FINAL GRANT REPORT
ATTACHMENT A

Habitat Status and Trends Monitoring for the Lower Columbia Region: Integrated Monitoring Design

FOR

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Habitat Status and Trends Monitoring for the Lower Columbia Region Integrated Monitoring Design

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ABSTRACT

In 2012, the City of Longview retained the Lower Columbia Fish Recovery Board (LCFRB) and initiated a collaborative project to design and implement an integrated Habitat and Water Quality Status and Trends Monitoring project (HSTM) in the Lower Columbia Region – comprised of the Columbia River mainstem from its mouth up to Hood River, and all Columbia River tributary subbasins from the mouth of the Columbia River up to and including the White Salmon River in Washington and the Hood River in Oregon, and the Willamette River up to Willamette Falls. The primary goal of the HSTM project is to complete a monitoring design to meet the status and trends monitoring needs of the Washington State Department of Ecology (Ecology), southwest Washington municipal stormwater permittees, LCFRB, and other partners of the Pacific Northwest Aquatic Monitoring Partnership's program for Integrated Status and Trends Monitoring.

This Design Report represents the culmination of the first two stages of a three-stage effort. Stage 1, completed in June 2013, developed the overarching framework for the coordinated strategy. Subsequently, this Design Report has now articulated the final goals and objectives for the integrated monitoring project for water quality and habitat, and it specifies the target populations, sampling stratification, and metrics proposed. The sampling strategy and recommended metrics vary between urban and non-urban areas within the Region with proposed sampling segments/sites derived from the "Washington Master Sample". Stage 3 of the HSTM project, currently planned for 2015-2016, will develop the final implementation plan, which will provide sufficient detail in data collection, management, and analysis to answer the management questions and objectives that drive the program as a whole, and to clarify stakeholder roles and responsibilities in order for data collection to begin.

DEFINITIONS OF ABBREVIATIONS AND ACRONYMS

Term	Definition
AREMP	Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Program
BFW	Bankfull Width
BLM	Bureau of Land Management
BMP	Best Management Practices
CDFG	California Department of Fish and Game
CHaMP	Columbia Habitat Monitoring Program
DA	Drainage Area
DPS	Distinct Population Segments
Ecology	Washington Department of Ecology
EMAP	EPA Environmental Monitoring and Assessment Program
ESA	Endangered Species Act
ESU	Evolutionarily Significant Units
GIS	Geographic Information System
GPS	Global Positioning System
GRSS	Grants of Regional or Statewide Significance
HSTM	Habitat and Water Quality Status and Trends Monitoring
ISTM	Integrated Status and Trends Monitoring
LC	Lower Columbia
LCFRB	Lower Columbia Fish Recovery Board
LCMS	Lower Columbia Master Sample
LCR	Lower Columbia River
LWD	Large Woody Debris
MS4	Municipal Separate Storm Sewer Systems
MSWPA	Municipal Stormwater Permit Area
NAWQA	National Water Quality Assessment
NIFC	Northwest Indian Fisheries Commission
NLCD	National Land Cover Dataset
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
PAH	Polycyclic Aromatic Hydrocarbons
PIBO	USDA Forest Service-BLM (Effectiveness Monitoring Program for PACFISH/INFISH Biological Opinion)
PNAMP	Pacific Northwest and Aquatic Monitoring Partnership
PS RSMP	Puget Sound Regional Stormwater Monitoring Program
QA	Quality Assurance
Qa/Qx	Water Quality and Water Flow
QAMP	Quality Assurance Monitoring Plan
QAPP	Quality Assurance Project Plan
RSMP	Regional Stormwater Monitoring Program

Term	**Definition**
S&T	Status and Trends
S/N	Signal to Noise
SWG	Puget Sound Ecosystem Monitoring Program Stormwater Work Group
TR3	Tetra Tech 2013
UC	Upper Columbia Monitoring Strategy
UGA	Urban Growth Area
USFS	United States Forest Service
USGS	United States Geological Survey
WA	Washington
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WHM	Washington State Department of Ecology's Watershed Health Monitoring Project
WQI	Water Quality Index
WRIA	Water Resource Inventory Area

GLOSSARY OF TERMS

Term	Definition
bankfull width	the width of the bankfull channel measured at a section perpendicular to streamflow
legacy sites	sites with existing water quality and/or habitat monitoring data in the Lower Columbia
Lower Columbia Evolutionarily Significant Unit	also referenced as the Lower Columbia Region Recovery domain, the ESU comprises the Columbia River mainstem from its mouth up to Hood River, and all Columbia River tributary subbasins from the mouth of the Columbia River up to and including the White Salmon River in Washington and the Hood River in Oregon, and the Willamette River up to Willamette Falls
master sample	a common set of random sites along the state's rivers and streams developed for use in comparable, complementary monitoring among separate monitoring organizations and across geographic scales
metrics	measures of quantitative assessment
National Land-Cover Dataset	a 16-class land cover classification scheme based on satellite imagery that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters
opportunistic design	a study design that selects sites based on ease of access, expert opinion, or other subjective criteria
persistence probability	the complement of a population's extinction risk (i.e., persistence probability = 1 - extinction risk)
Phase I municipal stormwater NPDES permittee	municipalities that operate separate storm sewer systems must obtain a National Pollutant Discharge Elimination System (NPDES) permit for their stormwater discharges. These permits require the implementation of a stormwater management program, which normally includes various types of monitoring. Phase I permittees are those cities and counties with populations of 100,000 or more. In the LCR, Clark County is the only Phase 1 municipal stormwater NPDES permittee.
Phase II municipal stormwater NPDES permittees	Phase II municipal stormwater NPDES permits cover small separate storm sewer systems in urbanized areas, as well as small systems outside the urbanized areas that are designated by the permitting authority (which, in Washington state, is the Department of Ecology). The LCR contains seven Phase II permittees: Cowlitz County and the cities of Camas, Longview, Vancouver, Battle Ground, Kelso and Washougal.
primary population	a population that is targeted for restoration to high or very high persistence probability
probabilistic design	a study design where sites are randomly selected across the entire area of interest
properly functioning condition	NMFS defines properly functioning condition as the sustained presence of natural habitat-forming processes that are necessary for the long-term survival and recovery of the species
pseudo-random	the addition of data (legacy sites) to a random sample of monitoring sites
reach	The portion of a stream sampled for habitat (20 times bankfull width)

Term	**Definition**
segment	The portion of a stream that receives drainage from a defined range of watershed areas; the sampling "unit" for Qa/Qx monitoring
signal to noise	analysis that compares the magnitude of "true" change in a metric with the magnitude of its random (or otherwise irreducible) variability
site	The proposed location of water quality and/or habitat sampling
site allocation and stratification	the framework for subdividing and categorizing the points of the master sample by some or all of their underlying attributes (such as drainage area or channel gradient) to ensure that monitoring of a subset of the categorized points will be representative of that group as a whole
statistical confidence	an expression of the expected variation in a given estimate
statistical power	ability of a test to detect an effect
stream segments (for Qa/Qx sampling)	a contiguous series of master sample points along a single stream with common drainage area classification (e.g., 2.5-50 km^2)
substrate size	the diameter of the sediment on the bed of a stream channel, normally presented as the percentage of particles within a series of size classes and summarized by the diameter of the median particle size (D_{50})
subwatersheds	drainage areas of 3,000-12,000 acres (about 12 to 49 km^2)
target population	candidate sampling sites drawn from the "Washington Master Sample," a common set of random sites that meet specified criteria along the state's rivers and streams developed for use in comparable, complementary monitoring among separate monitoring organizations and across geographic scales

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EXECUTIVE SUMMARY

In 2012, the Lower Columbia Fish Recovery Board (LCFRB) and the City of Longview initiated a collaborative project to design and implement an integrated Habitat and Water Quality Status and Trends Monitoring project (HSTM) in the Lower Columbia Region. Pursuit of such integration is motivated by two monitoring needs that face the region: supporting the recovery of salmonid species listed as threatened or endangered under the Endangered Species Act (Chinook, coho, chum, and steelhead), and addressing anticipated future monitoring requirements under municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits for eight jurisdictions in southwest Washington. By developing a coordinated strategy across these two monitoring programs, fiscal efficiencies and more robust and meaningful regional assessments should be achieved.

The primary goal of the HSTM project is to complete a monitoring design to meet the status and trends monitoring needs of the Washington State Department of Ecology (Ecology), southwest Washington municipal stormwater permittees, LCFRB, and other partners of the Pacific Northwest Aquatic Monitoring Partnership's program for Integrated Status and Trends Monitoring. This Design Report represents the culmination of past and present efforts conducted over the last 18 months, representing "Phase 2" of an envisioned three-phase effort. Phase 1, completed in June 2013, developed the overarching framework for the coordinated strategy. Subsequently, this Design Report has now articulated the final goals and objectives for the integrated monitoring project, and it specifies the target populations, sampling stratification, and metrics to be used. Phase 3, currently planned for 2015–2016, will develop the final *implementation* plan, which will include the pragmatic details necessary for the actual initiation of monitoring—site selection, measurement protocols, data analyses, data management, and reporting—all of which are essential for successful on-the-ground execution, but none of which affect the design of the program as a whole.

The project study area is envisioned to include all of the Lower Columbia Region Recovery domain, also referenced as the Lower Columbia Evolutionarily Significant Unit (ESU), which comprises the Columbia River mainstem from its mouth up to Hood River, and all Columbia River tributary subbasins from the mouth of the Columbia River up to and including the White Salmon River in Washington and the Hood River in Oregon, and the Willamette River up to Willamette Falls. The current phase of the project addresses only the monitoring design for tributaries in the Washington portion of the ESU. Future phases hope to include the Oregon portion of the Region upon participation and funding by Oregon agencies, and to incorporate monitoring of the Columbia River mainstem and tidally influenced habitats, in order to generate a more complete picture of the landscape and its habitats. At present, the project also addresses the anticipated requirements for status and trends monitoring for the one Phase I and seven Phase II municipal stormwater NPDES permittees in western Washington.

Methods

The methods and materials used to develop this final design report followed the same basic approach of Phase 1 of the HSTM project, including agency documents, peer-reviewed scientific literature, and ongoing input from project partners and stakeholders through weekly and monthly meetings, four public workshops, and review comments on draft and final reports.

The work was organized using the framework established in Phase 1, addressing each of the key components of monitoring design in turn:

- Guiding monitoring questions and objectives
- Target population(s) for monitoring
- Site allocation and stratification
- Metric evaluation and selection

The original monitoring questions from Phase 1 were refined to achieve greater specificity in their associated monitoring objectives, and to ensure that the overarching goals of the participants would be addressed by the final set of questions and objectives. They were also modified so that the resulting monitoring program would more likely be feasible and affordable for participants in the region.

The target population of candidate sampling sites was drawn from the "Washington Master Sample," a common set of random sites along the state's rivers and streams developed for use in comparable, complementary monitoring among separate monitoring organizations and across geographic scales. The master site list has 387,237 points in Washington, of which more than 100,000 are located in the Lower Columbia ESU. Identifying suitable combinations of alternative strata and categories made use of the preliminary conceptual framework for stratification developed during Phase 1, followed by extensive querying of the Master Sample to satisfy diverse requirements.

Prospective candidate metrics were evaluated from the same perspectives as the strata: technical relevance, regulatory needs, and financial feasibility. These considerations were evaluated using the same types of source information as was applied to the Master Sample stratification, with a particular emphasis on the experiences of other monitoring programs in terms of both data usability and cost. In particular, development of a final set of metrics focused on identifying those with sufficient precision and replicability in order to select those that yield reliable results that could be shared with other monitoring programs. Signal to noise (S/N) analyses, which compare the magnitude of "true" change in a metric with the magnitude of its random (or otherwise irreducible) variability, were used extensively to evaluate this attribute. Literature-reported ratings for S/N informed this determination, recognizing that strict equivalency between different monitoring programs is not commonly achieved in practice but that informed comparisons are nonetheless informative.

The integration of these considerations, based on both internal discussions and multiple consultations with project stakeholders, has led to the final suite of recommended metrics in this Design Report. Although this suite of metrics is tailored to the goals and objectives of this study, they are sufficiently universal in range and applicability that other monitoring programs, even those with a different suite of metrics or focus of study, should be able to achieve meaningful integration of data and understanding.

Results and Recommendations

Target populations, stratification, and site selection for water quality/water flow monitoring

Site selection for water quality/water flow ("Qa/Qx") sampling takes advantage of the continuity of flowing water, under the assumption that most of these metrics vary spatially only gradually, if at all, along a given channel in the absence of significant natural or manmade (i.e., stormwater outfall) tributary inputs. Thus, the population of Qa/Qx sites from which sampling locations will be drawn are channel *segments* (not individual *points*). Within a selected segment, the specific location chosen for sampling should have little influence on most types of collected data, and thus ancillary considerations (such as site access or the reoccupation of legacy sampling sites that are located within the selected segments) can be incorporated without undermining the random spatial design that underlies the Master Sample.

Within the Urban Growth Areas (UGAs) of NPDES permittees and draining predominantly urban watersheds, streams draining at least 2.5 km^2 and no more than 50 km^2 are recommended as the target population, in order to maximize the utility of these results for future management actions. Over 30 such channel segments are present within the Region that meet these criteria; about 15 such segments will be needed for monitoring to achieve adequate statistical confidence in the representativeness of monitoring data for the population of such channels as a whole. Selection can be strictly random, or on a combination of preemptive identification of stream segments with suitable long-term Qa/Qx data (“legacy sites”) plus additional randomly selected segments as needed to achieve the necessary number. Because several of the monitoring objectives may be better addressed with a more directed, pseudo-randomized site selection approach, the final strategy will be determined during a review of preexisting data at specific locations, in consort with the other relevant details of implementation (see below).

Once a segment has been selected, identifying a specific sampling location will begin at the downstream end, moving upstream to find the first feasible sampling location as guided first by logistical considerations of access and adjacent land ownership as identifiable through GIS and aerial photographs, and then by a field visit to each candidate site to confirm access and overall suitability for monitoring (particularly benthic macroinvertebrate and sediment chemistry sampling, which have specific requirements for substrate in order to yield meaningful results).

Qa/Qx sampling *outside* of designated UGAs encompasses a more diverse landscape than found in the urban NPDES areas, and so a greater degree of stratification is needed to achieve meaningful representation of the population (recognizing that watersheds even outside of an Urban Growth Area may nonetheless have predominantly “urban” land cover):

- Drainage area (0.6–2.5 km^2, 2.5–50 km^2, 50–200 km^2) = 3 categories
- Predominant watershed land cover as classified in the National Land-Cover Dataset into three major types (forested, agricultural, urban) = 3 categories

These three broad land cover classes (forested, agricultural and urban) represent most, albeit not all, conditions within the basins (for example, bare rock and wetlands are not included in any of these classes).

In addition to these two strata, the relative importance of some subbasins to regional salmon recovery over others suggests the need to identify high-priority areas explicitly through the final stratification framework. This will ensure that sufficient monitoring sites are located in those high-priority subbasins in support of recovery efforts, rather than relying on the random distribution of sites selected from the entire Master Sample to achieve adequate coverage. The 25 subbasins of the region has been subdivided into three categories by the number of Primary Populations (defined in the 2013 Lower Columbia River Salmon and Steelhead Recovery Plan as “a population that is targeted for restoration to high or very high persistence probability”) (0–2, 3, 4+ populations) and are included here in the final design for stratification.

The strategy used for allocating Qa/Qx sites among the approximately 400 segments in the region that lie outside of UGAs should proceed as described above for the urban NPDES Qa/Qx sampling. Candidate sampling locations should be evaluated from downstream to upstream, located where the logistics of access are first judged feasible, and then field-checked for actual suitability.

Target populations, stratification, and sample selection for habitat monitoring

Habitat monitoring will occur at selected Master Sample sites, located in continuous, freshwater streams with non-constructed channels above any influence of tides or backwatering of the Columbia River. Habitat monitoring will sample randomly chosen sites selected from all points that meet a specific set of strata-based selection criteria. Habitat monitoring sites do not have identical target populations or strata to those of Qa/Qx sites, however, because the attributes being measured by these two types of monitoring are fundamentally different in several respects. Habitat data are collected on physical features at a site, rather than water-column attributes that are relatively constant over long distances. Habitat features are also more sensitive to instream channel dynamics, and so their dependency on stream power must be incorporated into the stratification to ensure representative results for the population as a whole.

Although future habitat-monitoring needs of municipal stormwater NPDES permittees may not differ from those in the rest of the region, the same urban/non-UGA discrimination as for Qa/Qx monitoring is maintained to retain future flexibility. As such, sites for monitoring in urban NPDES areas and non-UGA areas of the region will be considered independently, albeit with a common set of recommended strata for both:

Drainage Area (0.6–2.5, 2.5–50, 50–200, 200–1,000, >1,000 km^2) = 5 categories
Stream Gradient Groups (<1.5%, 1.5–3%, 3–7.5%, >7.5%) = 4 categories
Predominant watershed land cover as classified in the National Land-Cover Dataset (forested, agricultural, urban) = 3 categories

In addition to the three common strata, the number of Primary Populations in the subbasin [(0–2, 3, 4+) = 3 categories] is recommended as an additional strata for habitat monitoring non-UGA areas. This supports salmon recovery priorities defined in the 2013 Lower Columbia River Salmon and Steelhead Recovery Plan and consistent with Qa/Qx stratification.

Although the total recommended habitat strata nominally define 240 unique combinations (urban 5 × 4 × 3 + non-UGA 5 × 4 × 3 × 3), a significant fraction of those strata combinations have few to no monitoring sites in the Master Sample. For example, large, steep channels do not generally exist; and urban-NPDES sites will rarely have any predominant land cover aside from “urban”. In order to be retained as a unique combination of strata, a sufficient number of monitoring sites must exist. Absent more consistent data on the variance of habitat data, the number of sample sites within each category will match the recommended Qa/Qx sampling, resulting in the guidance that 15+ potential habitat monitoring sites be identified for any given strata combination.

Once a site has been identified for habitat monitoring, a preliminary review of access and adjacent land ownership using GIS and aerial photographs should be made. If the site appears to be a viable candidate, a field visit will still be necessary to confirm access and overall suitability. An identify reach length 20 times the average bankfull width should be identified to be sampled for all metrics requiring a “reach” (instead of a “point,” such as LWD inventories). As with Qa/Qx monitoring, several of the monitoring objectives may be better addressed with a more directed, pseudo-randomized site selection approach, for which the final strategy will be made during implementation.

Metrics

Metrics were selected on the basis of their ability to provide meaningful information on water quality, water quantity, and habitat conditions within broad, inferred limits of likely financial resources. A key evaluation for each metric was made on its typical signal-to-noise ratio (S/N, the degree to which actual trends in the data exceed the variability imposed on multiple measurements by virtue of random fluctuations or inconsistencies among different observers), making use of published studies to the extent they are available and relevant to the HSTM design. Literature values of S/N ratios for various candidate metrics were converted to letter grades using a preexisting scoring scale and used as a guide for metric selection. Metrics that consistently generated grades of D or F (i.e., S/N ratios less than 2) were removed from consideration.

Metrics recommended for collection at all Qa/Qx sites include water temperature, conductivity, and stage (all continuously measured and recorded); and sediment metals, macroinvertebrates, bankfull width, bankfull depth, wetted width, and substrate size (all annually). This list of recommended metrics errs on the side of minimizing cost, with the expectation that if additional funds become available then the value of spending them on additional data collection can then be explored and weighed against the value that is already being delivered by the monitoring program in-hand. Conversely, were a monitoring program to be judged “too expensive” from the start, it would risk an outcome wherein no data whatsoever is collected.

Metrics recommended for collection at all habitat sites fall in two broad categories: those that are not expected to change rapidly and need be measured only once per five years, and those for which annual re-measurement is appropriate. Five-year metrics comprise bankfull width/depth, reach length (20 times the bankfull width), channel type, number of habitat units (e.g., pool, riffle, run), sinuosity, floodplain area, and length of side channel habitat. Annual measurements, to be made during a single day’s site visit in the summer, comprise bank stability (categorical), pools per unit length, residual pool depth, thalweg depth, density/distribution instream wood, substrate particle size (% composition by grain diameter), embeddedness, relative bed stability, shade at mid channel, riparian canopy (% cover), riparian understory (% cover), and flow category. Temperature should be measured at every visit; those sites with critically high values may merit more intensive and frequent measurements, but this can be determined only once implementation has begun.

