

# *Watershed Assessment Survey*

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## *Introduction*

This proposal outlines a monitoring program for assessing the status and long term trends in watershed health in the City of Portland using a probabilistic survey design. The proposed design unites monitoring for stream hydrology, water quality, aquatic habitat, riparian habitat, and aquatic organisms into a single monitoring program. The benefits of the program include rigorous statistical design, increased utility of data through collocation of sampling points for multiple indicators, and analysis of data that follows directly from the design. The use of standard field protocols for indicator collection increases the transparency of our monitoring efforts and simplifies data sharing with other agencies including other local agencies, DEQ, and EPA. Finally, the program uses sampling methods and protocols developed by EPA's National Health and Environmental Effects Laboratory. These methods have been widely used by EPA, states, tribes, and local agencies to report on the condition of stream resources.

## *Context*

The City of Portland currently monitors watershed health in a variety of ways. The city conducts water quality monitoring programs for individual watersheds, projects to assess the health of biological communities in some watersheds, project based monitoring to determine the effectiveness of watershed improvement projects, and regulatory monitoring for various permitted programs. These projects are often not based on rigorous statistical designs and can best be described as observational studies of watershed health. While the city's objectives are usually not clearly stated, the monitoring is usually motivated by regulatory requirements. These monitoring projects are not managed as a single program and the technical staff essential to planning, implementation, and analysis of these projects are spread across several workgroups. The result is a decentralized network of monitoring projects with different goals, designs, measurements and standards of quality.

The City of Portland's *Framework for Integrated Management of Watershed Health*<sup>1</sup> identifies four essential types of monitoring:

1. implementation monitoring

<sup>1</sup> Bureau of Environmental Services. Framework for integrated management of watershed health. Technical report, City of Portland, Oregon, December 2005

2. effectiveness monitoring
3. compliance monitoring
4. validation monitoring

This proposal is aimed at providing a relatively complete validation monitoring program for watershed health while fulfilling as many compliance monitoring requirements as possible. In the future, it is possible that some permits may be changed to allow the Watershed Assessment Survey data to fulfill additional compliance requirements.

The *Portland Watershed Management Plan Monitoring Strategy*<sup>2</sup> outlines a set of principles that should guide watershed monitoring. These principles are that monitoring should be targeted, effective and efficient, systematically and deliberately managed, coordinated, accessible, and responsive. The Watershed Assessment Survey adheres to these principles in the following way:

**targeted** The survey is designed to achieve the monitoring program goals set forward in the Watershed Management Plan and the strategy.

**effective and efficient** The survey is designed to collect numerous indicators at the same sites using a statistically efficient sample design. This will result in operational efficiency by reducing the cost of field work and increase the information content of data through the use of sample designs that are meant to reduce the redundancy of sample points.

**systematically and deliberately managed** The survey is designed to be managed by a core group of technical personnel from Watershed Services and Pollution Prevention Services. All survey details will be documented in a quality assurance monitoring plan. Data management will be based on tested EPA procedures and will be supported by BES IT staff. The consolidated management of monitoring programs will result in clear responsibilities for meeting the city's goals outlined in the Watershed Management Plan.

**coordinated** The survey is also designed to coordinate watershed and compliance monitoring for all stream resources and to provide a single source of information for watershed health data in the city. The use of the Oregon master sample means that coordination of monitoring with other agencies is possible in a much more structured way than has ever been done in the past<sup>3</sup>.

**accessible** The coordination benefits outlined above will greatly simplify the task of reporting data and analysis which will allow

<sup>2</sup> D. Kliever. Portland watershed management plan monitoring strategy. Technical report, City of Portland, June 2008. Draft

<sup>3</sup> D. Larsen, A. Olsen, S. Lanigan, C. Moyer, K. Jones, and T. Kincaid. Sound survey designs can facilitate integrating stream monitoring data across multiple programs. *Journal of the American Water Resources Association*, 43(2):384–397, 2007; and D. Larsen, A. Olsen, and D. Stevens Jr. Using a Master Sample to Integrate Stream Monitoring Programs. *Journal of Agricultural, Biological, and Environmental Statistics*, 13(3):243–254, 2008

for frequent, regular reports to managers and the public. A single source and consistent design will simplify automatic data reporting through web portals and other data sharing.

**responsive** The flexible nature of the sampling design means that the survey can adapt to changing needs through time. Sample intensity can easily be varied through time and space while indicators can be added and dropped from the survey with little structural change to the survey. A consolidated program with good documentation and a clear sample design will allow for much simpler peer review than a large number of dissimilar projects with no probability sample designs.

