

Indicators, Likely Methods, and Cost Considerations

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Table H-1. Indicators, likely methods, and cost considerations for monitoring the primary and secondary indicators of ecological health of Seattle's creeks. Monitoring would need to include a Quality Assurance Project Plan and follow established standard operating procedures.

Indicator or metric	Likely method(s)	Cost considerations
T_{Qmean} is the fraction of the year in which the mean annual discharge is exceeded. The higher the value, the more stable and less "flashy" the flow. i.e. Flashiness	Install continuous recording flow or staff gage at each major stream (where non-existent now)	Could install flow monitoring stations or staff gages. Staff gage use will require installation of pressure transducer(s) and surveys to develop a rating curve for each site, to relate stage to discharge. Estimate: collect measurements monthly during baseflow or small storm conditions, plus take measurements during 3-4 large storm events per year, one day each for two field technicians to collect depth and velocity measurements. Equipment costs and annual maintenance costs ~ $5000 per site per year. Likely $8000 per site in the first year.
Maximum temperature (7-day average) of stream waters i.e. High stream temperature	Install continuous temperature recording devices throughout each stream of interest; set to record temperature during summer, at 30 minute increments.	Measures the moving average of 7-day maximums (June through September). Assume 5 streams to be included in survey, with 3 to 5 continuous recording thermographs per stream deployed in an upstream to downstream series. Deployment in stream is from June 1 thru Oct 15. Data should be collected at 0.5 hr or 1 hr increments. Data analysis includes development of seven day moving average of daily maximum temperature and maximum instantaneous rate of change on daily basis. Cost of units is ~ $130 each. One person day to install devices per every stream. Locations where units are installed need to be documented with GPS coordinates and written descriptions. One person-day to retrieve units per every stream. Equipment should undergo a calibration check before installation and field audits every 3 months that unit is in field for greater data confidence. Forty hours to process all data and develop statistical analysis.
Dissolved oxygen	Install continuous dissolved oxygen recording devices	Install devices in all 5 streams and deploy for period coincident with temperature monitoring. One device per stream should be sufficient. "Continuous monitoring can integrate these indicators using OEM datasondes (~$5k to $8K each) or custom sensors for turbidity, temperature, DO (luminescent), pH and conductivity. This approach can generate high frequency, high quality data and integrate the key parameters already identified and highly supported as key indicators of stream health. Adding telemetry (~$5 to $10K per station depending on communications, location, etc) can provide real-time signals for rapid responses (i.e. illicit discharges), and reduce field work." (Scott Tobiason, pers. comm.). Frequent maintenance (up to weekly) and calibration is required. Time is also required to download,

Indicator or metric	Likely method(s)	Cost considerations
		manage, and analyze data.
Bank armoring (%), i.e. hardening	A field survey crew walks entire accessible length of stream channel, recording lineal length of banks armored, fixing beginning and end points with GPS.	Measures cumulative length (both sides) and overall percent of bank hardened or "armored" condition for each stream. Surveys should be repeated every 5 years or earlier if reduction in armoring at key locations is targeted for restoration work. A two-person crew can likely survey ~ 1 mile of channel per day, meaning roughly 10 miles of stream channel within 10 to 12 days of effort. Data collected onto field sheets that are transcribed into database to allow reporting of summary statistics. Data transcription and reporting would likely take ~ 20 hours.
Frequency of **woody debris**, occurrence in three size classes LWD (large woody debris)	Baseline data collection effort – survey ~ 50% of lineal length for LWD. Count pieces by size category.	Measures the frequency of woody debris in the stream, per size class (# per 100m; size classes as small, medium and large). Collect data at same time as bank armoring.
# **Pools** >0.3 m residual depth Pool depth	Data collection methods employ standard longitudinal profile with survey level and rod, for length of identified index reaches ~ 25 to 50% of length of stream	Measure residual pool depths of (>1 ft) (assumed sufficient for migrating adult salmon and rearing juveniles. Longitudinal survey allows accurate data collection. Data analysis is easily accomplished with readily available software (MS Excel). Collect data at same time as bank armoring.
Pool spacing	Done coincident with above	Performed coincident with above.
Artificial fish **barriers** Culvert barriers	Foot survey of each stream course to document current status of barriers, and detect any new ones.	A survey of physical barriers to upstream migration to document the number of full and partial man-made barriers will be completed for each stream within Seattle. Tracking improvements over time is an important factor to ensure progress and accountability. Such surveys should be re-done every 5 years or earlier if targeted for specific improvements. Alternatively, existing inventory records could be updated during field surveys for bank armoring, woody debris and pools.
B-IBI, **Benthic Index of Biological Integrity** Macroinvertebrates (aquatic insects)	Follows standard benthic invertebrate survey protocol conducted each year at specific index sites	Currently samples are collected every other year at sites in the five major streams. Samples are collected using volunteers and processed by an outside laboratory. For labor estimates, sampling would require one sampling field day per stream, and ~ 8 hours of sample processing to identify dominant taxa to family or genera level. Additional time will be needed for data