Next Steps

Following this Phase 2 monitoring design will be the development of a full Implementation Plan for the Lower Columbia Integrated HSTM Design, representing Phase 3 of the HSTM program. The overarching purpose of an implementation plan is to provide sufficient detail in data collection, management, and analysis to answer the management questions and objectives that drive the program as a whole, and to clarify stakeholder roles and responsibilities in order for data collection to begin.

During the process of implementation plan development, several outstanding issues will need to be resolved:

- What are the fiscal constraints on the scope of NPDES permittee-funded and regionally funded monitoring efforts?

- What and where are the high-priority legacy sites in the region, and how should pseudo-random site selection be integrated with fully random site-selection to incorporate them to greatest benefit?
- What should be the specific criteria for determining feasible access to candidate sampling sites?
- What should be the criteria and minimum standards for sharing data between programs?

Other tasks that will constitute the bulk of the implementation planning effort are the final identification of channel segments (for Qa/Qx monitoring) and sites (for habitat monitoring), quality checking and integrating the GIS-based landscape analysis into the site-selection and data-interpretation processes, defining the data-collection protocols for every metric, defining the procedures for data management and analysis, and establishing the framework and requirements for communicating the findings in ways that ensure their utility for the widest range of prospective end-users. In addition, a final Quality Assurance Project Plan will need to be prepared, covering many of these and related issues of data-quality objectives, quality control, data verification and usability that can only be finalized after the implementation plan is itself complete.

1 INTRODUCTION

1.1 Background

In 2012, the Lower Columbia Fish Recovery Board (LCFRB) and the City of Longview initiated a collaborative project to design and implement an integrated Habitat and Water Quality Status and Trends Monitoring project (HSTM) in the Lower Columbia Region. Pursuit of such integration is motivated by two monitoring needs that face the region: supporting the recovery of salmonid species listed as threatened or endangered under the Endangered Species Act (Chinook, coho, chum, and steelhead), and addressing anticipated future monitoring requirements under municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits for eight jurisdictions in southwest Washington. The project built on the progress of the Pacific Northwest Aquatic Monitoring Partnership's (PNAMP) Integrated Status and Trends Monitoring (ISTM) Project, which sought ways to design and implement more coordinated, efficient, and effective aquatic ecosystem monitoring than under the independence by which the various monitoring program had historically been conducted. By integrating status and trends monitoring related to municipal stormwater permits with other existing monitoring efforts in the WA Lower Columbia ESU, the intent is to gain fiscal efficiencies and more robust and meaningful regional assessments than could be achieved by either program in isolation.

The primary goal of the HSTM project is to complete a monitoring design to meet the status and trends monitoring needs of Ecology, southwest Washington municipal stormwater permittees, LCFRB, and other partners of the Pacific Northwest Aquatic Monitoring Partnership's program for Integrated Status and Trends Monitoring. This Design Report represents the culmination of past and present efforts conducted over the last 18 months, representing "Phase 2" of an envisioned three-phase effort. Phase 1, completed in June 2013, developed the overarching framework for the coordinated strategy. Subsequently, this Design Report has now articulated the final goals and objectives for the integrated monitoring project, and it specifies the target populations, sampling stratification, and metrics to be used. Some preliminary recommendations are offered herein, in recognition that any plan that does not describe a range of credible, tractable alternatives does not contribute to progress towards true implementation. However, the funding available for such a program cannot be known with certainty, and so a plausible design is presented herein, scaled by recent examples from around the region to guide this essential step.

"Phase 3" of this project (the Implementation Plan) will be the next and final step of this HSTM program and will immediately follow completion of Phase 2. It will develop the final *implementation* plan, which will include the pragmatic details necessary for the actual initiation of monitoring—site selection and confirmation, measurement protocols, data analyses, data management, and reporting—all of which are essential for successful on-the-ground execution, but none of which affect the design of the program as a whole.

1.2 Project Goals and Status

- Complete a monitoring design to meet the status and trends monitoring needs of Ecology, southwest Washington municipal stormwater NPDES permittees, LCFRB and other PNAMP ISTM partners. This is the primary goal of this project, and this Design Report represents the culmination and primary deliverable of the current effort.
- Secure the participation of Oregon agencies conducting monitoring and other PNAMP ISTM partners to the maximum extent possible to develop the Lower Columbia HSTM

design. This goal was spearheaded by PNAMP but to date (January 2015) has not been achieved.

- Develop a draft Quality Assurance Project Plan (QAPP) to support the proposed monitoring as outlined in the Design Report. That document has been prepared in conjunction with this Design Report and has been issued separately as a secondary deliverable. It is intended to be completed in the next phase of this project as part of the implementation planning.

1.3 Project Study Area

The project study area includes the Lower Columbia Region, also referenced as the Lower Columbia Evolutionarily Significant Unit (ESU), which comprises the Columbia River mainstem from its mouth up to Hood River, and all Columbia River tributary subbasins from the mouth of the Columbia River up to the White Salmon River in Washington (WRIAs 25, 26, 27, 28 and 29) and the Hood River in Oregon, and the Willamette River up to Willamette Falls (Figure 1). The current phase of the HSTM project was focused on the Washington portion of the ESU with intent to include the Oregon portion of the ESU at a later time, subject to participation and funding by Oregon agencies. The project area also includes the one Phase I and seven Phase II municipal stormwater NPDES permittees that are likely to see future requirements for status and trends monitoring as part of the permits expected in 2018.

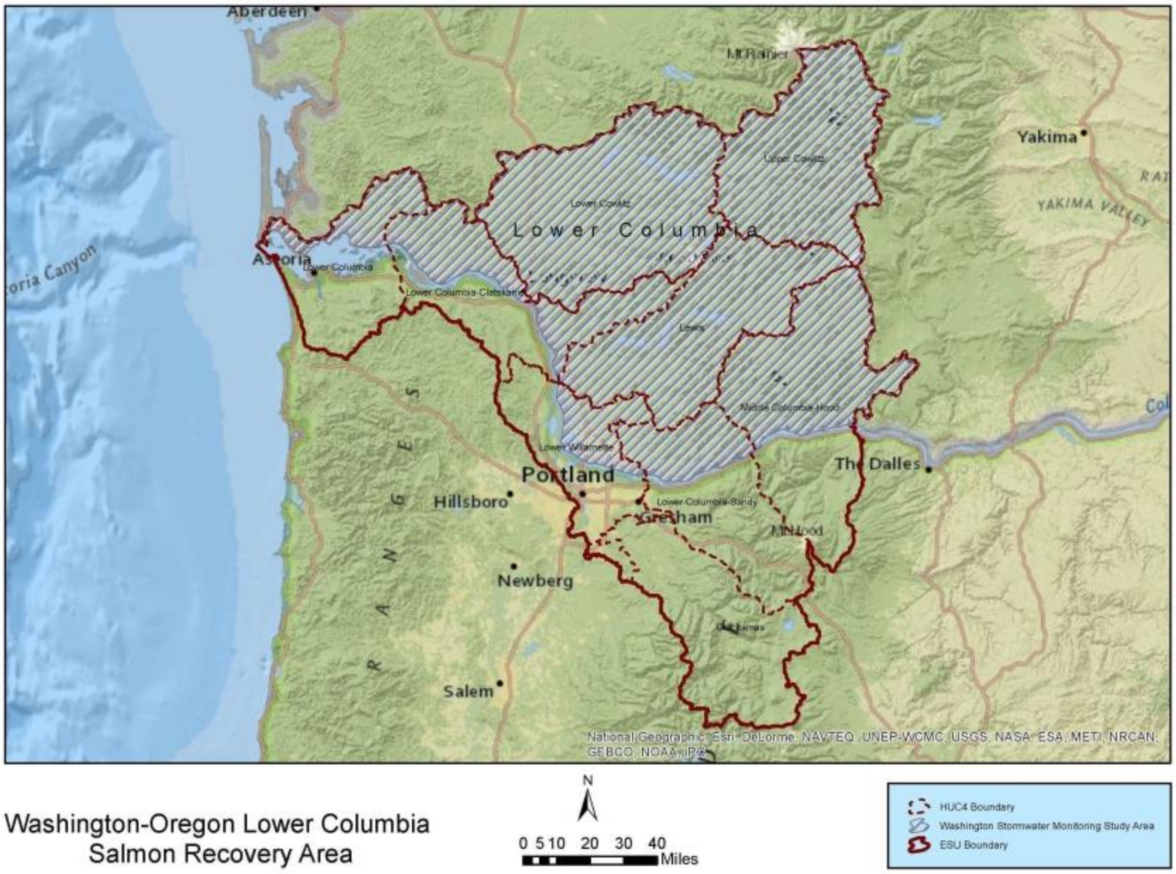

Figure 1. Lower Columbia ESU boundary, highlighting the Washington portion of the ESU. Source: LCFRB

1.4 Participants

Lower Columbia Region Habitat and Water Quality Status and Trends Monitoring Project participants include the following:

Integrated Status and Trends Monitoring (ISTM) project partners

- Pacific Northwest Aquatic Monitoring Partnership (PNAMP)
- Lower Columbia Fish Recovery Board (LCFRB)
- Washington State Department of Ecology (Ecology)
- US Forest Service (USFS)
- Bureau of Land Management (BLM)
- Columbia Habitat Monitoring Program (CHaMP)
- Oregon Department of Environmental Quality (ODEQ)
- Oregon Department of Fish and Wildlife (ODFW)
- National Marine Fisheries Service (NMFS)
- Washington Department of Fish and Wildlife (WDFW)

Participating SW Washington municipal stormwater NPDES permittees

- Phase I —Clark County (also an ISTM partner)
- Phase II—Cowlitz County and the cities of Camas, Longview, Vancouver, Battle Ground, Kelso and Washougal

Stakeholder input was provided throughout this Phase of the project (Phase 2) in the form of weekly conference calls with a technical team, monthly calls with a leadership team, product reviews and four public workshops with associated questionnaires to elicit stakeholder feedback.

2 METHODS

The methods used to develop this final design report followed the basic strategy outlined in Phase 1 of the HSTM project, beginning with the preliminary recommendations of that phase's final report (Tetra Tech 2013; hereafter "TR3"). The original set of monitoring questions presented in that report was refined, and greater specificity was developed for their associated monitoring objectives. Through a series of meetings (technical team and leadership team), a public workshop and interim product review, extensive feedback was received from the diverse stakeholders engaged in this project to ensure that the overarching goals of the various participants would be adequately addressed by the final set of questions and objectives, and that the monitoring program designed to address those questions was likely to be meaningful, feasible, and affordable for participants in the region.

Once this foundation for the monitoring program was settled, the specifics of the monitoring design—target populations, spatial strata, and site allocation—were determined. As with the questions and objectives, the products of the Phase 1 effort provided the initial framework, but closer inspection of their underlying assumptions and of the actual distribution of streams and prospective monitoring sites has resulted in adjustments to that preliminary design, as described below in Section 3. This "Phase 2" monitoring design also benefited from stakeholder input throughout the process. Lastly, the final set of recommended monitoring metrics has benefitted from both the initial Phase 1 recommendations and from further evaluation of agency documents and peer-reviewed literature on the utility, accuracy, precision, and variability (the latter two collectively termed "signal to noise") of various metrics. The work was organized using the framework established in Phase 1, addressing each of these key components of monitoring design in turn.

2.1 Questions and Objectives

Although the goal of this project is to describe and implement a status and trends monitoring program that integrates the needs of both regional salmon recovery managers and municipal stormwater NPDES permittees, the geographic domains and regulatory requirements are sufficiently different that they require somewhat independent development and presentation. The following questions and objectives are thus organized to reflect the explicitly "nested" structure of the HSTM project, first with a focus on the status and trends of watershed health in support of salmon recovery, at the scale of the entire Lower Columbia Region; and secondly with a more narrowly defined focus on the geographic areas (and more specific needs) of the municipal stormwater NPDES permittees within the region. These nested monitoring needs are complementary, and they should each generate information of value to the other while avoiding duplication of effort or increase in cost. The questions and objectives below are provided in support of this expectation; however, explicitly distinguishing the monitoring needs at each of these two scales separately provides the clearest path forward for project partners.

2.1.1 Regional-scale questions and objectives

Because "regional" monitoring also spatially incorporates municipal stormwater NPDES monitoring in a nested hierarchy, all land uses and jurisdictional areas are included at this broad scale. However, land uses across the region as a whole are predominately forestry, agriculture, or rural residential, and so monitoring questions and randomly selected sites at the regional scale will primarily reflect the status and trends of watersheds covered by these non-urban land uses, and in areas not covered by municipal stormwater NPDES permits. Thus, additional monitoring questions that more specifically address the needs of these NPDES permittees are developed separately in Section 2.1.2.

2.1.1.1 Water quality and water quantity (Qa/Qx)

The goal for this component of the project, as articulated in TR3, is to evaluate the status and trends of water quality and stream flow in surface waters to support beneficial and other water-dependent uses. This goal is common to many such monitoring efforts, but it requires further refinement and definition to clearly guide the specific elements of a monitoring program.

Predominant land uses in the Lower Columbia Region are forestry, agriculture, and rural residential. Multiple prior studies across the Pacific Northwest and elsewhere have implicated these land uses in reduced watershed health and limiting the quality of salmonid habitat, primarily through increases in fine sediment and turbidity, temperature, pesticides, and nutrients (e.g. Horner et al. 1997, National Research Council 2009). Alterations to the flow regime from loss of mature forest vegetation is also widely discussed in the scientific literature, but most such studies yield statistically reliable results after only many decades of carefully designed (and typically paired-watershed) studies. Therefore, a broad characterization of regional status and trends (Question 1) is coupled with more focused and achievable efforts (Question 2) to support the overarching goals of this project.

Question 1 (TR3, p. 14): What are the status and trends of water quality and stream flow in surface waters?

Objective 1.1 (status): In wadeable and non-wadeable streams, as stratified by predominant land-use categories in their contributing watersheds[1], evaluate whether water-quality conditions generally support the waterbody-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602) and meet the "Properly Functioning" conditions of NOAA (1996), using the metrics recommended in Section 3.5 of this report.

Objective 1.2 (trends): For the population of sites measured under Objective 1.1, evaluate whether measured water-quality metrics show a statistically significant trend over a 10-year period towards the best conditions represented by the population of sites in the random draw from the Master Sample, and as described as "Properly Functioning" in NOAA (1996).

Question 2: What are the status and trends of water quality in surface waters draining watersheds with a substantial fraction of land that has been cleared for agriculture or recent (<20 years) forest harvests? (In other words, are our forest practices or agricultural BMPs making a difference in the status and trends of these working landscapes?)

Objective 2.1 (status): In wadeable and non-wadeable streams primarily draining agricultural areas outside of Urban Growth Areas, evaluate whether measured water-quality metrics generally support the waterbody-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602).

Objective 2.2 (trends): In wadeable and non-wadeable streams primarily draining subwatershed(s) with recent (<20 years) forest harvest area(s), evaluate whether measured water-quality metrics show a statistically significant trend over a 10-year period towards reference conditions as established by other sites draining relatively undisturbed watersheds (as identified through the "Landscape" evaluation in Section 2.1.1.3, below).

2.1.1.2 Habitat

Habitat status and trends monitoring addresses physical and biological attributes that affect watershed health and salmon recovery. The combined habitat and water Qa/Qx monitoring is designed to integrate with fish status and trend monitoring, being developed and implemented under other programs, to support a comprehensive status and trends monitoring program for watershed health and salmon recovery. This regional habitat and water quality status and trends monitoring strategy will generate the information necessary to support the following questions and objectives.

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[1] From TR3, p. 28: "A subwatershed would be assigned to either the forested land use/class category, or a combined urban/suburban/rural land use/class category, based on the category with at least 51% cover in that subwatershed."

Question 3: What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions (in terms of both quality and quantity)?

Objective 3.1 (status): In wadeable and non-wadeable streams, as stratified by predominant land-use categories in their contributing watersheds, evaluate the status of biological and habitat conditions according to the habitat metrics (Section 3.5) relative to Properly Functioning Conditions (Appendix A).

Objective 3.2 (trends): Analyze for statistically significant spatial and temporal trends of biological and habitat metrics (annually), recognizing that statistically significant trends may not be evident for many years (Section 3.5.2).

Question 4: Do in-stream biological health and in-stream/riparian habitat conditions correlate to changes in abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population at the reach/subwatershed scale?

Objective 4.1 (trends): Identify statistically significant correlations between trends in select habitat metrics and trends in fish population metrics (e.g., abundance, productivity, spatial structure, and diversity) being conducted by other monitoring programs, recognizing that statistically significant trends may not be evident for many years. Specific habitat metric selection should focus on conditions known to limit fish populations and should be determined before monitoring begins.

2.1.1.3 Landscape

For monitoring in-stream conditions, characterizing status and trends in the surrounding landscape can help separate the regional influence of natural variability from the more localized impacts (both positive and negative) of human actions. Although the following “landscape” monitoring questions are not explicitly addressed by the in-stream monitoring activities that form the majority of the recommendations of this Design Report, the questions remain highly relevant. Furthermore, the analyses they will generate are critical to several of the habitat and Qa/Qx monitoring elements of this program (particularly Questions 2 and 8). For these reasons, the importance of this category has been recognized since Phase 1 of the HSTM project (where it was termed “Landscape-Level Conditions”).

Question 5: Where on the landscape are key potential land-use activities occurring, and in what watersheds are one or another of these activities dominant?

Objective 5.1 (status): Identify subwatersheds of the Lower Columbia Region at a suitable size to support other monitoring efforts under this program (i.e., 2.5–50 km^2, the recommended size of the Qa/Qx catchment areas) having "dominant" land uses of urban, agriculture, or recent (<20 year) forest harvest. Also identify subwatersheds with dominant intact (>20 year old) forest cover for use as regional controls (see Objective 2.2).

Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?

Objective 6.1 (trends): Identify and quantify areas of land-cover change in subwatersheds of the Lower Columbia Region that drain to habitat and/or Qa/Qx monitoring sites at 5-year intervals. A regionally relevant example of demonstrated utility is the 12 land-cover categories of King County's recent report, "Assessing Land Use Effects". If this presents an infeasible magnitude of GIS and airphoto analysis at the scale of the entire Region, however, then reduce the level of effort required by either (1) restricting the spatial domain to only those subwatersheds that are largely or fully included within Urban Growth Areas, or (2) conducting a GIS-only evaluation of a larger region but using fewer categories that do not require parallel GIS-airphoto analysis.

Objective 6.2 (trends): Identify and quantify how land cover is changing within a selected buffer zone (e.g., 60 m) around channels included in the Qa/Qx and habitat monitoring elements, at 5-year intervals, using the same land-cover categories as for Objective 6.1, and restricting the analysis to a fixed distance (e.g., 1 or 5 km) upstream of each monitoring site.

2.1.2 Municipal stormwater NPDES permit-related questions and objectives

Although fully nested within the regional status and trends monitoring effort, for which questions and objectives are presented above in Section 2.1.1, southwest Washington municipal stormwater NPDES permittees have specific monitoring needs and requirements that are unique to the areas that both are under their jurisdiction and are served by municipal separate storm sewer systems (MS4s).

Several of the following monitoring objectives are intentionally restricted to areas where stormwater management activities are required by the municipal stormwater permits. For purposes of developing objectives, the mapped boundaries of UGAs are assumed to represent the approximate permitted extent of MS4s as well areas targeted for future development and eventual inclusion into permitted cities (i.e., “urban NPDES areas”).

Clark County is the exception to this rule; its stormwater discharges outside of designated Urban Growth Areas (UGAs) is also regulated, under its Phase I Municipal Stormwater NPDES permit. However, because stormwater impacts and management approaches in rural areas are different from those in urban areas, the areas outside Clark County UGAs (but still within the Clark County Phase 1 municipal stormwater permit) are grouped for monitoring purposes with the remainder of the Lower Columbia Region that lies outside of municipal stormwater NPDES permit areas altogether.