The Strategy also outlines an "idealized monitoring program" with several components. The watershed health characterization component of the program is identified as the highest priority component and would be almost entirely addressed by the probability survey and sample protocols recommended here. In addition, compliance monitoring is listed as the City's second highest priority. The Watershed Assessment Survey also fills several compliance monitoring needs including NPDES surface water monitoring, TMDL monitoring, and ESA monitoring. Thus, a probability survey based watershed monitoring program would go a long way toward implementing the recommendations in the monitoring strategy.

### *Probability Surveys*

Probability surveys, such as political polls and the surveys performed by the US Census, are a statistical method which uses random sampling to estimate the value of metrics for a well defined target population. In the context of natural resource monitoring, the randomization occurs in the choice of monitoring sites so that estimates for the population of all possible sites can be generated.

Probability survey designs are increasingly used as a tool to perform environmental monitoring in a scientifically rigorous manner. There are several environmental monitoring probability surveys in the Northwest including Environmental Monitoring and Assessment Program western pilot (EMAP-West), Regional EMAP, the Puget Sound Ambient Monitoring Program (PSAMP), and several surveys<sup>4</sup> that are part of the Oregon Plan for Salmon and Watersheds (Western Oregon Assessment, Lower Columbia Wadeable Streams Assessment, Willamette Basin Streams and Rivers Assessment). In addition, the state of Washington has a statewide status and trends salmon monitoring program using a probability survey design<sup>5</sup>. Finally, there are examples of a local government and a watershed council<sup>6</sup> using

<sup>4</sup> M. Mulvey. Coastal coho stream assessment: Summary report by deq. Technical Report 08-Lab-010, Oregon Department of Environmental Quality, Hillsboro, OR, 2008; and M. Mulvey and A. Borisenko. Lower columbia wadeable stream conditions assessment. Technical Report 08-LAB-002, Oregon Department of Environmental Quality, Hillsboro, OR, 2005

<sup>5</sup> R. Cusimano, G. Merritt, R. Plotnikoff, C. Wiseman, and C. Smith. Status and trends monitoring for watershed health and salmon recovery: quality assurance monitoring plan. Technical report, Washington Department of Ecology, 2006

<sup>6</sup> D. Koellmann. Skagit county salmon habitat monitoring program. Technical report, Skagit County Public Works, March 2004; and C. Thieman. Stream health and water quality in the Long Tom watershed: 1999 - 2006. Technical Report 2007-M-01, Long Tom Watershed Council, Eugene, OR, April 2007. URL [http://www.longtom.org/documents/archive\\_reports/WQ\\_Report2007/WQReport\\_2007.pdf](http://www.longtom.org/documents/archive_reports/WQ_Report2007/WQReport_2007.pdf)

probability surveys for stream monitoring.

Typically, the City of Portland's monitoring sites are chosen using targeted (also known as judgment) sampling where the sample locations are not random but are chosen to be representative of a particular resource. Unfortunately, the results of such monitoring programs tend to be biased when used to make inferences about the population as a whole. The bar chart at right plots the numbers of spawning fish per mile for Oregon coastal Coho salmon for two different monitoring designs: a traditional survey based on targeted sampling and a probability based survey design. As you can see, the traditional survey has a very large bias and overstated the size of the spawner population by about 300%. EPA guidance<sup>7</sup> clearly draws the distinction between targeted sampling and probability sampling and makes clear that the analysis resulting from targeted sampling is anecdotal when used for inference about watersheds. For judgement samples, they state that "statistics cannot be used to draw conclusions about the target population." The City of Portland's reliance on targeted designs with monthly water quality sampling implicitly assumes that we are most interested in temporal variability and change at a few targeted locations in the city rather than on unbiased estimates of watershed condition throughout the city.

In general, the reliability of the data from a probability survey is much higher than data collected where there is no probability model for the sample collection process. Probability surveys reduce bias as was shown in the Coho example above. Probability surveys also allow for calculation of confidence intervals without assuming a statistical model. The EPA quality guidance referenced above indicates that the results obtained from judgment sampling can only be applied to an area upstream and downstream of the sampling site in which the conditions are not likely to change. Given the heterogeneous nature of the urban environment, it is unlikely that targeted sampling locations will apply to more than a few hundred meters of stream reach. Thus, a probability survey is the only method capable of providing information on the status of all streams in the City of Portland.