Indicator or metric	Likely method(s)	Cost considerations
	on each stream.	management and analysis. For more specific site remediation evaluation where structural restoration work has been completed, field data collection efforts can be part of project evaluation metrics.
Fish, seasonal distribution and relative abundance	Electro-fishing survey of selected index reaches performed every year for first 10 years and then every other year.	Level of effort is rather high. Requires a two-person field crew to spend one full day at each stream site. Survey routine includes identification of species, length, weights and habitat associations. Fish sampling surveys that are performed periodically as part of an extensive monitoring program will establish year-to-year estimates of distribution, abundance, and growth for both native and non-native fish within Seattle urban streams. Tracking over time will provide evidence of increasing or decreasing trends in overall condition of native salmon and trout, and overall species composition of the stream community. An alternative indicator is species diversity and abundance, with snorkel surveys conducted to collect counts of fish by species and size class. This would be a less costly technique, although snorkeling may be restricted by shallow stream depths.
Streamside (riparian) Shade	Aerial photo interpretation with integration into GIS data layer representing locations where streamside vegetation provides shade	Remote characterization of stream-side shading can be done from aerial photos and results catalogued in Arc GIS. Criteria for trees providing shade (including location, density, canopy diameter) will need to be defined. Data would be represented by lineal length of stream with riparian shade and percent of stream channel having shade. Estimate that this analysis would take ~ 20 hours per stream for air photo interpretation, and ~ 20 hours for field verification, if warranted, for each stream. Subsequent re-calibrations to be done every 5 years from new aerial photos, as available.
Secondary Indicators		
Bed surface particle size distribution at index spawning areas	Wolman (1954) method for bed particle size characterization; completed at subsample of sites suitable for spawning of anadromous fish	Cost is relatively low as this involves ~ 20 minutes of labor for a two-person crew to collect and measure particles at each site, exclusive of travel time. Can be done in conjunction with other habitat survey work. Data compilation and analysis is easily accomplished with MS Excel and graphics automatically generated. Suggested number of "samples" depends upon monitoring objectives and relative distribution of suitable spawning areas. Suggest min. 10 sites per creek, with sampling repeated every other year.
Floodplain connectivity (as measured by Width-to-depth ratio),	Channel cross sectional surveys done at specific locations where stream width and gradient are appropriate	Reaches of Seattle streams with actual floodplains are limited in number, and easily identified. All such sites can be detected from aerial photos and results from longitudinal surveys. To the extent that these locations might be the focus of restoration efforts to re-connect channels with floodplains, further site evaluation will be in order once further analysis has been done at individual sites.
Aquatic health toxicity	Not yet defined	Done in conjunction with ongoing investigations of coho pre-spawning mortality studies in certain Seattle streams. Methods will need to be defined before cost estimate can be provided.

Indicator or metric	Likely method(s)	Cost considerations
Continuous turbidity	Not yet defined	Turbidity would need to be measure continuously. Costs include purchase of equipment, frequent maintenance (up to weekly) and calibration, and data download, management, and analysis.