2.1.2.1 Water quality and water quantity (Qa/Qx)

For the Qa/Qx NPDES-related monitoring, Question 1 of the “regional” monitoring effort is repeated in this section, because the specific monitoring needs of the MS4 municipal stormwater NPDES permittees may require a different suite of metrics (or the same data collected but at more frequent intervals). A second question in this section targets a specific subset of these potential sampling sites for which additional insight may be derived with the inclusion of opportunistically selected locations.

Question 7: What are the status and trends of water quality and stream flow in surface waters draining subwatersheds that are primarily within the jurisdiction of municipal stormwater NPDES permittees?

Objective 7.1 (status): In streams in urban NPDES areas, evaluate whether water-quality conditions generally support the watershed-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602), using the metrics as recommended in Section 3.5.1. Locations should include "legacy sites," to take advantage of the longer record that these can provide for Objective 7.2. Note that the status of water quality and stream flow in the non-UGA but permitted portion of Clark County permit area is addressed in Objective 1.1 above, and so an equivalent effort is intentionally not duplicated here.

Objective 7.2 (trends): For the population of sites measured under Objective 7.1, evaluate whether measured water-quality metrics show statistically significant trends over a 10-year period towards the best conditions as represented by the population of sites in the regional monitoring (i.e., from Objective 1.1) and described as "Properly Functioning" in NOAA (1996).

Question 8: What are the status and trends of water quality and stream flow in surface waters that are being affected by stormwater discharges from urban areas first developed under requirements of the 2013 municipal stormwater permits (recognizing that such areas are limited and will likely require opportunistic selection from the larger population of sites identified for Objective 7.1)?

Objective 8.1 (status): In streams whose catchment areas now drain primarily non-urbanized areas within Urban Growth Areas, evaluate whether water quality generally supports the watershed-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602) and meet the "Properly Functioning" conditions of NOAA (1996).

Objective 8.2 (trends): In the sample population of Objective 8.1, evaluate whether measured water-quality and flow (i.e., stage) metrics show statistically significant trends over a 10-year period in those subwatersheds that have experienced measureable land-use changes while under provisions of the 2013 (or later) municipal stormwater permit.

2.1.2.2 Habitat

For the municipal stormwater NPDES-related monitoring sites, we repeat the text of Questions 3 of the "regional" monitoring effort in this section as a separate inquiry, because the specific monitoring needs of the municipal stormwater permits may require a different suite of metrics from that of the regional effort (or the same data collected but at more or less frequent intervals).

Question 9: What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions that are primarily within the jurisdiction of NPDES stormwater permittees (in terms of both quality and quantity)?

Objective 9.1 (status): In streams in urban NPDES areas, evaluate the status of biological and habitat conditions according to the habitat metrics (Section 3.5.2) relative to Properly Functioning Conditions (NOAA 1996). As with Objective 7.1, non-UGA portions of Clark County will be assessed as part of the regional questions and objectives (Question 3).

Objective 9.2 (trends): Analyze for statistically significant spatial and temporal trends of biological and habitat metrics (annually) in urban NPDES areas, recognizing that statistically significant trends may not be evident for many years.

Question 10: Do in-stream biological health and habitat conditions correlate to changes in observed abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population (reach/subwatershed scale)?

Objective 10.1 (trends): Identify statistically significant correlation between trends in select habitat metrics and trends in fish population metrics (e.g., abundance, productivity, spatial structure, and diversity) being conducted by other monitoring programs, recognizing that statistically significant trends may not be evident for many years. Specific habitat metric selection should focus on conditions known to limit fish populations and should be determined before monitoring begins.

2.2 Target Populations

Within the broad guidance provided by Phase 1 of this project, long-standing considerations for effective monitoring locations were applied to develop the overall spatial design. Monitoring sites should be selected across the Lower Columbia Region within the Washington portion of the ESU, drawing from the "Washington Master Sample," a common set of random sites along the state's rivers and streams developed for use in comparable, complementary monitoring among separate monitoring organizations and across geographic scales. The master site list has 387,237 points in Washington, of which more than 100,000 are located in the Lower Columbia ESU. The Master Sample also includes legacy site locations. If desired, site selection can be based on a combination of preemptive identification of legacy sites having suitable long-term datasets, plus additional randomly selected sites/reaches (pseudo-random site selection); otherwise, a strictly random selection can be made from the Master Sample. The final choice between a pseudo-random and fully random site selection process will be made during preparation of the Implementation Plan.

Within the context of the Master Sample, the target populations from which sites will be selected for Qa/Qx and habitat monitoring sites have not been assumed to be identical, given the intrinsic differences between the chemical characterization of a flowing continuum of water and the physical characterization of a specific location or reach of channel. In other words, there is no *a priori* assumption that these two types of monitoring activities will draw from the identical population of Master Sample sites. The overall goal has been to identify effective monitoring locations that can address the monitoring questions and objectives that are guiding this HSTM program, rather than to require equivalent target populations as an overarching principle.

2.3 Spatial Strata and Site Allocation

Stratifying a sample population ensures that "like" is being compared to "like," and that a subset of that population provides a credible representation of its group as a whole. For example, published reference conditions for large woody debris loading distinguish between values for wide rivers and narrow streams; pool frequency is not equivalent in low-gradient meandering streams and steep cascade channels. Thus, subdividing the population of sample sites on the basis of physical attributes is commonly necessary to align with scientific understanding; subdivision on the basis of jurisdictional or regulatory considerations (e.g., recovery planning) may also be necessary to improve the utility of results for management. The drawback of stratification, however, is that the number of sites necessary to achieve meaningful statistical power increases geometrically with the number of strata and the number of categories within each stratum. Every unique combination of strata and categories requires an adequate sample size to yield a statistically valid characterization of conditions and to detect a specified minimum magnitude of change.

Determining how best to stratify the greater than100,000 points of the Master Sample within the Washington state portion of the Lower Columbia Region was accomplished by using the conceptual framework for stratification developed during Phase 1, stakeholder input, and extensive querying of the Master Sample using a variety of alternative strata and categories to find combinations that were both meaningful from a technical perspective and feasible to implement. The geographic location of each Master Sample point and its association with river subbasin and regional recovery area were obtained from LCFRB and can be uploaded from the website https://www.monitoringresources.org/Sites/Master/Detail/5.

Gradient and upstream drainage area for each sample point were calculated from a 10-m Digital Elevation Model, along with the determination of additional geographical information (land cover classification, Urban Growth Areas and municipal stormwater NPDES permit areas). Attributes for each sample point were determined in GIS (methods detailed in Appendix B) and downloaded to an Excel spreadsheet for evaluation of various strata combinations. For consistency across data sources and spatial characterization, all areas are expressed in square kilometers; where acreages from TR3 are referenced in this Design Report, they have been rounded to their near-equivalent value in km^2.

Land cover, a recognized determinant of both water-quality and habitat conditions in Pacific Northwest streams, was categorized into three major types using the 2006 National Land-Cover Dataset (NLCD) developed by the Multi-Resolution Land Characteristics Consortium (http://www.mrlc.gov) and available at http://www.mrlc.gov/nlcd06_data.php. Its results were applied without modification, except for the grouping of its 16 primary classes into the three categories used for stratification in the HSTM project. They are defined in the NLCD in Table 1.

Table 1. Major land use types developed by the Land Characteristics Consortium. (http://www.mrlc.gov)

HSTM land cover category	**2006 National Land Cover Dataset Class and Description**
Urban	Developed, Open Space—*Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.*
	Developed, Low Intensity—*Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49% of total cover. These areas most commonly include single-family housing units.*
	Developed, Medium Intensity—*Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79% of the total cover. These areas most commonly include single-family housing units.*
	Developed, High Intensity—*Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100% of the total cover.*
Agriculture	Pasture/Hay—*Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.*
	Cultivated Crops—*Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled*
Forested	Definition: Deciduous Forest—*Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.*
	Evergreen Forest—*Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.*
	Mixed Forest—*Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.*

HSTM land cover category	2006 National Land Cover Dataset Class and Description
Other classes, not included in the HSTM 3-part classification	Open Water—*All areas of open water, generally with less than 25% cover or vegetation or soil*
	Perennial Ice/Snow—All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
	Barren Land (Rock/Sand/Clay)—*Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.*
	Shrub/Scrub—*Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.*
	Grassland/Herbaceous—*Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.*
	Woody Wetlands—*Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*
	Emergent Herbaceous Wetlands—*Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*

The Master Sample database includes a field that identifies one of four land-cover categories (urban, agricultural, forested, other) associated with the point itself. For purposes of evaluating the feasibility of various stratification alternatives, this at-a-site land cover determination was assumed to correspond to the predominant land cover over the watershed as a whole. Once prospective sampling sites have been selected during the implementation phase, this assumption will be confirmed through GIS analysis and the land-cover category of the point adjusted if/as needed to reflect the land cover of the *watershed*, rather than just of the *point* (this was not judged feasible for the entire 101,341 points in the LCR Master Sample in Washington State, however, it must be done for all candidate sites prior to any field work).

An additional stratum was defined from the management classification established in the Lower Columbia River Salmon Recovery Plan (LCFRB 2004), namely the clustering of subbasins according to the number of primary populations of ESA listed salmonids species that they support. Primary Populations are defined in the 2013 Lower Columbia River Salmon and Steelhead Recovery Plan as “a population that is targeted for restoration to high or very high persistence probability.” Selection of subbasins according to the number of primary populations was included in the monitoring design, not because it is presumed to be a driver of habitat conditions but because future monitoring or management actions may be targeted, at least in part, by the relative importance of a subbasin for salmon recovery. To facilitate this application, subbasins were stratified into three groups (0–2, 3, 4+ primary populations) to help identify key subbasins relative to salmonid populations.

Based on expressed stakeholder concerns, information was also acquired to help identify sites subject to tidal or backwater effects from the Columbia River. A set of airphotos taken during the

February 1996 flood on the Columbia River (about a 50-year event and the flood of record at USGS gage 14246900) and archived by Clark County (at http://gis.clark.wa.gov/mapsonline/?site=AerialPhotography&ext=1) proved invaluable in identifying extreme elevations for which water quality data might be influenced unduly by non-local-watershed conditions, or where physical habitat was the product of hydraulic conditions not experienced by other sites lying within what might otherwise be thought of as the "same" stratum.

2.4 Temporal Scale

The frequency of sampling has critical implications for both data utility and program affordability. Because the features measured by the two primary elements of the HSTM program, Qa/Qx and habitat, have such different temporal variability, the methods used to determine the appropriate temporal scales for their measurement (as well as the outcomes of those determinations) differ. For Qa/Qx, where water-column metrics can vary hourly or even more frequently, considerations of temporal scale embraces the guidance of NRC (2009), which states unequivocally that "In order to use stormwater data for decision making in a scientifically defensible fashion, grab sampling should be abandoned as a credible stormwater sampling approach for virtually all applications" (p. 8). Although this guidance applies strictly just to the monitoring of stormwater discharges, it is likely to be applicable to receiving waters that are strongly influenced by stormwater discharges as well. Until data prove otherwise, episodic grab sampling is not anticipated to generate statistically meaningful data for water-column constituents and so is not included in the monitoring design recommended here. For less transient Qa/Qx data (such as sediment chemistry), however, and for the physical habitat metrics, the preliminary recommendations from Phase 1 as modified by the guidance of other published reports have provided the basis for final recommendations here.

2.5 Signal to Noise

Effective environmental management requires monitoring information that is accurate, precise, and ecologically relevant (Kaufmann et al. 1999). Accuracy reflects the proximity of measurement results to the true value; precision reflects the repeatability of the measurement; and ecological relevance requires meaningful information for interpreting controls on biota (limiting factors) or impacts of human activity.

An important consideration in this long-term, broad-scale monitoring design was to explore precision in the proposed metrics in order to address two key concerns: 1) select repeatable metrics that yield reliable results and 2) consider the sharability of data with varying degrees of reliability and potentially different collection protocols. It's essential to understand the first concern in order to inform the second. Signal to noise (S/N) is a commonly used measure of precision in statistical analyses and for interpreting differences in subpopulation means (Zar 1999).

Signal to noise is the ratio of variance between sites and the pooled variances of repeatedly visited sites. Kaufmann et al. (2014) provide the following explanation: "High noise in habitat descriptions relative to the signal (i.e., low *S/N*) diminishes statistical power to detect differences among subpopulations. Imprecise data limit the ability to detect temporal trends (Larsen et al. 2001, 2004). Noise variance also limits the maximum amount of variance that can be explained by models such as multiple linear regression (Van Sickle et al. 2005, Kaufmann and Hughes 2006). By reducing the ability to quantify associations between variables (Allen et al. 1999, Kaufmann et al. 1999), imprecision compromises the usefulness of habitat data for discerning likely controls on biota and diagnosing probable causes of impairment…noise variance includes the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, and uncertainty in the precise relocation of the unmarked sample reaches (relocated on subsequent visits using global positioning system (GPS) receivers, map, compass, landmarks, and field notes).”

This variance is assessed by analyzing multiple sampling data during periods in which the measured conditions are believed not to have changed, and the resulting variance is compared to that of measurements made at the design sampling interval. Thus, literature-based ratings for S/N are only strictly applicable if both the sampling protocols and the intervals between sampling are equivalent to the monitoring program in question. Although these conditions of strict applicability are not commonly achieved in practice, useful guidance from prior analyses of S/N is nonetheless available and relatively widespread in published literature.

Initial scoping of this component of the monitoring design was conducted in consultation with LCFRB and PNAMP and other stakeholders to fully understand the intended use of the results. Next, a literature review was conducted to explore the extent of existing, applicable S/N studies and determine the need for additional information and analysis. The results of that literature review were used to guide the water quality and habitat metric selection process and to stimulate further stakeholder dialogue to determine what additional S/N work will be needed as part of the Implementation Plan.

2.6 Metrics

The choice of metrics is closely interwoven with (1) the specific monitoring needs for addressing the questions and objectives, (2) the relative value of some metrics over others in their ability to detect meaningful changes, (3) the instream changes that environmental changes (both positive and negative) are anticipated to create; (4) regulatory requirements; and (5) financial constraints. Phase 1 evaluated a range of metrics and ultimately recommended the least extensive slate of all that had been considered, but subsequent evaluations have suggested that even the final Phase 1 list may still be overly costly to implement and includes metrics unlikely to produce meaningful results (e.g., metrics with low S/N). The integration of these considerations, based on both internal discussions and feedback from project stakeholders in public workshops and frequent conference calls, has led to the final suite of recommended metrics. In particular, development of a final set of metrics focused on identifying those with sufficient precision and replicability in order to select those that yield reliable results that could be shared with other monitoring programs.

The integration of these considerations, based on both internal discussions and multiple consultations with project stakeholders, has led to the final suite of recommended metrics in this Design Report. Although this suite of metrics is tailored to the goals and objectives of this study, they are sufficiently common in range and applicability that other monitoring programs, even those with a different suite of metrics or focus of study, and should be able to achieve meaningful integration of data and understanding.

2.7 Landscape Analysis

Several of the monitoring questions and objectives require some degree of “landscape” analysis (Question 5: Where on the landscape are key potential land-use activities occurring? and Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?). They are included in the Design Report because their results will provide necessary support to other monitoring objectives, and the landscape stratification will provide necessary context for much of the monitoring data collected under the HSTM program. The specific activities envisioned by the monitoring objectives associated with these questions are not further expanded upon in this report, however, because they involve region-wide spatial analysis and thus are not influenced by details of spatial design, target populations, or metrics. The specific methodology for their implementation, and their incorporation into the overall HSTM plan, will be detailed as part of the forthcoming Implementation Plan.

3 RESULTS

3.1 Spatial Design

Most of the monitoring objectives (Section 2.1) will be addressed using a *probabilistic design*, wherein sites are randomly selected across the entire area of interest. This approach stands in contrast to the more commonly implemented *opportunistic design*, with sites selected for ease of access, expert opinion, or other subjective criteria. However, two of the Qa/Qx monitoring objectives (Objectives 2.2 and 8.2) can only be addressed with a more directed, pseudo-randomized approach as first proposed in Phase 1 of this project (Tetra Tech 2013). The affirmation of a pseudo-randomized approach may be evaluated as part of the forthcoming Implementation Plan depending upon further input from the stakeholders and the availability of sufficient data for generating meaningful results.

3.1.1 Target populations for Qa/Qx sampling

Qa/Qx sampling will take advantage of the “continuity” of flowing water, under the assumption that most water-quality metrics vary spatially only gradually, if at all, along a given channel segment in the absence of tributary or manmade inputs. In other words, water quality data are assumed to represent the conditions within an entire *segment* of channel, not just the *point* at which it is taken. Thus, the population of Qa/Qx sites from which sampling locations will be drawn are segments (not individual points), and which have a specified range of drainage areas (see Section 3.2.1 for specific site-selection criteria and the boundaries of an individual segment). Within each selected segment, the location chosen for sampling should have only modest influence on the collected data, and thus ancillary considerations (such as site access or the reoccupation of legacy sampling sites that are located within the selected segments) can be incorporated without undermining the random spatial design.

This approach to target populations for Qa/Qx sampling reflects a modest adjustment of TR3’s recommendation for Qa/Qx sites being selected to drain “randomly selected subwatersheds,” defined in the Washington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan (LCFRB 2010) as encompassing drainage areas of 3,000–12,000 acres (about 12 to 49 km^2), in order to characterize the cumulative status of the upstream area. In particular, the example provided in TR3 (their Figure 4, reproduced below in Figure 2) identified the set of gold circles as comprising all potential Qa/Qx sampling sites in this watershed. However, many of those sites lie on channels that actually drain as much as 130,000 acres (e.g., the three lowermost points along the mainstem Kalama River), over an order of magnitude greater area than recommended for suitable Qa/Qx sites. There are, in fact, a large number of Master Sampling sites along the river and its tributaries that *do* have drainage areas within the specified range; their positions are not limited to the mouths of designated “subwatersheds,” however, and restricting sampling to these locations is not essential to characterizing Qa/Qx conditions at a regional scale.

Thus, this Design Report recommends that *all* Master Sample sites within a specified range of drainage areas should be used to define stream segments as potential Qa/Qx sampling sites. To maintain data independence, however, no selected segment should drain into any other selected segment.

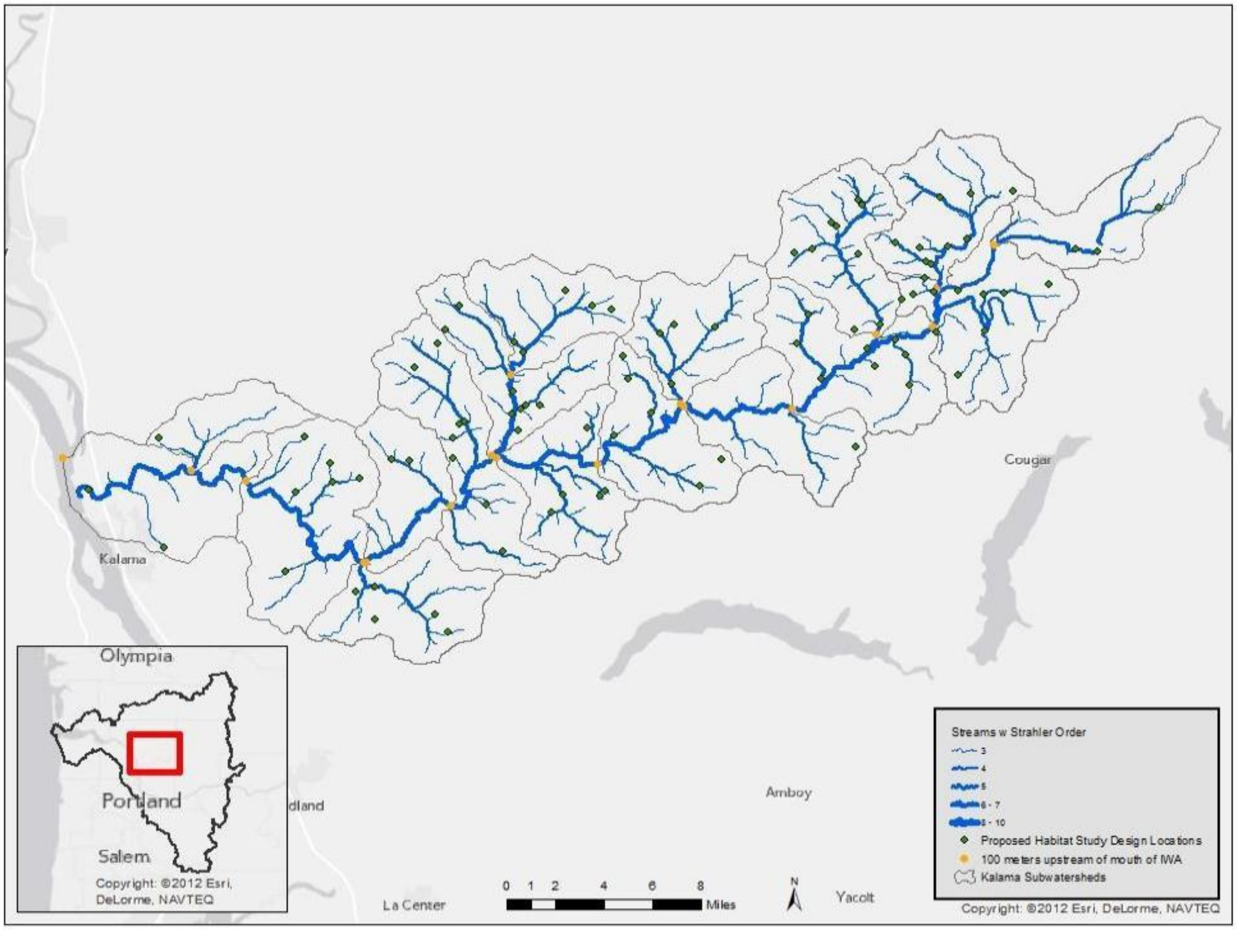

Figure 2. The envisioned distribution of candidate monitoring sites (TR3, their Figure 4). Note that although the gold circles along the mainstem river have subwatersheds associated with them that extend only upstream to the next such point, they in fact drain the entire upstream watershed and so many exceed greatly the target drainage area for Qa/Qx sampling.