There are several key elements to a probability survey design:

1. Objectives stated precisely and quantitatively;
2. Target population explicitly, precisely defined;
3. Sampling frame constructed that represents the target population;
4. Decision on which survey design meets needs;
5. Selection of sites using survey design;

<sup>7</sup> Guidance for choosing a sampling design for environmental data collection. Quality System Series EPA QA/G-5S, U.S. Environmental Protection Agency, Washington, D.C., December 2002

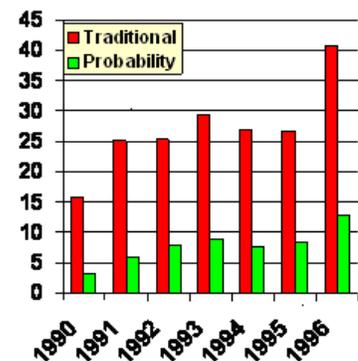


Figure 1: Comparison of results of traditional versus probability surveys of Coho spawner abundance.

## 6. Statistical analysis matches survey design.

These elements are at the heart of the survey design process and must be addressed before a program can be implemented. The remainder of this document is organized around these key elements.

### *Objectives and Target Population*

A statement of a survey objective needs to include the the research question, domain (i.e., the target population), and the precision required. For example, one objective is:

Estimate the proportion (within  $\pm 10\%$ ) of stream length in the City of Portland whose average *E. coli* concentration is greater than 126 MPN/100mL.

In reality, the objectives of the survey are numerous as the questions, target population, and precision vary. Rather than explicitly stating all of the possible objectives, we will identify the questions of interest, the target populations and the precision separately. In this way, any objective derived from these three components can be achieved through this survey.

The research questions for this survey are based on estimating the status and trend of indicators identified in the *Framework for Integrated Management of Watershed Health* and finalized in the *Priority Indicators and Metrics for Watershed Health* memo. These indicators were identified as the most important indicators for measuring watershed health in the City of Portland. Targets and benchmarks are being developed for these indicators that are based on a variety of sources including regulatory standards, watershed science, and reference site data. These benchmarks will be used to construct classes for each indicator which describe the range of values that indicate whether a stream is supportive of watershed health or not (see the draft watershed health index for more information). The benchmarks and classes will be used to classify data generated from the survey and to estimate the proportion of stream length in each class. The research questions about these indicators include estimating the value on the scale of the indicator (e.g., MPN/100mL), the proportion of stream length in a category defined by a benchmark, target or standard (e.g., proportion greater than 126 MPN/100mL), and trend in either of these metrics.

The target population for the Watershed Assessment Survey is streams and rivers contained within the City of Portland other than the mainstem of the Willamette and Columbia Rivers. One group of subpopulations of interest is defined by the individual watersheds managed as units by the City of Portland. These include the Columbia Slough, Johnson Creek, Fanno-Tryon, and Willamette watersheds. These subpopulations represent stream resources that differ

in their morphology, stressors, and management. Thus, separate inferences about these watersheds are a requirement for any status and trends program.

Because significant portions of the City of Portland's stream network are dry during the summer, perennial and non-perennial streams were also identified as target subpopulations. Different indicator subsets will be measured at perennial versus non-perennial streams, since some indicators require flowing water for measurement. Because the indicator subset used in non-perennial streams will be much smaller than the indicator subset used in perennial streams, the per-site cost of monitoring non-perennial streams will be much lower than perennial streams.

The precision required for the survey is defined here as the largest distance between the estimated value of the indicator and the confidence interval bounds. For the research questions that involve estimating the proportion ( $p$ ) of stream length in each category defined by a benchmark, the precision can be stated as a percentage as we did in the example objective above. For planning purposes, a simple binomial model can be used for all of these proportions and confidence intervals generated according to this model. This allows us to choose a single precision for all of the indicator questions involving proportions rather than identifying a statistical model for each indicator and a target precision on the scale of each indicator. This considerably simplifies the planning process.

The precision of an estimated proportion depends on the confidence level, the proportion being estimated, and the sample size. The confidence level is usually determined by convention, with 95% and 90% both being relatively common. Here we will use 95% because it is the most commonly used. Because we are measuring many indicators and have little prior information on the values of these indicators, we will assume that the proportion being estimated is 0.5. Because a proportion of 0.5 results in the largest confidence interval width (see figure at right), this is a conservative approach. Actual results from the implemented survey will be better depending on the extent to which the estimated proportions differ from 50%. Values close to zero or one will result in much narrower confidence intervals and more precise results.