Another recommendation of Phase 1 was that the population of potential sites for habitat monitoring should be restricted to those subwatersheds with designated Qa/Qx sampling. Although a laudable criterion for integrating the two types of monitoring, pragmatic limits on the total number of sampling sites would likely result in an overly restrictive population of prospective habitat monitoring sites once the Qa/Qx sites have been identified. Therefore, this earlier guidance is not applied in the analyses and recommendations that follow.

3.1.2 Target populations for habitat sampling

In habitat monitoring, stream reaches associated with selected Master Sample sites are the appropriate target population for assessing habitat, which is consistent with recommendations from Phase 1. Sampling sites will be located in reaches of continuous, freshwater streams with non-constructed channels[2] and lotic, perennial flow. To adequately represent variability across stream reaches throughout the ESU, habitat monitoring will sample randomlychosen sites selected from all points that meet a specific set of strata-based selection criteria (Section 3.2.2). This design approach reflects a departure from recommendations provided in Phase 1, which as noted above recommended that habitat sites be restricted to those catchments with a Qa/Qx monitoring site at their outlets.

For both Qa/Qx and habitat sampling, areas subject to Columbia River backwater effects should be excluded from further consideration for this monitoring program, insofar as their conditions reflect very different drivers from sites elsewhere in the Lower Columbia Region and would violate the stratification criterion of comparing “like” vs. “like” (Section 2.3). The maximum extent of this potential concern is well-illustrated by the area of inundation from the flood of record (1996) on the Columbia River, focusing in on the Ridgefield-Woodland area just downstream of Vancouver (Figure 3).

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[2] *Non-constructed channels* exclude irrigation channels, power canals, drainage ditches, and other waterways that may exhibit many of the following criteria (Washington State Department of Ecology 2012): built where no waterbody previously existed; constructed of impervious material; not used for recreation or potable water; constructed, operated, and maintained for a specific purpose or need; controlled ingress and egress; or surface continuity with a natural water body interrupted by a pipe, pump, dike, etc.

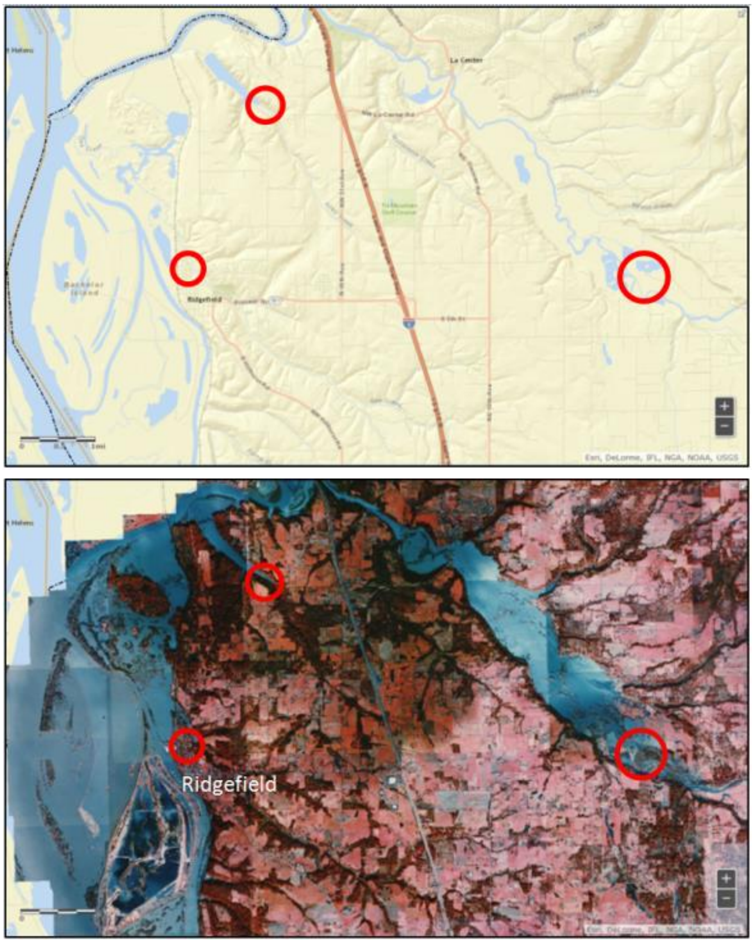

Figure 3. Location map (top) and aerial photo near the peak of the 1996 flood (bottom), showing the extent of backwater inundation on several low-lying steams (red circles). The upper elevation of standing water in the smaller of these channels Gee Creek, just north of Ridgefield) is about 20’. Map and imagery courtesy of Clark County.

These maps suggest that relatively few sites within the Master Sample are likely to be affected, and all lie within about 10’ elevation of the low-flow surface of the Columbia River. During implementation, any selected sites should be screened for such a potential, but the likelihood of exclusion on this basis is judged to be quite low (and will be readily identifiable). This evaluation also addresses to the previously expressed concerns about tidally influenced channels, since the tidal amplitude throughout nearly all of the region is at most a few feet.

3.2 Spatial Strata and Site Allocation

3.2.1 Strata for Qa/Qx sites

The recommended stratification for Qa/Qx sampling differs somewhat between the two spatial scales of monitoring. For monitoring within Urban Growth Areas that lie within the jurisdiction of an NPDES stormwater permittee (i.e., urban NPDES areas), stratification should be based only on drainage area. Qa/Qx sampling *outside* of urban areas encompasses a more diverse landscape than found in the urban NPDES areas, however, and so a greater degree of stratification is needed to achieve meaningful representation and adequate coverage of the population of stream segments as a whole, considering a wider range of drainage areas, the predominant land cover of the contributing watershed, and the number of Primary Populations in the subbasin in which the monitoring site is located. Specific criteria and categories for sampling stratification also differ slightly between these two spatial scales and are described in detail below in Sections 3.2.1.1 and 3.2.1.2.

This recommendation reflects a refinement of Phase 1's recommended strata for Qa/Qx sites, which included inside/outside the jurisdiction of a NPDES municipal stormwater permittee (2 categories), Recovery Plan area (Cascade/Coast/Gorge) (3 categories), and drainage area (a single category of 3000–12,000 acres). A reevaluation affirmed this overall framework but recognized that an additional stratum based on predominant watershed land cover is also important to address the monitoring questions of Section 2.1, given the widely recognized, systematic differences in water chemistry from different land covers types. Also recognized were important differences in the application of Qa/Qx data depending on whether or not the sites are located inside of a municipal stormwater NPDES jurisdiction. Thus, the following discussion of site identification and location is separated by this jurisdictional criterion.

For any sampling effort, the number of sites needed to characterize water-quality conditions within a specified level of precision must be determined. This issue has been investigated in greatest detail with respect to monitoring urban stormwater quality, which provides a credible basis for assigning a minimum number of sites per strata combination absent more specific information. NRC (2009), reproducing the findings of earlier studies, offered a now-standard representation of the trade-off between data variability, desired level of analytical certainty, and required numbers of samples (Figure 4). For stormwater data, the coefficient of variation is widely reported to lie between about 0.5 and 1.0; to ensure an error in estimating the median value of a metric that is no worse than 50 to 100% of the true mean of the population requires between about 10 and 20 samples. For purposes of evaluating the consequences and feasibility of the monitoring design, a mid-point value of 15 samples per unique strata combination has been assumed for all receiving water (stream) monitoring efforts.

Although the quality of such an estimate is rather poor, the number of samples needed to substantially improve it, given the high variability of stormwater data in general, is rather daunting, and so striving for greater precision is not recommended at present for this monitoring program. Furthermore, the actual variability of the data collected from receiving waters may be significantly less than what has been found for stormwater discharges; once data collection begins, either a greater level of statistical confidence or a lower number of required samples may be determined.

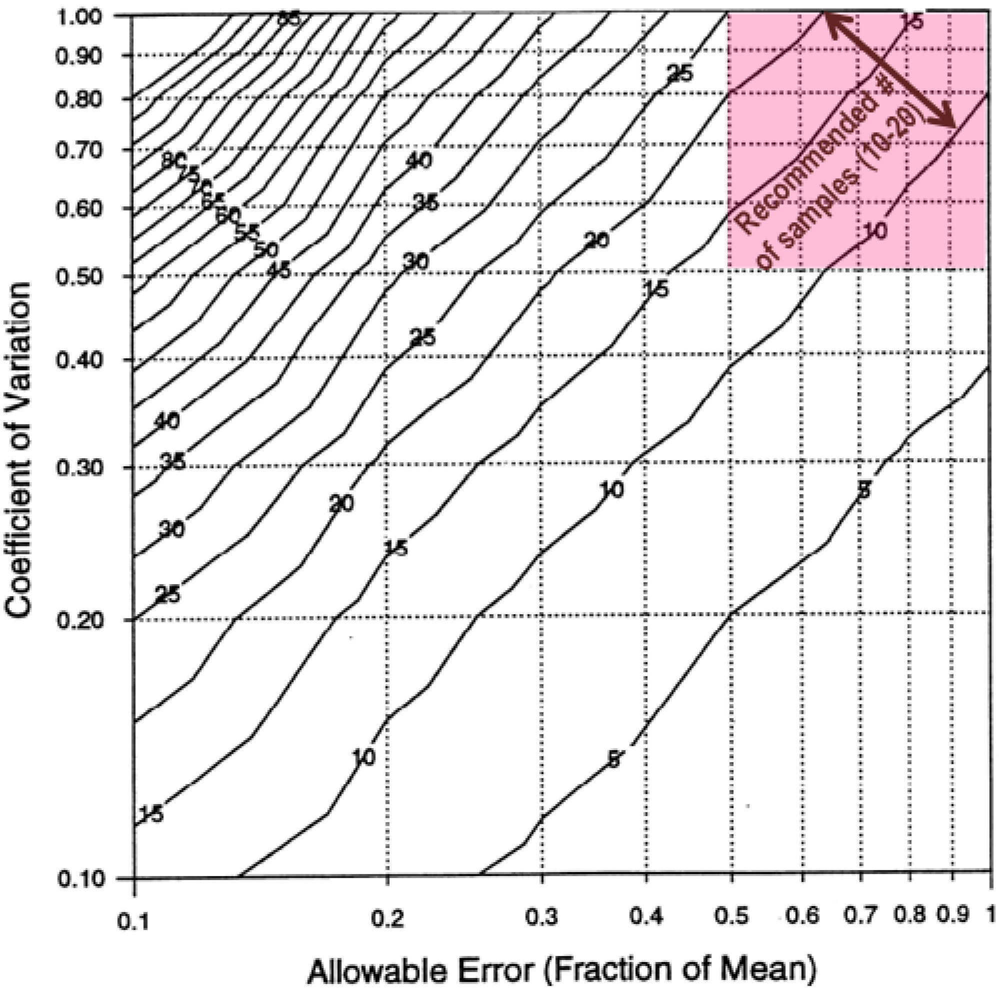

Figure 4. Number of samples (labeled diagonal lines) needed to characterize a sample median with a chosen allowable error, with a power of 80% and confidence of 95%. Figure 4.5 of NRC (2009), reproduced from Burton and Pitt (2002).

3.2.1.1 Qa/Qx within urban NPDES areas

For Qa/Qx sampling within the urban areas of municipal stormwater permittees, stream segments should have a predominant urban land cover in their contributing watershed with drainage areas between 2.5 and 50 km^2. By inspection of the distribution of segments and land cover types in these urban NPDES areas (see below), a total population of about thirty such stream segments exists across the LCR. Several times that number of watersheds with *non*-urban land cover but still within Clark County's jurisdiction exist (and so within their Phase I NPDES permit area), but their conditions should be adequately represented by the regional Qa/Qx sampling program (Section 3.2.1.2). Therefore, they are not recommended for specific inclusion via a distinct stratum.

The following strategy for site allocation for Qa/Qx sites in municipal stormwater NPDES permit areas is therefore recommended, guided by Questions 7 and 8 and their associated objectives:

- From the population of stream segments within urban NPDES areas and draining watersheds with predominantly urban land cover that meet a drainage-area criterion of 2.5–50 km^2, select at least 15 such segments.
    - If desired, selection can be based on a combination of preemptive identification of stream segments with legacy sites having suitable long-term Qa/Qx data, plus additional randomly selected segments that have a predominant coverage of urban land uses; otherwise, a strict random selection can be made. This choice between a fully random and a pseudo-random selection process will be made during preparation of the Implementation Plan, once the inventory of legacy sites is complete.
- Given the continuity of flow along a stream segment, the precise location for sampling should be of limited importance to the quality and applicability of Qa/Qx data (with the possible exceptions of temperature and stream benthos). We recommend beginning at the downstream end of a selected segment and moving upstream, identify the first sampling location guided first by logistical considerations of access and adjacent land ownership as identifiable through GIS and aerial photographs, followed by a field visit to each prospective site to confirm access and overall suitability for monitoring (particularly benthic macroinvertebrate and sediment chemistry sampling, which have specific requirements for substrate in order to yield meaningful results) (e.g., Washington State Department of Ecology 2014).

The rationale for this recommendation is based on a variety of considerations. Water-quality sampling to address NPDES-related questions (in particular, Questions 7 and 8 of Section 2.1) requires a sufficient number of independent sites to draw meaningful inferences, and those sites need to be located so as to reflect the predominant influence of the jurisdiction(s) covered by the permit. The present design focuses municipal stormwater-related Qa/Qx monitoring within just the *urban* areas (i.e., within designated UGAs), recognizing that monitoring data from eastern unincorporated Clark County (where the *non*-UGA areas covered under the Phase I municipal stormwater permit are located) will be most meaningful if grouped with data from the rest of the (non-UGA) Lower Columbia Region.

We explored the consequences of this recommended stratification in the Lower Columbia Region by identifying only those sites within municipal stormwater NPDES jurisdictional boundaries of Washington, excluding the small portion of Pierce County (which is fully covered by a Phase I permit) on the flanks of Mount Rainier within Mount Rainier National Park. Each point was coded by its upstream cumulative drainage area, using the following categories: 10–50 km^2 (similar to the original recommendation for Phase 1 of this project), 2.5–50 km^2 (an expansion of that original range to provide more potential sites), and those with greater (i.e., >50 km^2) or lesser (i.e., <2.5 km^2) drainage areas. The raw results within the Lower Columbia Region are shown in Figures 5 through 7 for the two areas with the largest areas under NPDES jurisdiction.

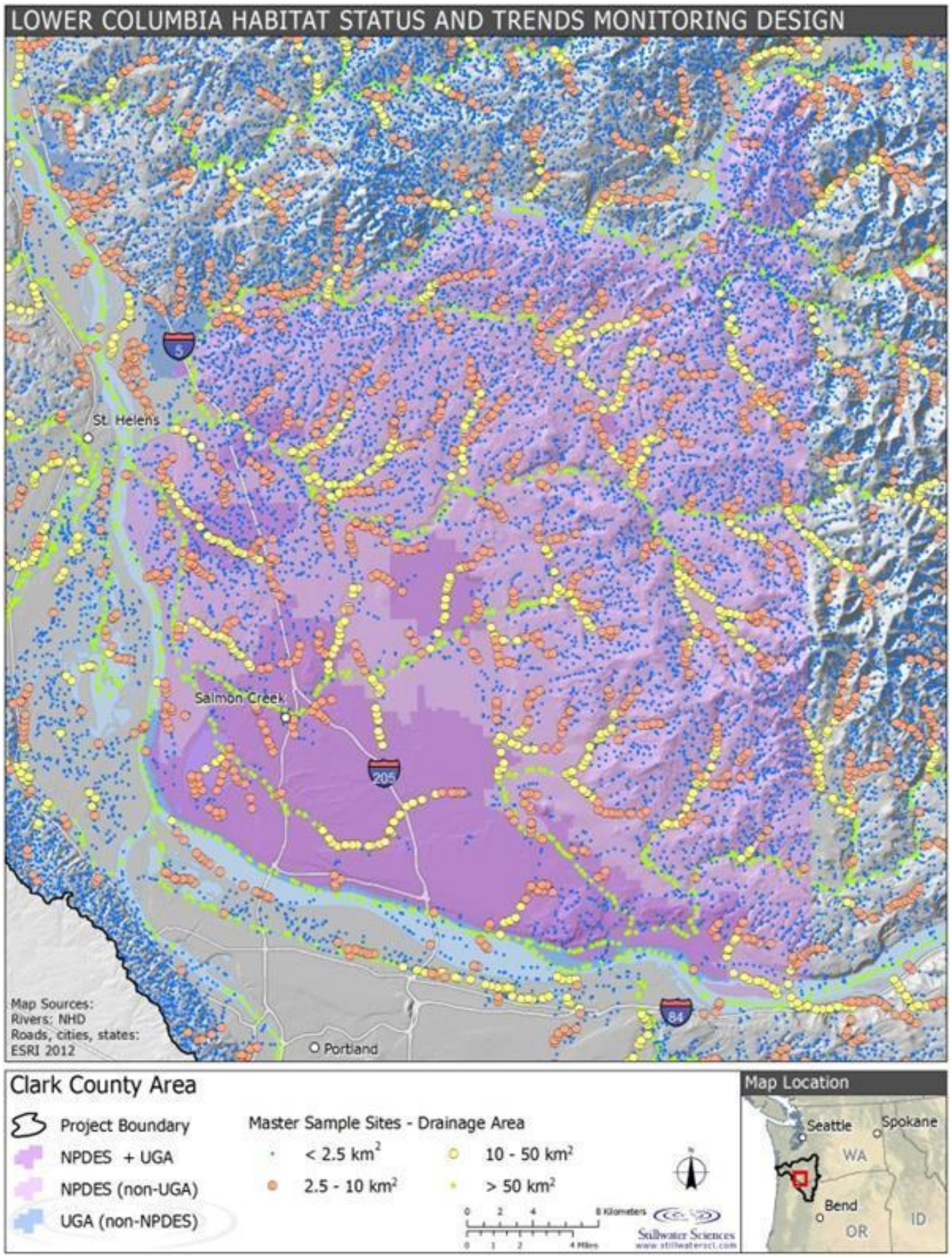

Figure 5a. GIS view of the Master Sample points in two areas covered by municipal stormwater NPDES MS4 permits, also highlighting Urban Growth Areas. Individual points meeting the recommended drainage-area criteria are highlighted by red circles (2.5–10 km2 drainage area) or yellow circles (10–50 km2). Blue dots are Master Sample sites with too small drainage areas to meet the recommended drainage-area criterion; green circles are sites with overly large drainage areas.

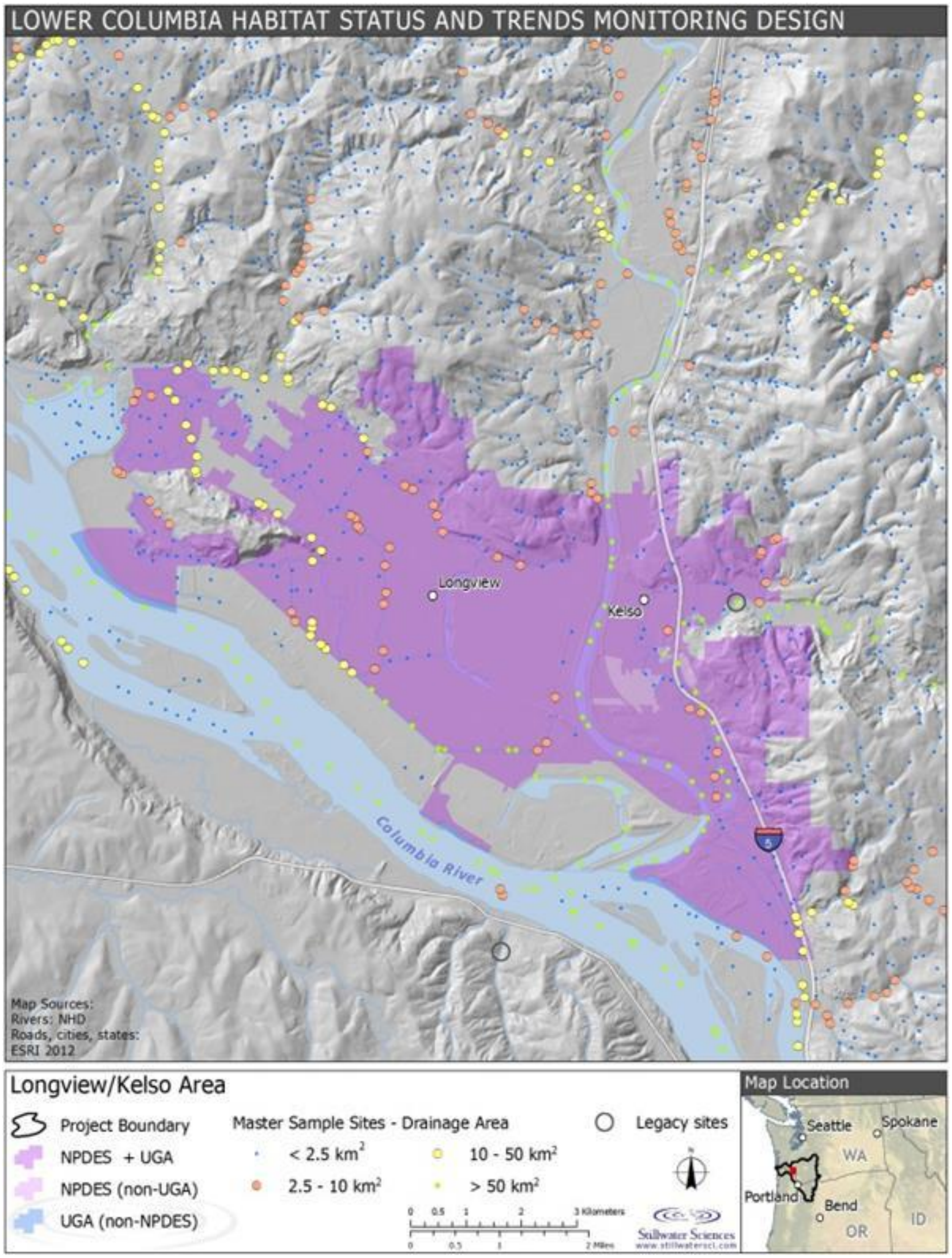

Figure 5b. GIS view of the Master Sample points in two areas covered by municipal stormwater NPDES permits, also highlighting Urban Growth Areas. Individual points meeting the recommended drainage-area criteria are highlighted by red circles (2.5–10 km^2 drainage area) or yellow circles (10–50 km^2). Blue dots are Master Sample sites with too small drainage areas to meet the recommended drainage-area criterion; green circles are sites with overly large drainage areas.

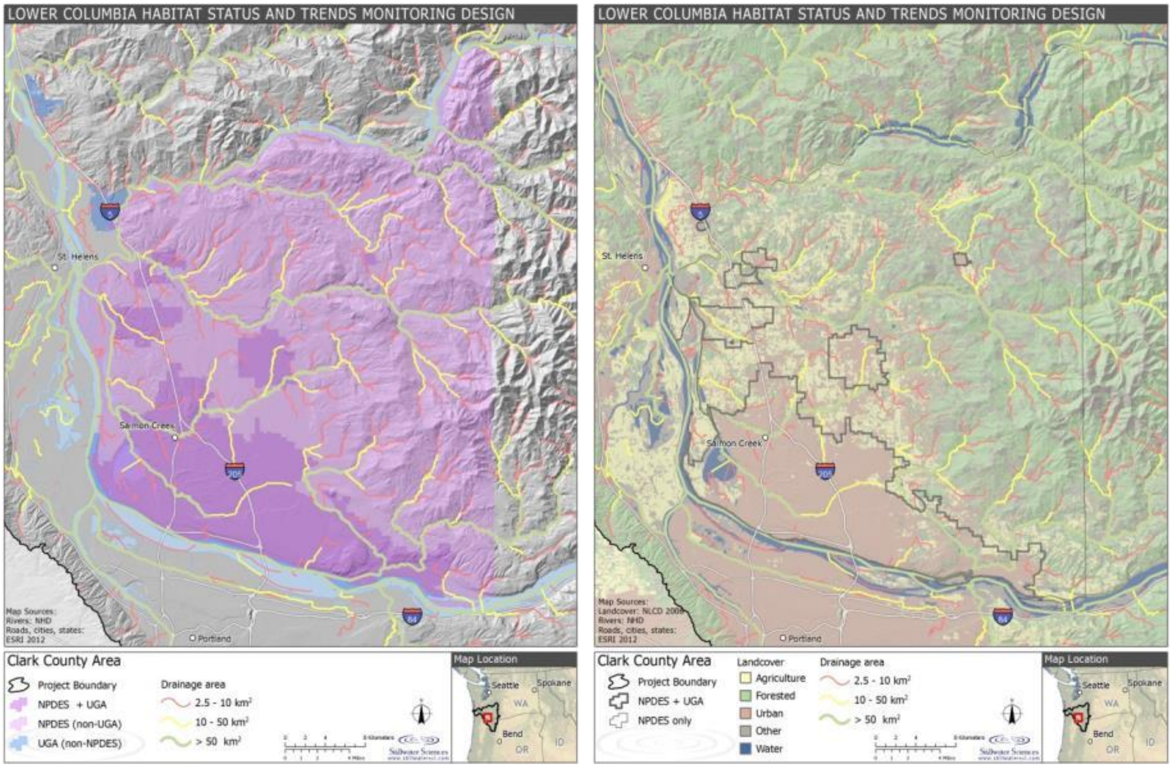

Figure 6. Stream segments of Clark County that contain Master Sample points meeting the recommended drainage-area criteria: red (2.5–10 km^2) or yellow (10–50 km^2). Pale green segments drain larger areas and would not be sampled under this stratification. Darker polygons (left panel) highlight the Urban Growth Areas within this region; other areas in Clark County are largely in agriculture, rural-residential, or forestry land uses (right panel).

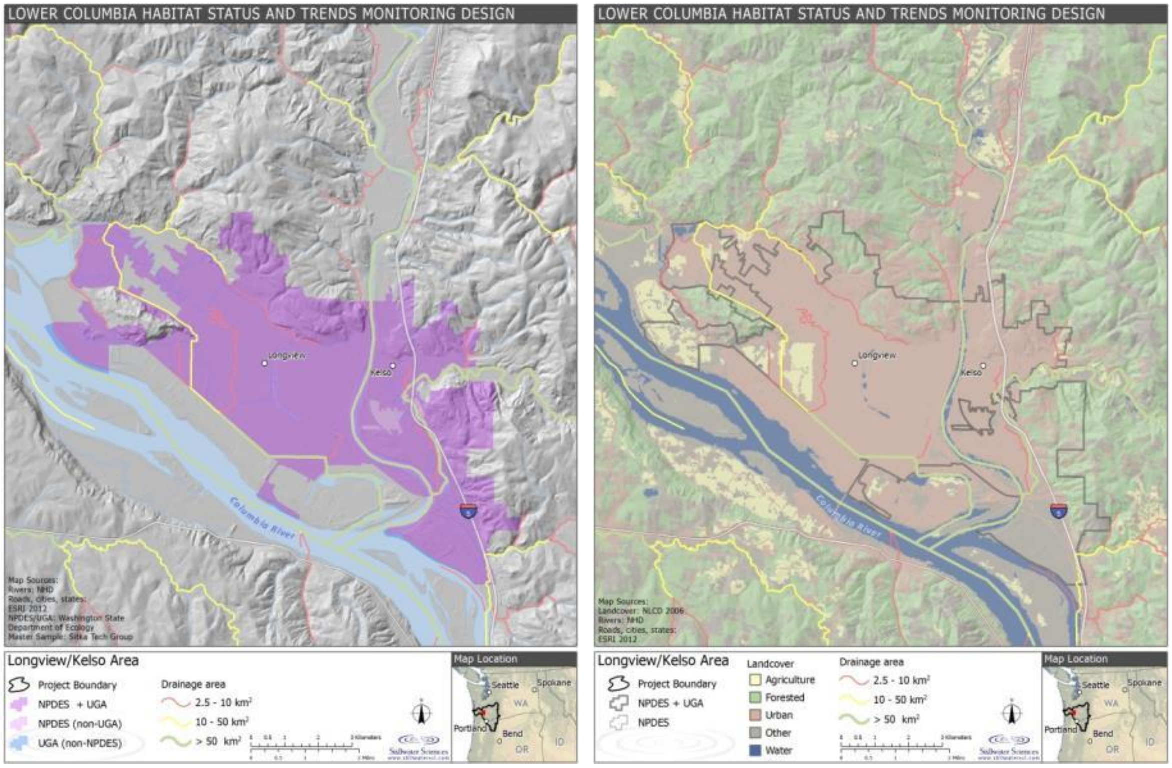

Figure 7. Stream segments in the Longview and Kelso area that contain Master Sample points meeting the recommended drainage-area criteria: red (2.5–10 km^2) or yellow (10–50 km^2). Pale green segments drain larger areas and would not be sampled under this stratification. Virtually all of Longview/Kelso is an Urban Growth Area (left panel); segments with drainage areas outside of the UGA drain primarily forestry land uses (right panel).

Within the two areas highlighted in the figures above, only a few segments with drainage areas of 10–50 km^2 (the "yellow" channels) drain predominately urban areas. In contrast, about two dozen channels with drainage areas between 2.5 and 10 km^2 (the "red" channels") lie within the UGAs; and although not all of these smaller streams have predominately urban watersheds, most of them do. Given this distribution of sites, this Design Report recommends that an expansion of the Phase 1 drainage-area stratum (i.e., to 2.5–50 km^2) be used to select Qa/Qx sites within the urban NPDES areas to ensure a sufficient population of sites that drain predominantly urban land uses, and with the expectation that most of the selected sites will drain no more than 10 km^2.

An additional consequence of this approach is that the Phase-1 recommended "Recovery Plan" stratum is largely irrelevant for municipal stormwater NPDES permit-related sampling. Of the 1,338 Master Sample points within permittees' jurisdictional areas meeting the 2.5–50 km^2 drainage-area criterion (exclusive of the portion of Pierce County on the upper slopes of Mount Rainier), over 96% lie within the "Cascade" subregion, with only one or two independent stream systems in either of the two other subregions. Therefore, there is no opportunity to achieve a statistically meaningful number of samples in any but the Cascade subregion. For this reason, together with the lack of any obvious scientific rationale for anticipating subregion-specific differences between Qa/Qx data sets, this stratum is abandoned altogether.

Although this approach should be sufficient to address Objectives 7.1 and 7.2, most sites selected are unlikely to be useful for addressing Objectives 8.1 or 8.2[3]. For these objectives, a more opportunistic (yet non-random) selection process will be necessary, wherein individual stream segments meeting the watershed-size criterion will need to be evaluated independently for recent development activity within its contributing watershed. Most such watersheds within current municipal stormwater NPDES boundaries are largely developed already, and so the conditions anticipated by Question 8 simply do not apply. However, some such areas already exist within the Region (e.g., Figure 8), and others are likely to be created in the future as urbanization continues and designated Urban Growth Area boundaries are shifted in response.

We recommend the continued inclusion of Objectives 8.1 and 8.2 even if they cannot be addressed feasibly at present with full statistical rigor, because their underlying question is a primary motivation for status and trends monitoring under the municipal stormwater NPDES permits.

Figure 8. Comprehensive Plan Map (Figure 3.1 of http://www.cityofbg.org/DocumentCenter/Home/View/598) for the northwest corner of the City of Battle Ground (left panel). Looking upstream (white arrow) into the 40-acre dark purple area, zoned "Mixed Use Employment," shows fully undeveloped land drained by a stream (right panel) that could be a potential location for long-term monitoring pursuant to addressing Objectives 8.1 and 8.2.

The magnitude of this recommended monitoring effort can be compared to another broadly analogous regional water-quality monitoring program overseen by the Puget Sound Ecosystem Monitoring Program Stormwater Work Group (SWG; http://www.ecy.wa.gov/programs/wq/psmonitoring/swworkgroup.html), a coalition of federal,

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[3] Objectives (from Section 2.1):

7.1: In streams in urban NPDES areas, evaluate whether water-quality conditions generally support the watershed-specific beneficial uses.
7.2: For the population of sites measured under Objective 7.1, evaluate whether measured water-quality metrics show statistically significant trends.
8.1: In streams whose catchment areas now drain primarily non-urbanized areas within Urban Growth Areas, evaluate whether water quality generally supports the watershed-specific beneficial uses.
8.2: In the sample population of Objective 8.1, evaluate whether measured metrics show statistically significant trends in those subwatersheds that have experienced measureable land-use changes.

tribal, state and local governments, together with business, environmental, agriculture, and research interests that was convened to develop a coordinated, integrated approach to quantifying the problems associated with stormwater in Puget Sound. Their final recommendations (as of July 2014) for regional status and trends monitoring for municipal stormwater permittees are as follows:

- Monitor stream benthos and sediment chemistry at 100 small streams sites; 50 inside UGAs and 50 outside UGAs.
- Sample periphyton at 30 sites inside UGAs.
- Collect small stream Water Quality Index (WQI), metals, and PAH data at no fewer than 30 inside and 30 outside UGAs.
- Monitor nearshore sediment chemistry and mussels at a total of 40 nearshore sites.

Recognizing that the two regions differ substantially in geography, access, population, and financial resources, the magnitude of the SWG effort is surely an upper limit on what is feasible for the Lower Columbia Region, at least insofar as program elements were to be funded solely by municipal stormwater NPDES permittees.

3.2.1.2 Regional Qa/Qx monitoring

As with the Qa/Qx monitoring within urban NPDES areas, the spatial stratification and site allocation for Qa/Qx sampling *outside* of urban growth areas (“regional Qa/Qx monitoring”) must be guided by the monitoring questions (Section 2.1): What are the status and trends of water quality and stream flow in surface waters? (Q1); and, What are the status and trends of water quality in surface waters draining watersheds with a substantial fraction of previously forested land that has been recently cleared? (Q2). The spatial scale of these questions spans that of the entire Lower Columbia Region, and so unlike the NPDES-related monitoring there is no obvious reason to restrict the sampling domain to a particular maximum watershed size. Given the expanded range over which the data will be collected, sampling sites are recommended to be stratified into 3 categories of drainage area (0.6–2.5 km^2, 2.5–50 km^2, and 50–200 km^2).

The expanded geographic scope of the prospective sample population, and the organizational value of aligning with the regional habitat monitoring (as much as is both possible and technically relevant), suggest value in having additional strata for the “regional” Qa/Qx monitoring. These additional strata are recommended to be the number of Primary Populations of salmonid species within the contributing subwatershed (Figure 9) and the predominant watershed land cover. In addition to the three categories of contributing drainage area, these strata yield a total of 27 unique combinations of categories. Based on considerations previously discussed for obtaining representative data with sufficient statistical power, this would suggest the need for a total of ~400 sites. There is a potential for fewer sites, either because the variability of these Qa/Qx data may be systematically less than what has been documented for urban stormwater (i.e., less than 15 samples per unique category required for the same level of statistical confidence), or because some combinations of strata categories are not represented in the Lower Columbia Region (e.g., large urban drainages). Should the final tally of sites nonetheless prove infeasible to implement once budgetary other logistical considerations have been determined, then removing one of these strata could reduce the total level of effort by up to two-thirds.

Thus, the preliminary recommended strata for regional Qa/Qx sampling are as follows:

- Number of Primary Populations (0–2, 3, 4+) = **3 categories**
- Drainage area (0.6–2.5 km^2, 2.5–50 km^2, 50–200 km^2) = **3 categories**

- Predominant watershed land cover (forested, agricultural, urban) = **3 categories**

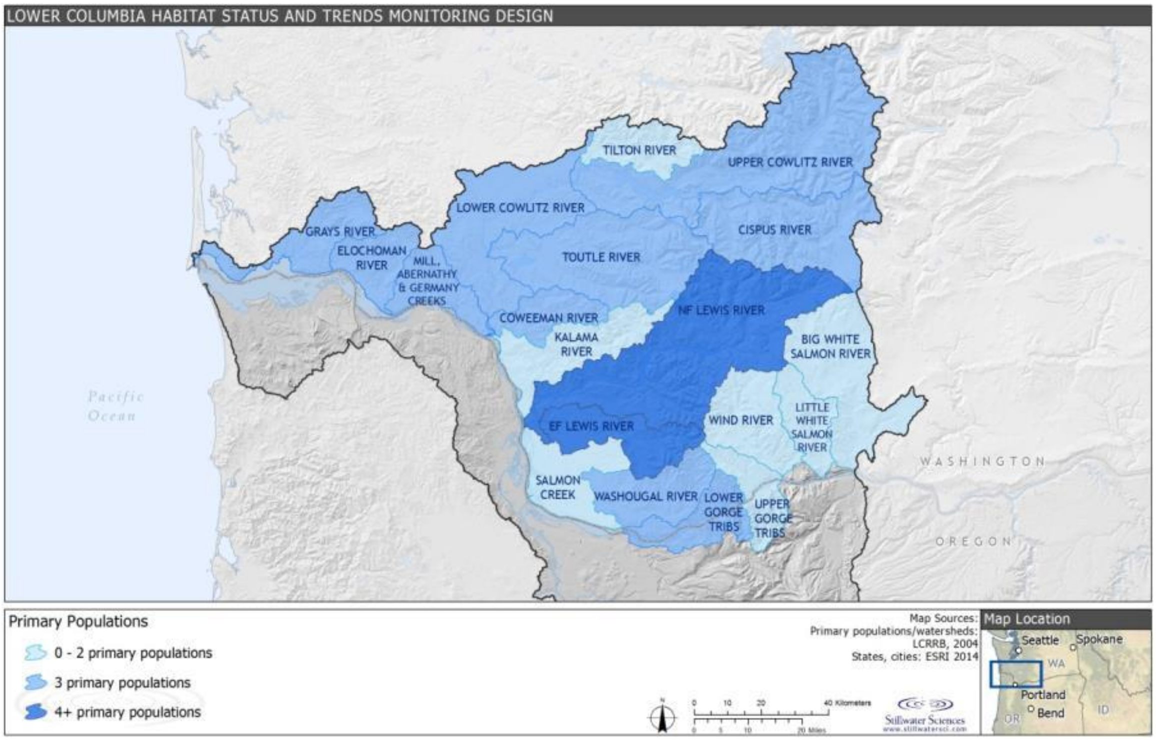

Figure 9. Categories for the number of Primary Populations in each of the subbasins of the Lower Columbia Region in Washington state.

Each of the unique combinations of categories defined by drainage area and Primary Populations have more than 400 Master Sample points (Table 2), indicating ample opportunity for random selection of a sufficient number of sites.

Table 2. Number of Master Sample segments under the recommended regional Qa/Qx stratification.

Number of Primary Populations	Drainage area (km^2)			Totals
	0.6–2.5	2.5–50	50–200	
0–2	3,306	2,768	514	6,588
3	8,040	6,596	1,214	15,850
4+	2,952	2,410	468	5,830
Totals	**14,298**	**11,774**	**2,196**	**28,268**

In addition, the Region is host to 12 rivers in addition to the Columbia (Big White Salmon, Chinook, Coweeman, Elochoman, Gray, Kalama, Lewis, Mill, Cowlitz, Salmon, Toutle, and Washougal) with drainage areas greater than 200 km^2 (about 77 mi^2). Each have unique characteristics such that they probably cannot be treated as part of a randomized, "representative" sampling scheme, and so their relevance to and inclusion in a regional monitoring program is acknowledged but not included in the following discussion. The merits and feasibility of their inclusion in a regional Qa/Qx monitoring program is deferred until the preparation of the Implementation Plan.

Ideally, the logistical and financial benefits of this coordinated HSTM program would be enhanced by using the same sample sites to support both municipal stormwater permit requirements and salmon recovery wherever possible. Unfortunately, in the 2.5–50 km^2 drainage area category for which the two groups overlap, only about 10% of the Master Sample points lie within municipal stormwater NPDES jurisdictions, and even less within their urban areas. This suggests that no more than one or two of the 15 regional Qa/Qx sites in this drainage-area category could be shared by both programs within each Primary Population subbasin category.

Specific locations for conducting the regional Qa/Qx sampling should use the same approach as described for the urban NPDES sampling (Section 3.2.1.1). Segments should be identified and stratified with respect to drainage area and number of Primary Populations. Beginning at the downstream end of a selected segment and moving upstream, identify the first sampling location guided first by logistical considerations of access and adjacent land ownership as identifiable through GIS and aerial photographs, followed by a field visit to each prospective site to confirm access and overall suitability for monitoring. Given the order-of-magnitude ranges in drainage areas, independence of data is likely even for geographically nested sites occupying different drainage-area categories; however, each of the sites selected *within* a given drainage-area category should preclude any additional sites selected up- or downstream along the same channel within the same category.

The two monitoring questions associated with this effort require different treatments. The full population of sites needed to address Question 1 ("What are the status and trends of water quality and stream flow?") should be identified first, and then these locations should each be evaluated to determine which could also satisfy the conditions needed to address Question 2 ("What are the status and trends of water quality from recently cleared land?"). A rather small number will likely meet this second test, concentrated in the smallest drainage-area category and insufficient to provide statistically meaningful results. However, they may provide some site-specific indications of potential effects with minimal additional cost, offering some indications of whether a more concentrated, directed effort might be worthwhile.

3.2.2 Strata for habitat sites

Habitat monitoring sites do not have identical target populations or strata to those of Qa/Qx sites because the attributes being measured by these two types of monitoring are fundamentally different in several respects. Habitat data are collected on physical features at a site, rather than water-column attributes that are relatively constant over long distances. Habitat features are also more sensitive to instream channel dynamics, and so their dependency on stream power (a function of channel slope and discharge, for which drainage area is a credible surrogate for the latter) must be incorporated into the stratification to ensure representative results for the population as a whole.

Although future habitat-monitoring needs of municipal stormwater NPDES permittees may not differ from those in the rest of the region, the same jurisdictional discrimination for Qa/Qx monitoring is maintained in this monitoring design to retain future flexibility (urban NPDES areas). As such, sites for monitoring in urban NPDES areas and outside an urban growth area of the region are considered independently, albeit with a common set of recommended strata for both:

- Drainage Area (0.6–2.5, 2.5–50, 50–200, 200–1,000, >1,000 km^2) = **5 categories**
- Stream Gradient Groups (<1.5%, 1.5–3%, 3–7.5%, >7.5%) = **4 categories**
- Predominant watershed land cover (forested, agricultural, urban) = **3 categories**

In addition to these three strata common to both urban NPDES and non-UGA habitat monitoring, the number of Primary Populations in the subbasin [(0–2, 3, 4+) = 3 categories] is recommended as an additional strata for habitat monitoring in non-UGA areas. This supports salmon recovery priorities defined in the 2013 Lower Columbia River Salmon and Steelhead Recovery Plan and is consistent with Qa/Qx stratification.

These strata, modestly revised from Phase 1, are recommended to define habitat monitoring sites, guided by Questions 3, 4, 9 and 10 and their associated objectives[4]. As discussed in Section 2.3, a primary justification for stratification is to reduce environmental variation and compare conditions that are anticipated to be similar (“like” vs. “like”). This logic results in the selection of drainage area, stream gradient and land cover strata as depicted in Figures 10, 11, and 12. Primary Populations stratification serves to support a management goal of focusing restoration efforts in areas of greatest need in support of salmon recovery. However, given the limited number of sample sites within the urban growth area of the municipal stormwater NPDES permittees and the different goals and objectives for this domain, stratification by Primary Populations is not recommended for these areas.

The following logic was applied in defining the final list of recommended habitat strata:

- Drainage area categories align with those identified for regional municipal stormwater NPDES permit monitoring.
- Gradient categories are based on the broadly applied habitat classification established by Buffington et al. (2004). Figures 13 and 14 illustrate the effect of such gradient stratification on site locations.
- The three recommended land-cover classes (forested, agricultural and urban) are readily generated in GIS from the 2006 National Land Cover Dataset (NLCD). Although an additional “cleared” land-cover category would be relevant to address Question 6, it cannot be delineated for this phase of the HSTM program due to insufficient detail available in the NLCD 2006 dataset and the limitations noted in Objective 6.1. Accurate representation of changes in this land-cover category will require a combination of GIS and airphoto analysis during subsequent implementation phase(s) of the program.

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[4] **Question 3:** What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions?

Question 4: Do in-stream biological health and in-stream/riparian habitat conditions correlate to changes in abundance, productivity, spatial structure, and diversity of the natural-origin?

Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?

Question 9: What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions that are primarily within the jurisdiction of NPDES stormwater permittees?

Question 10: Do in-stream biological health and habitat conditions correlate to changes in observed abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population?

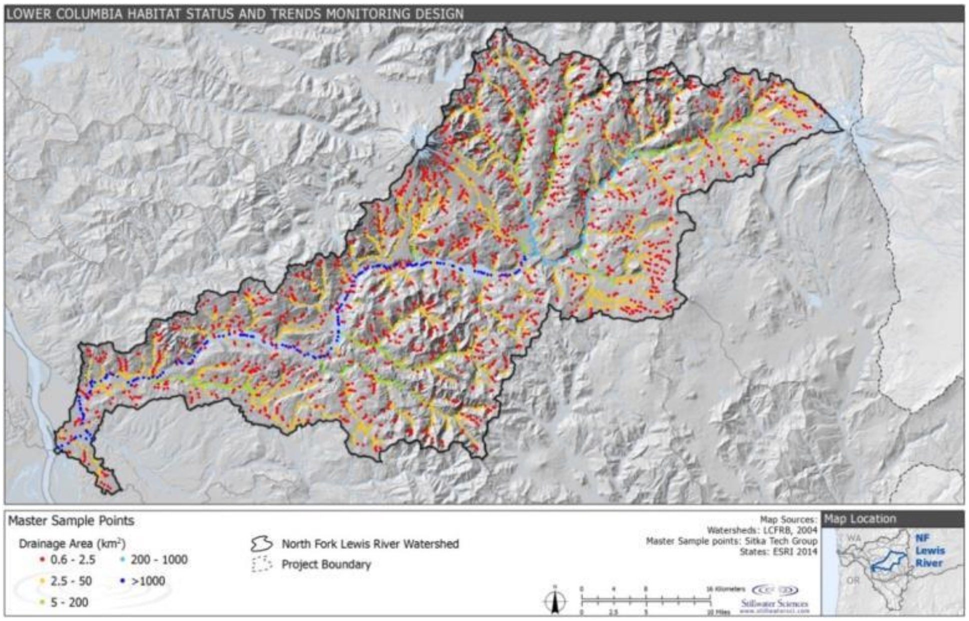


Figure 10. Drainage area categories for Master Sample points in the North Fork Lewis Watershed.

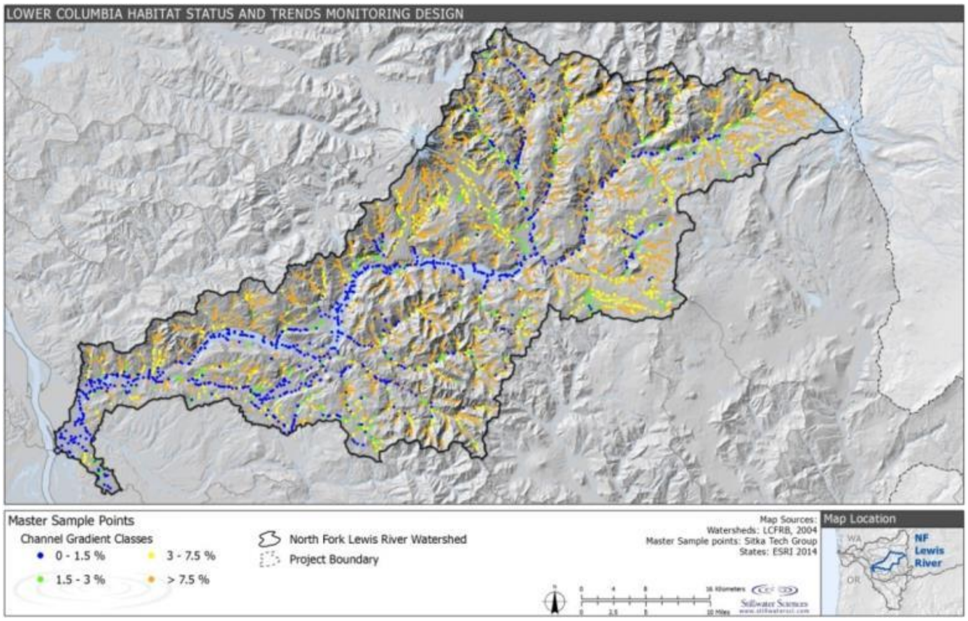


Figure 11. Channel gradient classes for Master Sample points in the North Fork Lewis Watershed.

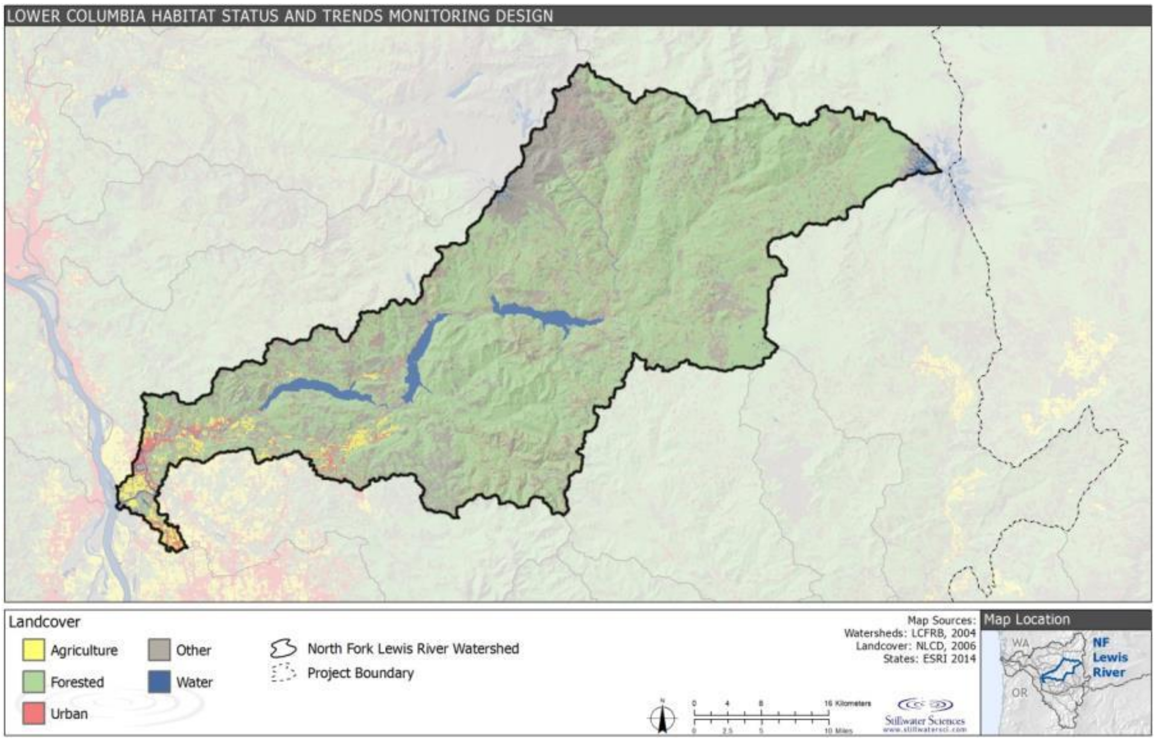
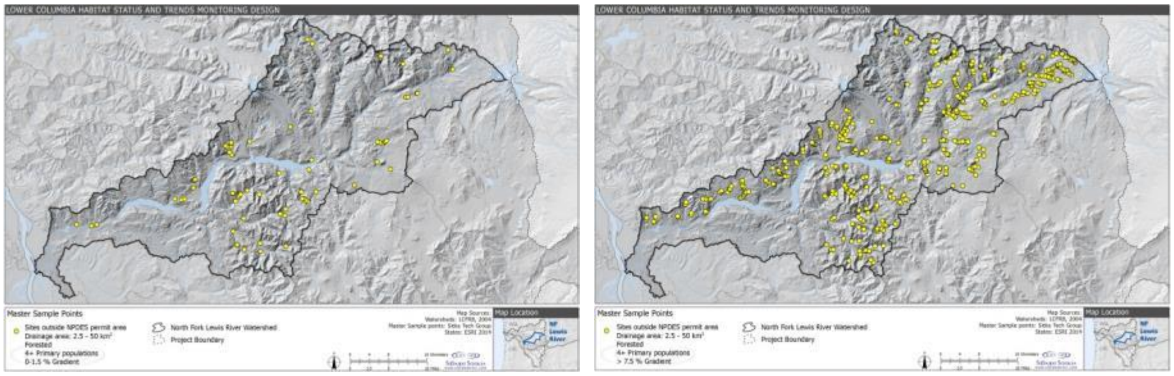


Figure 62. Land cover classes in the North Fork Lewis Watershed



Figures 13 and 74. Master samples points that illustrate the effect of varying gradient classes in the North Fork Lewis River Watershed. Figure 13 (left) shows Master sample points for 0–1.5% gradient; in contrast, Figure 14 (right) shows Master sample points for gradients 7.5% or greater. All other strata are held constant (land cover, drainage area, and location relative to UGA and municipal stormwater NPDES permit areas).

The recommended habitat strata reflect a refinement of the proposed habitat strata in Phase 1 of this project, which included three strata for habitat monitoring sites and resulted in 150 unique combinations (primarily as a result of the "subbasin" stratum): Inside/outside the combined area within an incorporated City boundary and/or an unincorporated Urban Growth Area (UGA) = **2 categories**; Subbasin (as defined in recovery plan) = **25 categories**; and Stream Power (Strahler stream order or channel gradient) = **3 categories**. Subsequent reevaluation of this framework affirmed these three strata in concept, but noted that: (1) replacing the UGA criterion with that of urban NPDES areas would better align the approaches for identifying Qa/Qx and habitat sites and likely serve the needs of municipal stormwater NPDES jurisdictions better, and (2) the sheer number of recovery plan subbasins (25) would likely render any framework that included this stratum infeasible. In an effort to support recovery objectives while maintaining a feasible number of monitoring sites, this Design Report recommends a stratum based on Primary Populations rather than subbasins, resulting in significantly fewer categories while maintaining a link to recovery planning priorities. In addition, "stream power" as a channel attribute requires *both* channel gradient and a measure of discharge, of which drainage area is a more reliable representation than stream order. Watershed land cover has been included in the present recommendation, insofar as it is likely to be as important a determinant of habitat as it is with water quality.

Although the total recommended habitat strata nominally define 240 unique combinations (urban NPDES = [5 × 4 × 3] + non-UGA = [5 × 4 × 3 × 3]), a significant fraction of them have too few monitoring sites in the Master Sample (Tables 2 and 3). Given the variability in the proposed habitat metrics and conditions to be monitored, determining the minimum number of sites necessary for valid statistical analyses has proven difficult to determine prior to implementation. An examination of published literature did not reveal a recommended minimum sample size or acceptable level of variability. Therefore, the monitoring design presumes a consistent number of habitat and Qa/Qx monitoring sites (i.e., 15 sites per unique strata combination).

Based on that criterion, only 9 unique strata combinations with 15+ potential monitoring sites are present within urban NPDES areas (Table 3). Outside of urban areas, a preliminary screening of the Master Sample suggests that no more than 75 unique combinations will have sufficient monitoring sites (Table 4). Not all potential monitoring sites will prove viable from consideration of access and other logistics, and so the number of strata combination may be further reduced if the number of viable locations within any given strata combination drops below 15. If contingency plans are necessary, stakeholders will be encouraged during preparation of the Implementation Plan to consider either less rigorous statistical thresholds (to reduce the number of sites) or a further reduced set of metrics. This will require greater certainty in the level of financial resources than is currently available.

Table 3. The number of Master Sample points in a given strata combination (based on land cover, drainage area and slope category) within the urban NPDES areas. Gray shaded cells include 15 or more sites.

Drainage area	Slope	Forested	Agriculture	Urban
0.6–2.5 km^2	<1.5%	9	14	52
	1.5–3%	7	6	17
	3–7.5%	9	0	21
	>7.5%	11	0	8
2.5–50 km^2	<1.5%	15	21	111
	1.5–3%	13	0	16
	3–7.5%	2	0	10
	>7.5%	1	0	1
50–200 km^2	<1.5%	6	2	22
	1.5–3%	1	0	0
	3–7.5%	1	0	0
	>7.5%	0	0	0

Drainage area	Slope	Forested	Agriculture	Urban
200–1,000 km^2	<1.5%	1	1	16
	1.5–3%	0	0	0
	3–7.5%	0	0	0
	>7.5%	0	0	0
>1,000 km^2	<1.5%	0	0	1
	1.5–3%	0	0	0
	3–7.5%	0	0	0
	>7.5%	0	0	0

Table 4. The number of Master Sample points in a given strata combination (based on land cover, Primary Populations, drainage area and slope category) outside of UGAs. Gray shaded cells include 15 or more sites.

Drainage area	Slope	Forested			Agriculture			Urban		
		Primary population categories								
		0–2	3	4+	0–2	3	4+	0–2	3	4+
0.6–2.5 km^2	<1.5%	68	288	32	28	118	28	28	62	17
	1.5–3%	115	304	58	5	21	7	11	31	11
	3–7.5%	434	959	298	9	20	9	46	68	24
	>7.5%	1629	3313	1300	10	20	2	90	130	32
2.5–50 km^2	<1.5%	199	671	123	75	150	33	52	114	29
	1.5–3%	285	594	159	6	15	4	20	50	11
	3–7.5%	687	1111	516	5	8	2	44	44	16
	>7.5%	628	1392	549	0	8	0	0	0	0
50–200 km^2	<1.5%	97	236	101	30	23	1	25	29	3
	1.5–3%	98	138	57	5	4	0	6	6	2
	3–7.5%	44	127	42	1	1	0	0	6	2
	>7.5%	13	32	15	0	0	0	2	0	0
200–1,000 km^2	<1.5%	135	127	70	0	0	0	13	20	7
	1.5–3%	33	35	8	0	1	0	0	2	0
	3–7.5%	33	13	2	0	0	0	0	1	0
	>7.5%	10	9	2	0	0	0	0	0	0
>1,000 km^2	<1.5%	2	40	4	0	1	0	1	5	1
	1.5–3%	0	5	0	0	0	0	0	0	0
	3–7.5%	0	3	0	0	0	0	0	0	0
	>7.5%	0	0	0	0	0	0	0	0	0

The following strategy for site allocation is therefore recommended, guided by Questions 3, 4, 9 and 10 (those pertaining to the status and trends of habitat and biological health) and their associated objectives:

- From each of the unique strata combinations meeting their respective criteria, select 15 sites from the sample population. If desired, selection can be based on a combination of preemptive identification of stream segments with legacy sites having suitable long-term habitat data (such as EMAP metrics collected by Clark County at 10 long-term index sites), plus additional randomly selected sites; otherwise, a strict random selection can be made from the Master Sample. This choice will be made during preparation of the Implementation Plan.

- Identify a reach length segment of 20 times the average bankfull width (Harrelson et al. 1994, p. 10) downstream from the randomly selected site location to be sampled for all metrics requiring a "reach" (instead of a "point"). An example procedure for this identification is given in Washington State Department of Ecology (2014).
- Sites should be given a preliminary review of access and adjacent land ownership using GIS and aerial photographs, given that not all sites will be viable candidates for monitoring due to logistical constraints. If the site appears to be a viable candidate, a field visit will still be necessary to confirm access and overall suitability (see Washington State Department of Ecology 2014 for an example of specific criteria).

Note that the analysis of monitoring data needed to answer Questions 3 and 4 will need to rely on only those sites identified outside of UGAs. Questions 9 and 10 will rely on sites identified within urban NPDES areas.

The closest analogy to the program proposed here is Ecology's Watershed Health Monitoring (WHM) project (http://www.ecy.wa.gov/programs/eap/stsmf/), which collects data on river and stream health by region at approximately 350 sites across the state, most of which are sampled once every four years. Sites are stratified only by Strahler stream order into five categories, with at least 30 sites (total) distributed across these categories within each of the eight statewide salmon recovery regions (of which the Lower Columbia Region is one). In the preliminary document for this program (Cusimano et al. 2006) a suite of habitat measurements similar to those recommended for this program (Section 3.5) were specified, requiring about 3–4 hours of field work for a crew of two, plus travel time:

- % Substrate by size e.g., % fines or % sand/fines
- Embeddedness: % bottom particles' surfaces that are surrounded by sand/fines
- Relative bed stability = observed diameter vs. predicted
- % of bank that is unstable (with actively eroding banks)
- Fish cover by type % of wetted channel with cover
- Mean residual pool vertical profile area
- Thalweg depth; bankfull depth
- Wetted width; bankfull width
- Bankfull or wetted cross-sectional area (channel capacity)
- Sum of length of side channels
- LWD pieces, by length, diameter, and position—standardized to km reach;
- Large wood volume estimated from size class tally
- Riparian vegetation structure (% cover in 3 layers, by type, size)
- Percent canopy as measured with a densiometer
- Riparian disturbance

If this state-wide allocation of effort reflects the general magnitude of effort likely to be feasible in the Lower Columbia Region under the present effort, then a total of about 90 unique combinations of categories is likely to represent an upper bound limit (and for which subsequent constraints may impose further reductions). The tally of currently proposed unique categories exceeds that upper bound limit. Reductions in the number of proposed sampling sites can be achieved in several ways: (1) if lower metric variability is determined, (2) by lowering the targets for statistical power/confidence, (3) by reducing the number of strata, (4) by condensing or truncating strata categories, and (5) by employing cost saving data collection measures (e.g., remotely-sensed data).

3.3 Temporal Scale

In addition to deciding where to sample (spatial scale), it is critical to consider the frequency of sampling (temporal scale). While some conditions change seasonally, others change on annual or longer timeframes. Section 3.5 below provides the appropriate temporal scale of monitoring according to specific metrics. Phase 1assumed that most sites would be visited once every five years, and that a subset of sites would be visited every year. However, a number of habitat metrics are more responsive to chronic or systematic changes in streamflow or sediment loading and so are herein recommended for annual data collection.

3.4 Signal to Noise Analysis—Phase 1

Phase 1 of the signal to noise (S/N) analysis resulted in a compilation of relevant literature from numerous sources (Kaufmann et al. 1999, Cusimano et al., 2006, Whitacre et al. 2007, Roper et al. 2010, Merritt and Hartman 2012) and the identification of an ongoing study to compare CHaMP and PIBO metrics (Jordan and Roper 2014). These S/N studies were conducted by the following monitoring programs and organizations:

AREMP—Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Program;
CDFG—California Department of Fish and Game Protocols;
EMAP—EPA Environmental Monitoring and Assessment Program;
NIFC—Northwest Indian Fisheries Commission;
ODFW—Oregon Department of Fish and Wildlife;
PIBO—USDA Forest Service-BLM (effectiveness monitoring program for PACFISH/INFISH biological opinion);
UC—Upper Columbia Monitoring Strategy.

Kaufmann et al. (1999) provided a useful interpretation of S/N values as follows: "the adverse effects of noise variance in environmental monitoring are negligible when S/N >10, becoming minor as S/N decreases to 6, increasing to moderate as S/N decreases to 2, and becoming severely limiting as S/N approaches 0." Such information is highly valuable when considering the suitability of a given metric to detect meaningful signals (trends). It is also useful to evaluate the potential for monitoring programs to share data. Although some monitoring programs may find their data to be sharable based on standard protocols, if one program produces high S/N ratios and the other low S/N ratios, it would be ill-advised to pool such data.

Along with reported S/N ratios, most studies provided "grades" for each metric to facilitate interpretation (Kaufmann et al. 1999, Cusimano et al. 2006, Whitacre et al. 2007, Merritt and Hartman 2012). S/N values reported by Roper et al. (2010) were converted to letter grades using the scoring scale in Merritt and Harman (2012). These results were compiled (the last column in Tables 4 and 5) and used as a guide for metric selection (Section 3.5). Metrics generating grades of D or F were removed from consideration unless there higher grades reported were in other studies. In such cases, the metrics were retained for additional consideration during the implementation planning process. The sharability issue with respect to protocols will be also be explored during Implementation planning (Phase II of the S/N study).

While the metrics analyzed, methods used, sampling timeframe and areas of application varied in each of the studies, the published literature provides a significant body of evidence from which management decisions can be made and additional study needs identified. In the early stage of monitoring design development, we proposed a compilation and analysis of relevant, existing data to address a subset of metrics not adequately characterized by the literature. However, given the abundant literature results and the significant challenge of obtaining suitable datasets not specifically collected for an alternative S/N study, we believe additional stakeholder input is necessary to determine the best course of action for any subsequent refinement of S/N analysis (e.g. decisions to be made regarding the sharability of data).

3.5 Metrics

The current recommended lists for Qa/Qx and habitat monitoring, subject to further evaluation as the scope of project funding is further refined, are given in the following two sections.

3.5.1 Qa/Qx metrics

The Qa/Qx metrics recommended for this HSTM program (Table 5, first two columns) have been identified on the basis of historic utilization and regional experience, prior recommendations from Phase 1 of this project (and archived in TR3), known issues with data quality and variability, cost of implementation, and direct relevance to the monitoring questions that are guiding this program (Section 2.1) (see Appendix C for a summary of the rationale for metric inclusion or exclusion). Relative to many other water-quality monitoring programs, the most noteworthy aspects of this recommended program are its emphasis on continuously monitored (or otherwise integrative) metrics, and the overall brevity of the list. These outcomes are driven by considerations long-articulated by project partners and stakeholders: statistical and scientific rigor of the chosen metrics, and feasible cost of implementation.

A rigorous, defensible metric that is useful for regional status and trends monitoring needs to meet several goals: it should not be subject to significant variability that is dependent only on the vagaries of the day or hour when it is measured, its variability due to watershed and in-stream conditions should be high relative to the random or non-systematic variability that cannot be eliminated by the sampling protocol (i.e., a high signal-to-noise ratio), it should be responsive to the environmental stressors of greatest concern to resource managers, and its collection and analysis should be affordable.

Many traditional water-quality metrics, including many considered in earlier stages of this project, fail one or more of these criteria. Most problematic are those that have been long-accepted as part of a “normal” or “conventional” stormwater monitoring program (e.g., National Research Council 2009), but which are known either to have high random variability (e.g., total phosphorus, total suspended solids, pH; Merritt and Hartman 2012) or to express instantaneous conditions that would require continuous water-column sampling that is likely cost-prohibitive because of the required degree of site maintenance (e.g., dissolved oxygen, dissolved metals, dissolved nutrients, turbidity) to generate useful data on regional status and trends. As stakeholder involvement and budget are still being determined, the list of recommended metrics in this

Design Report errs on the side of minimizing cost, with the expectation that if additional funds become available the value of spending them on additional data collection can then be evaluated.

Table 5 reflects the integration of these considerations, and in so doing it diverges from the final recommendations of Phase 1 in several important respects (see Appendix C). For the present recommendation, time-integrative metrics are emphasized, either through the use of reliable, low-cost continuous sensors that require little field maintenance (temperature, conductivity, stage), or with metrics that are integrative by nature (sediment metals, macroinvertebrates). The four metrics noted for “future consideration” likely meet the goals for utility, but their incremental benefits for characterizing the status and trends of streams of the Region are uncertain at present. and will be informed by the findings of other programs’ efforts in 2015. These metrics will be (re)considered during development of the Implementation Plan, making use of new data and conclusions from other relevant studies across the region as they become available (such as Clark County’s long-term index monitoring program and the Regional Stormwater Monitoring Program in Puget Sound) but they are not included in the primary Qa/Qx monitoring program as recommended here.

Table 5. Qa/Qx recommended metrics including the frequency of sampling.

Water-quality metrics	**2015 HSTM Recommendation**	**"Conventional" stormwater pollutants[5]**	**2015 PS RSMP (7/2013 + 7/2014)[6]**	**2013 Phase 1 of HSTM (TR3, Table 2)**	**2015 USGS NAWQA #3[7]**	**S/N Rating**
Water Temperature	X[c]	X	X[m]	hourly	X	B[1]
Sediment metals	X[a]		X[5]	X[5]		
Conductivity	X[c]	X	X[m]	X[m]	X	A[1]
Chloride	*	X	X[m]	X[m]		A[1]
Total Nitrogen	*	X	X[m]	X[m]	X	A[1]
Sediment PAHs	*		X[5]			
Other metrics						
Stage (surrogate for flow)	X[c]		X[m]	X[m]		
Macroinvertebrate Index	X[a]		X[5]	X[a]		C[1]
Periphyton	*		X[5]	X[a]		
Habitat metrics at Qa/Qx sites:						
Bankfull width, depth	one-time		X[5]		?	A[1] A (10.9 AREMP[2]) B (6.8 CDFG[2]), C (2.5 EMAP[2]) A (24.7 NIFC[2]) C (2.8 ODFW[2]) A (58.1 PIBO[2]) A (20.2 UC[2]) A (24)[3] D (1.2 AREMP)[3] D (1.93 EMAP)[3] A (30.32 PIBO)[3]

Water-quality metrics	**2015 HSTM Recommendation**	**"Conventional" stormwater pollutants[5]**	**2015 PS RSMP (7/2013 + 7/2014)[6]**	**2013 Phase 1 of HSTM (TR3, Table 2)**	**2015 USGS NAWQA #3[7]**	**S/N Rating**
Wetted width	each visit		X^5			A (14)[4] A[1]
Substrate	one-time		X^5			A/B[1] <u>% fines</u> A (21.73 AREMP)[3] A (69.94 EMAP)[3] A (21.24 PIBO)[3] A(15)[4]

X^a = annual data collection
X^5= data collection once per municipal stormwater NPDES permit cycle (typically 5 years)
X^c = continuous collection
X^m = monthly collection
* = for future consideration based on experience and findings of 2015 monitoring programs
Blank cells in the far right column indicate no signal to noise ratios or ratings identified in the literature search.

Footnotes:

[1] Merritt and Hartman (2012)

[2] Roper et al. (2010). Numbers indicate reported S:N ratios, converted to letter grades using scoring criteria from Merritt and Hartman (2012). AREMP – Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Program; CDFG – California Department of Fish and Game Protocols; EMAP – EPA Environmental Monitoring and Assessment Program; NIFC – Northwest Indian Fisheries Commission; ODFW – Oregon Department of Fish and Wildlife; PIBO - USFS–BLM (biological opinion effectiveness monitoring program; UC – Upper Columbia Monitoring Strategy.

[3] Whitacre et al. (2007)

[4] Kaufmann et al. (1999)

[5] See, for example, NRC (2009)

[6] As recommended by dated memos/reports of the Stormwater Work Group for forming the Puget Sound Regional Stormwater Monitoring Program (PS RSMP); see https://sites.google.com/site/pugetsoundstormwaterworkgroup/swg-recommendations

[7] Cycle 3 of the US Geological Survey's National Water Quality Assessment

3.5.2 Habitat metrics

The habitat metrics recommended below (Table 6) have been identified on the basis of historic utilization and regional experience, prior recommendations from Phase 1 of this project, known issues with data quality and variability, cost of implementation, and direct relevance to the monitoring questions that are guiding this program (Section 2.1). The habitat metrics, along with a listed subset of Qa/Qx metrics, are to be collected at habitat monitoring sites identified in Section 3.2.2. The majority of these metrics have been presented at workshops and vetted by project partners and stakeholders during the development of this HSTM design.

Metrics recommended for collection at all habitat sites fall in two broad categories: those that are not expected to change rapidly and need be measured only once per five years, and those for which annual re-measurement is appropriate. Five-year metrics comprise bankfull width/depth, reach length (20 times the bankfull width), channel type, number of habitat units, sinuosity, floodplain area, and length of side channel habitat. Annual measurements, to be made during a single day's site visit in summer months, comprise (categorical) bank stability, pools per unit length, residual pool depth, thalweg depth, density/distribution instream wood, substrate particle size (% composition by grain diameter), embeddedness, relative bed stability, shade at mid channel, riparian canopy (% cover), riparian understory (% cover), and flow category. Temperature should be measured at every visit; those sites with critically high values may merit more intensive and frequent measurements, but this can be determined only once implementation has begun.

In support of Objective 4.1 and 10.1 (seeking correlations in trends between habitat and fish-population metrics; Section 2.1), the metrics for habitat sites have been clustered according to categories of limiting factors as defined by NMFS (Hamm 2012) (Table 6). This is consistent with the presentation of metrics in Appendix B of the ISTM habitat monitoring report (PNAMP 2014). Additional detail about the metrics based on extensive prior reviews, including a summary of the rationale for metric inclusion or exclusion from Phase 1 to current, has been provided in Appendix D.

Table 6. Habitat metrics including the frequency of sampling, whether or not the metric was identified in Phase 1 of this HSTM program (TR3), the number of Lower Columbia Monitoring Programs collecting the recommended metric (Puls et al. 2014) and Signal/Noise ratings from various sources.

Habitat metrics	Current recommendation	TM3	Collected by LC monitoring programs	S/N rating[1]
Limiting factor—Channel structure and form				
Reach length	once	X	5	C (2.83 AREMP)[2] | B (9.16 EMAP)[2] B (8.37 PIBO)[2]
Channel type	once	X	7	
Density of habitat type	every 5 years		3	
Sinuosity	every 5 years	X	7	A (10.9 AREMP)[3] | B (6.8 CDFG)[3] D (1.28 AREMP)[2] | C (2.32 PIBO)[2] C (2.5 EMAP)[3] | A (24.7NIFC)[3] C (2.8ODFW)[3] | A (58.1PIBO)[3] A (20.2 UC)[3] | A[4] | D (1.1)[5]
Bankfull width/depth	every 5 years	X	4	C (2.1 AREMP)[3] | D (1.7 CDFG)[3] F (0.53 AREMP)[2] | C (4.01 PIBO)[2] D (1.7 EMAP)[3] | B (6.1 NIFC)[3] C (3.5 ODFW)[3] | D (1.5 PIBO)[3] D (1.6 UC)[3] | B (6.5)[5]
Bank stability (categorical)	annually	X	7	A[4] | D (1.3)[5] (bank condition)
Pools per unit length	annually		5	D (1.0 AREMP)[3] | F (0.2 CDFG)[3] D (1.8 EMAP)[3] | D (1.1 NIFC)[3] B (5.5 ODFW)[3] | F (0.8 PIBO)[3] D (1.6 UC)[3]
Residual Pool depth	annually		7	B (6.3 AREMP)[3] | F (0.2 CDFG)[3] B (6.1 EMAP)[3] | C (4.9 NIFC)[3] C (3.2 ODFW)[3] | B (7.4 PIBO)[3] A (11.9 UC)[3] | A (pool unit depth)[4] A (37.31 PIBO)[2] | B (9)[5]
Thalweg depth	annually		7	A[4] | B (6.9)[5]

Habitat metrics	Current recommendation	TM3	Collected by LC monitoring programs	S/N rating[1]
Density/distribution instream wood	annually	X	7	A (53.3 AREMP)[3] | C (4.4 CDFG)[3] A (10.8 EMAP)[3] | A (87.1 NIFC)[3] A (24.5 ODFW)[3] | A (19.4 PIBO)3 A (13.6 UC[3])[**] | B,D[4]|B (7)[5] B (AREMP)[2] | F (0.74 EMAP)[2] D 1.19 (PIBO)[2]
Limiting factor—Sediment conditions				
Substrate particle size (% comp by particle size category)	annually	X	7	C (3.7 AREMP)[3] | B (6.9 EMAP)[3] B (9.4 PIBO)[3] |C (2.3 UC)[3*] A/B(percent fines)[4] | A (15)[5] A (21.73 AREMP) % fines[2] A (69.94 EMAP) % fines[2] A (21.24 PIBO) % fines[2]
Embeddedness	annually		5	C,A[4] | B (7.7)[5]
Relative bed stability	annually	X	3	
Limiting factor—Riparian condition				
Shade at mid channel	annually	X	3	A[6] | A (15)[5]
Riparian canopy (% cover)	annually		3	A[6] | A (17)[5]
Riparian understory (% cover)	annually			B[6] | F (0.9)[5]
Limiting factor—Water quantity				
Flow Category[7]	annually		7	
Limiting factor—Peripheral and transitional habitats				
Floodplain area	every 5 years			
Length of side channel habitat	every 5 years		3	
Limiting factor—Water quality				
temperature	TBD	X[ai]	3	B[4]

Blank cells indicate no signal to noise ratios or ratings identified in the literature search

[1] When two grades are present, the first is for wadeable streams and the second is for larger rivers

[2] Whitacre, Roper, and Kershber 2007;

[3] Roper et al. 2010. Converted to letter grades using scoring in Merritt and Hartman 2012;

[4] Merritt and Hartman, 2012

[5] Kaufmann et al. 1999

[6] Cusimano et al. 2006

[7] free-flowing, sluggish (<1ft /sec), stagnant, dry

* $\log_e$ of D_{50} performed best

** $\log_e$ of LWD/100 m performed best

As previously discussed, a rigorous, defensible metric for regional status and trends monitoring needs to meet several goals:

- It should be tied to program-specific questions and objectives

- It should be responsive to the environmental stressors of greatest concern to resource managers,
- Its variability due to watershed and in-stream conditions should be high relative to the random or non-systematic variability that cannot be eliminated by sampling protocol (i.e., a high signal to noise ratio), and
- Its collection and analysis should be affordable.

Some traditional habitat metrics fail under one or more of these criteria. The table above reflects the integration of these considerations, and in so doing it diverges from the final recommendations of Phase 1 in some cases (see Appendix C).

3.6 Lessons Learned

The LCFRB generated the following reflections at the conclusion of Phase 2 of this HSTM project.

Developing a regional monitoring program through the integration of multiple existing monitoring programs is a complex undertaking requiring:

- *Active participation of stakeholders;*
- *Recognition of varying interests;*
- *Sufficient time for review of work products;*
- *Clear articulation of the question to be answered;*
- *Measurable objectives;*
- *Flexibility to alter course to address emerging technical and policy issues; and*
- *Tempering technical design with cost and implementation considerations.*

3.7 Next Steps

Following this Phase 2 monitoring design will be the development of a full-scale Implementation Plan for the Lower Columbia Integrated HSTM Design, which will represent Phase 3 of the HSTM program. Prior to or concurrent with its execution, however, several outstanding issues will need to be addressed. They have been noted individually throughout the above Design Report where relevant, and they are restated below for ease of reference:

- Establish fiscal sideboards for Regional and NPDES-related monitoring to define the scope of a “feasible” program and so constrain the details of the final Implementation Plan;
- Choose between a pseudo-random and fully random site-selection process with respect to inclusion of legacy sites for specific assessment questions and strata;
- Finalize the specific criteria for identifying sampling sites within a selected Qa/Qx segment and include in the Quality Assurance Project Plan (QAPP);
- Quality-check (by desk top evaluation, not field confirmation) GIS data for all selected sample sites with respect to drainage area, stream gradient, and watershed land cover;
- Specify the details of implementing the landscape analysis into the overall HSTM plan;
- Identify the criteria for achieving adequate sharability of data; and
- Identify opportunities to link HSTM with specific fish monitoring programs and metrics.

The Implementation Plan will be conducted in two parts: (1) Planning - Data Collection and Management, and (2) Reporting - Data Analysis and Interpretation. As included in the application for the Centennial Clean Water Grant issued by Ecology to fund Phase 3 of the HSTM project, LCFRB (in collaboration with Stillwater Sciences and HSTM stakeholders) have characterized the primary elements of the Implementation Plan. The effort will result in a complete implementation plan that describes how data will be collected, defines roles and responsibilities, and articulates how quality will be ensured and how the data will be analyzed, interpreted, and reported.

At its most fundamental level, the implementation plan for the Lower Columbia ESU will describe how the monitoring design will be carried out in sufficient detail to ensure that data is shareable, and of adequate quality to answer the management questions and objectives. The implementation plan will outline protocols for data collection and quality assurance, develop data management protocols, develop indicators based on the management questions and objectives, and develop timelines, roles and responsibilities. Criteria for the identification of specific sampling locations once prospective sites have been selected identified from the Master Sample will be developed as part of this Implementation Plan (see Washington State Department of Ecology 2014 for one such example).

The Data Collection and Management task will use the results of a thorough signal to noise analysis to finalize metrics and measurements and guide discussion and identification of sampling procedures and field protocols. Sampling procedures refer to the collection of samples that are collected from the field site and are subsequently analyzed in a lab (water, sediment, macroinvertebrates, and periphyton). Field protocols refer to the methods used to make measurements of conditions at the site. This task will also outline Quality Control procedures for both field and lab work, data management procedures (storing and sharing of raw data), describe reporting conventions, and provide guidance on data verification, validation, and QA. These elements will be compatible with Ecology's QAPP. Formatting the implementation plan to include these elements will facilitate the creation of a QAPP for entities who would conduct monitoring under the Lower Columbia HSTM design to address Ecology's management questions and objectives.

The Data Analysis, Interpretation, and Reporting task will describe the pertinent components of Water Quality, Habitat, and Landscape Indicators. These components include the sampling and measurement procedures, measurement quality objectives, quality control, how results are interpreted beyond just reporting the numbers, and data management, review and validation of metrics and indicators.

The effort described above will provide a complete implementation plan that describes how we will collect the data, how we will ensure quality, and how we will analyze, interpret, and report on the data and findings.

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Appendices

Appendix A

Table of Properly Functioning Conditions

TABLE OF PROPERLY FUNCTIONING CONDITIONS (NOAA 1996)

The ranges of criteria presented here are not absolute; they may be adjusted for unique watersheds.

Pathway	**Indicators**	**Properly functioning**	**At risk**	**Not properly functioning**
Water Quality	Temperature	50–57° F[1]	57–60° (spawning) 57–64° (migration &rearing)[2]	> 60° (spawning) > 64° (migration & rearing)[2]
	Sediment/Turbidity	< 12% fines (<0.85mm) in gravel[3], turbidity low	12–17% (west-side)[3] 12–20% (east-side)[2] turbidity moderate	>17% (west-side)[3], >20% (east side)2 fines at surface or depth in spawning habitat[2], turbidity high
	Chemical Contamination/Nutrients	low levels of chemical contamination from agricultural, industrial and other sources, no excess nutrients, no CWA 303d designated reaches[5]	moderate levels of chemical contamination from agricultural, industrial and other sources, some excess nutrients, one CWA 303d designated reach[5]	high levels of chemical contamination from agricultural, industrial and other sources, high levels of excess nutrients, more than one CWA 303d designated reach[5]
Habitat Access	Physical Barriers	any man-made barriers present in watershed allow upstream and downstream fish passage at all flows	any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at base/low flows	any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at a range of flows
Habitat Elements	Substrate	dominant substrate is gravel or cobble (interstitial spaces clear), or embeddedness <20%[3]	gravel and cobble is subdominant, or if dominant, embeddedness 20–30%[3]	bedrock, sand, silt or small gravel dominant, or if gravel and cobble dominant, embeddedness >30%[2]
	Large Woody Debris	Coast: >80 pieces/mile >24"diameter >50 ft. length[4]; East-side: >20 pieces/ mile >12"diameter >35 ft. length[2]; and adequate sources of woody debris recruitment in riparian areas	currently meets standards for properly functioning, but lacks potential sources from riparian areas of woody debris recruitment to maintain that standard	does not meet standards for properly functioning and lacks potential large woody debris recruitment

Pathway	Indicators	Properly functioning	At risk	Not properly functioning
Habitat Elements	Pool Frequency channel width # pools/mile[6] 5 feet 184 10 " 96 15 " 70 20 " 56 25 " 47 50 " 26 75 " 23 100 " 18	meets pool frequency standards (left) and large woody debris recruitment standards for properly functioning habitat (above)	meets pool frequency standards but large woody debris recruitment inadequate to maintain pools over time	does not meet pool frequency standards
	Pool Quality	pools >1 meter deep (holding pools) with good cover and cool water[3], minor reduction of pool volume by fine sediment	few deeper pools (>1 meter) present or inadequate cover/temperature[3], moderate reduction of pool volume by fine sediment	no deep pools (>1 meter) and inadequate cover/temperature[3], major reduction of pool volume by fine sediment
	Off-channel Habitat	backwaters with cover, and low energy off-channel areas (ponds, oxbows, etc.)[3]	some backwaters and high energy side channels3	few or no backwaters, no off-channel ponds[3]
	Refugia (important remnant habitat for sensitive aquatic species)	habitat refugia exist and are adequately buffered (e.g., by intact riparian reserves); existing refugia are sufficient in size, number and connectivity to maintain viable populations or sub-populations[7]	habitat refugia exist but are not adequately buffered (e.g., by intact riparian reserves); existing refugia are insufficient in size, number and connectivity to maintain viable populations or sub-populations[7]	adequate habitat refugia do not exist[7]
Channel Condition and Dynamics	Width/Depth Ratio	<10[2,4]	10–12 (we are unaware of any criteria to reference)	>12 (we are unaware of any criteria to reference)
	Streambank Condition	>90% stable; i.e., on average, less than 10% of banks are actively eroding[2]	80–90% stable	<80% stable
	Floodplain Connectivity	off-channel areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession	reduced linkage of wetland, floodplains and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of wetland function, riparian vegetation/succession	severe reduction in hydrologic connectivity between off-channel, wetland, floodplain and riparian areas; wetland extent drastically reduced and riparian vegetation/succession altered significantly

Pathway	Indicators	Properly functioning	At risk	Not properly functioning
Flow/Hydrology	Change in Peak/ Base Flows	watershed hydrograph indicates peak flow, base flow and flow timing characteristics comparable to an undisturbed watershed of similar size, geology and geography	some evidence of altered peak flow, baseflow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography	pronounced changes in peak flow, baseflow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography
	Increase in Drainage Network	zero or minimum increases in drainage network density due to roads[8,9]	moderate increases in drainage network density due to roads (e.g., ~5%)[8,9]	significant increases in drainage network density due to roads (e.g., ~20–25%)[8,9]
Watershed Condtions	Road Density and Location	<2 mi/mi²[11], no valley bottom roads	2–3 mi/mi², some valley bottom roads	>3 mi/mi², many valley bottom roads
	Disturbance History	<15% ECA (entire watershed) with no concentration of disturbance in unstable or potentially unstable areas, and/or refugia, and/or riparian area; and for NWFP area (except AMAs), ≥15% retention of LSOG in watershed[10]	<15% ECA (entire watershed) but disturbance concentrated in unstable or potentially unstable areas, and/or refugia, and/or riparian area; and for NWFP area (except AMAs), ≥15% retention of LSOG in watershed[10]	>15% ECA (entire watershed) and disturbance concentrated in unstable or potentially unstable areas, and/or refugia, and/or riparian area; does not meet NWFP standard for LSOG retention
	Riparian Reservces	the riparian reserve system provides adequate shade, large woody debris recruitment, and habitat protection and connectivity in all subwatersheds, and buffers or includes known refugia for sensitive aquatic species (>80% intact),and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/ composition >50%[12]	moderate loss of connectivity or function (shade, LWD recruitment, etc.) of riparian reserve system, or incomplete protection of habitats and refugia for sensitive aquatic species (~70–80% intact), and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/composition 25–50% or better[12]	riparian reserve system is fragmented, poorly connected, or provides inadequate protection of habitats and refugia for sensitive aquatic species (<70% intact), and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/composition <25%[12]

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[8] Wemple, B.C., 1994. Hydrologic Integration of Forest Roads with Stream Networks in Two Basins, Western Cascades, Oregon. M.S. Thesis, Geosciences Department, Oregon State University.

[9] e.g., see Elk River Watershed Analysis Report, 1995. Siskiyou National Forest, Oregon.

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Appendix B

Attribution of the Lower Columbia Master Sample

ATTRIBUTION OF THE LOWER COLUMBIA MASTER SAMPLE

In order to stratify the Lower Columbia Master Sample (LCMS), Stillwater Sciences developed additional attribution of the LCMS by calculating and incorporating contributing drainage area (DA), stream slope, urban growth area (UGA), municipal stormwater permit area (MSWPA) - synonymous with the National Pollutant Discharge Elimination System (NPDES) permit area, and National Land Cover Dataset (NLCD) to each LCMS site. The following text provides GIS methods and pertinent information.

Contributing drainage area

Drainage area was developed from the USGS 1/3 Arc National Elevation Dataset (NED) and the USGS National Hydrographic Dataset at High resolution (NHD High). The 1/3 NED for the study area was extracted and downloaded from the USGS website and then projected to a 10-m DEM. Sinks were removed from the original 10-M DEM and a filled 10-m DEM created.

NHD High features representing streams and connector or artificial paths were selected from the whole NHD High dataset, excluding ditches, canals and waterways obtaining a representation of the “natural” channel network. NHD High streams were used to excavate or “burn” their alignments into the filled 10-m DEM to adjust for inconsistencies with the DEM-derived channels. Standard ArcGIS flow direction and flow accumulating routines were run on the “burned” DEM to obtain a grid with drainage areas.

Contributing area to each LCMS site was obtained from the “burned” drainage area grid. LCMS site locations were adjusted (or moved) to the closest “burned” DEM drainage area grid. Several iterations of the same process were run, starting with a low snapping tolerance value and increasing the value in each iteration for LCMS sites that did not obtain the drainage area from the grid (were further away from the burned drainage area grid than the snapping tolerance).

Channel slope

Channel slope was developed by overlaying the NHD High streams on the filled 10-m DEM. The elevation for the upstream and downstream ends of each NHD High arc-segment was obtained. From these elevations, the elevation drop and the slope for each arc-segment was calculated. The LCMS sites were then linked to the closest streams and the channel slope from the NHD High stream-segment was transferred to the LCMS sites.

Land use and land cover classification

2014 Urban Growth Areas and 2013 Municipal Stormwater Permit Areas were downloaded from the Washington State GIS download website. The 2006 NLCD was downloaded from the USGS GIS download website. All three datasets were overlaid with the LCMS Sites to find whether the sites were inside or outside of each area.

Appendix C

Table of Recommended Water-Quality Metrics

Table of water-quality metrics recommended in Phase 1 report (Tetra Tech 2013), and final recommendations. Metrics listed in muted font are not recommended at this time.

WATER-QUALITY METRICS:	**Phase 1, TR3, Table 2**	**THIS REPORT**	**Rationale for inclusion or omission**	**"Conventional" stormwater pollutants**	**RSMP (Puget Sound)**	**WQI S/N "grade"**	**USGS NAWQA #3**
Water Temperature	hourly & monthly	X^c	Key metric with biological consequences, for which only continuous data can suffice. Data recorders inexpensive, reliable.	X	X^m	B	X
Sediment metals	Once per 3 yr (Cu, Pb, Zn)	X^a	Good integrator of heavy metal contamination. Expanded suite (Cd, Cr, Cu, Ni, Pb, and Zn) aligns with current literature for modest additional cost.		X^5		
Conductivity	monthly	X^c	Good general indicator of water-quality conditions; continuous data easily obtained.	X	X^m	A	X
Sediment PAHs	Once per 3 or 5 yrs	*	Potential utility but cost, value uncertain in widespread S&T monitoring. Await findings of RSMP (Puget Sound region).		X^5		
Chloride	monthly	*	Potentially useful indicators, excellent S/N, but non-continuous sampling a potential drawback. Await findings of RSMP.	X	X^m	A	
Total Nitrogen	monthly	*		X	X^m	A	X
Total Phosphorus	monthly		Non-continuous sampling is problematic; continuous samplers do not exist or require significant maintenance. Very poor S/N characteristics.	X	X^m	D	X
Total Susp. Solids	monthly			X	X^m	D	X
pH	monthly			X	X^m	F	
Turbidity	monthly				X^m	F	X
Ammonia	monthly			X	X^m		
Nitrate+Nitrite-N	monthly			X	X^m		
Dissolved Oxygen	monthly				X^m	B	
Fecal Coliform	monthly			X	X^m		
Total Solids	monthly						
OTHER METRICS:							
Flow	monthly	stage^c	Flow data meaningful as a continuous time series; stage provides most of the contextual information without expense of full gauging.		X		
Macro-invertebrate Index	annually	X^a	Well-established biological metric for PNW; standardized protocols.		X^5		
Periphyton	annually	*	Less well-established biological metric for PNW; await findings of RSMP.		X^5		

X^c = continuous data collection
X^a = annual data collection
X^m = monthly data collection
X^5 = data collection once per 5 years
* = for future consideration

Appendix D

Table of Recommended Habitat Metrics

Table of habitat metrics: current recommendations, Phase 1 recommendations (Tetra Tech 2013), rationale and S/N ratings. Metrics listed in muted font are not recommended at this time.

Habitat metrics	Current recommendation	Phase 1, TM3	Rationale for inclusion or omission	Collected by LC Monitoring Programs	S/N rating[1]
Limiting factor - Channel Structure and Form					
Reach length	once		Baseline information for the monitoring site	5	C (2.83 AREMP)[2] | B (9.16 EMAP)[2] B (8.37 PIBO)[2]
Channel type	once	annually	Baseline information for the site	7	
Density of habitat type	every 5 years	annually	Standard measurement with value to salmon recovery	3	
Sinuosity	every 5 years	annually	Useful metric with conflicting S/N grades	7	A (10.9 AREMP)[3] | B (6.8 CDFG)[3] D (1.28 AREMP)[2] | C (2.32 PIBO)[2] C (2.5 EMAP)[3] | A (24.7NIFC)[3] C (2.8ODFW)[3] | A (58.1PIBO)[3] A (20.2 UC)[3] | A[4] | D (1.1)[5]
Bankfull width/depth	every 5 years	Annually/once every 5 years	Valuable metric with conflicting S/N grades. Retain due to value and carefully define measurement procedures to improve precision	4	C (2.1 AREMP)[3] | D (1.7 CDFG)[3] F (0.53 AREMP)[2] | C (4.01 PIBO)[2] D (1.7 EMAP)[3] | B (6.1 NIFC)[3] C (3.5 ODFW)[3] | D (1.5 PIBO)[3] D (1.6 UC)[3] | B (6.5)[5]
Bank stability (categorical)	annually		Valuable metric with conflicting S/N grades. Applying a categorical metric is likely to improve precision (raise the S/N grade)	7	A[4] | D (1.3)[5] (bank condition)
Pools per unit length	TBD		Valuable metric with poor S/N grades. Consider further given the value to fish populations	5	D (1.0 AREMP)[3] | F (0.2 CDFG)[3] D (1.8 EMAP)[3] | D (1.1 NIFC)[3] B (5.5 ODFW)[3] | F (0.8 PIBO)[3] D (1.6 UC)[3]
Residual Pool depth	annually		Valuable metric with acceptable S/N grades	7	B (6.3 AREMP)[3] | F (0.2 CDFG)[3] B (6.1 EMAP)[3] | C (4.9 NIFC)[3] C (3.2 ODFW)[3] | B (7.4 PIBO)[3] A (11.9 UC)[3] | A (pool unit depth)[4] A (37.31 PIBO)[2] | B (9)[5]

Habitat metrics	Current recommendation	Phase 1, TM3	Rationale for inclusion or omission	Collected by LC Monitoring Programs	S/N rating[1]
Thalweg depth	annually		Valuable metric with good S/N grades	7	A[4] | B (6.9)[5]
Density/distribution instream wood	annually	annually	Valuable metric with good S/N grades	7	A (53.3 AREMP)[3] | C (4.4 CDFG)[3] A (10.8 EMAP)[3] | A (87.1 NIFC)[3] A (24.5 ODFW)[3] | A (19.4 PIBO)3 A (13.6 UC[3])[**] | B,D[4]|B (7)[5] B (AREMP)[2] | F (0.74 EMAP)[2] D 1.19 (PIBO)[2]
Limiting factor - Sediment Conditions					
Substrate particle size (% comp by particle size category)	annually	annually	Valuable metric with good S/N grades	7	C (3.7 AREMP)[3] | B (6.9 EMAP)[3] B (9.4 PIBO)[3] |C (2.3 UC)[3*] A/B(percent fines)[4] | A (15)[5] A (21.73 AREMP) % fines[2] A (69.94 EMAP) % fines[2] A (21.24 PIBO) % fines[2]
Embeddedness	annually			5	C,A[4] | B (7.7)[5]
Relative bed stability	annually	annually	Easy to measure and consistent with objectives	3	
Limiting factor - Riparian Condition					
Shade at mid channel	annually	annually	A measure of habitat quality with good S/N grades	3	A[6] | A (15)[5]
Riparian canopy (% cover)	annually		A measure of habitat quality with good S/N grades	3	A[6] | A (17)[5]
Riparian understory (% cover)	annually		A measure of habitat quality with conflicting S/N grades. To be further considered	3	B[6] | F (0.9)[5]
Limiting factor - Water Quantity					
Flow Category[7]	annually		Useful and efficient measure of relative flow conditions to provide context for the other metrics	7	

Habitat metrics	Current recommendation	Phase 1, TM3	Rationale for inclusion or omission	Collected by LC Monitoring Programs	S/N rating[1]
Limiting factor - Peripheral and Transitional habitats					
Floodplain area	every 5 years		An important measure of rearing habitat		
Length of side channel habitat	every 5 years		An important measure of rearing habitat	3	
Limiting factor - Water Quality					
pH	Omit	Once per year	Very low S/N grade	3	F[4]
Alkalinity	Omit	Once per year	Commonly sampled, but not particularly useful as it largely reflects bedrock/groundwater chemistry and is unlikely to change	2	
Conductivity	TBD	Once per year	Good general indicator of water quality conditions; continuous data easily obtained, but costly to implement	3	A[4]
Turbidity	Omit	Once per year	Very low S/N grade	3	F[4]
Temperature	TBD	X^{ai}	Highly valued data if continuous, but costly to maintain. Consider a two tiered plan: 1) sample temp the first time. If close to a predetermined threshold, then 2) install a temp thermister and measure for 3 months	3	B[4]

Blank cells indicate no signal to noise ratios or ratings identified in the literature search

[1] When two grades are present, the first is for wadeable streams and the second is for larger rivers

[2] Whitacre, Roper, and Kershber 2007;

[3] Roper et al. 2010. Converted to letter grades using scoring in Merritt and Hartman 2012;

[4] Merritt and Hartman, 2012

[5] Kaufmann et al. 1999

[6] Cusimano et al. 2006

[7] free-flowing, sluggish (<1ft /sec), stagnant, dry

* $\log_e$ of D_{50} performed best

** $\log_e$ of LWD/100 m performed best

X^{ai} annual instantaneous