A plot of the precision versus sample size for a variety of sample sizes is shown in figure 3. A precision of less than ten percent is considered acceptable for this survey. Achieving a ten percent precision requires a sample size greater than about 100. This plot along with a cost per site will allow us to determine a sample size that meets our precision requirements and is within our budget.

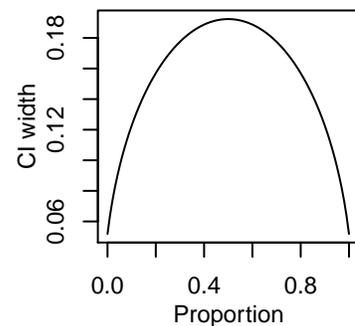


Figure 2: Confidence interval width versus estimated proportion for  $n = 100$ .

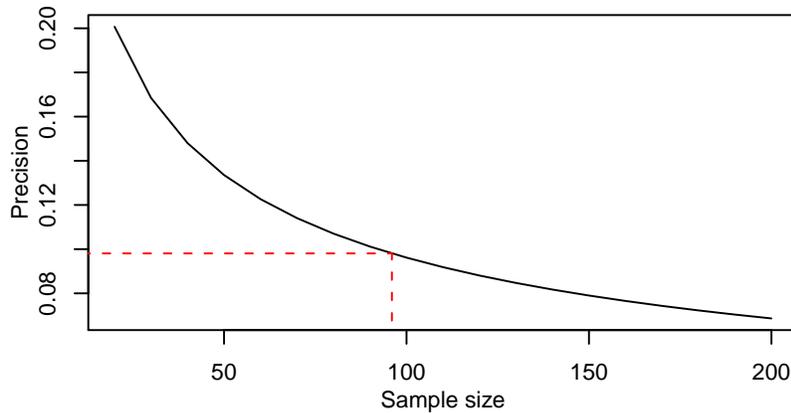


Figure 3: Precision versus sample size for binomial confidence interval where  $p = 0.5$ . The precision and sample size for the recommended design are in red.

### *Sampling Frame*

Our next key element is the development of a sampling frame that represents our target population. Since our target population is all streams within the City of Portland, our sample frame is a GIS layer that digitally represents all streams in the city. For the Watershed Assessment Survey, the new LIDAR based stream layer for the Metro area will be used. This layer is in active development by Metro and local municipalities including the City of Portland. When completed in late 2009, the layer will be the most accurate data regarding the City of Portland's stream network. In addition, the layer will be incorporated into the National Hydrography Dataset<sup>8</sup>, so the probability survey will be based on a standardized stream network available for use at a statewide and nationwide scale. This is an important consideration for sharing probability survey data with outside agencies.

### *Survey Design and Site Selection*

The survey design is based on the Generalized Random-Tessellation Stratified<sup>9</sup> (GRTS) survey design. This method was developed by statisticians at EPA and Oregon State University to overcome the limitations of traditional sampling techniques when applied to natural resources. GRTS samples are spatially balanced samples which can incorporate panel designs, stratification, and unequal probability sampling. The City has used GRTS designs to sample UICs and macroinvertebrates in Fanno Creek and Tryon Creek.

Figure 3 shows that we need approximately 100 sites to meet our precision goals. It is not possible to monitor 100 sites each year so rotating panels will be used. Panels are groups of sites that are mea-

<sup>8</sup> J. Simley and W. Carswell. The national map - hydrography. Fact Sheet 2009-3054, U.S. Geological Survey, September 2009

<sup>9</sup> D. Stevens Jr and A. Olsen. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association*, 99(465):262-278, 2004

sured repeatedly over a period of time; a four year rotating panel design has four panels where a different panel is measured each year (i.e., panel 1 in year 1, panel 2 in year 2, . . .). After four years, the panels are revisited using the same rotating pattern (i.e., panel 1 in year 5, panel 2 in year 6, . . .). This design allows the necessary sample size to be built up over four years, but also allows for the estimation of long term trends in indicators by repeating the measurements every four years.

For the Watershed Assessment Survey, the recommended sample design is a four rotating panel design with 40 sites per panel. Thus, the total sample size would be 160 sites measured over four years. See table 1 for the number of sites sampled each year for a 20 year, four rotating panel design. In order to ensure an equal number of sites in each watershed management group, a stratified random sample will be used to allocate 10 sites to each watershed within each panel. Of the 40 sites per panel, 24 sites will be allocated to perennial streams and 16 will be allocated to intermittent streams for total sample sizes of 96 perennial streams and 64 intermittent streams. The sample size and precision for the perennial stream component of this design are identified in red in 3. The design for each of the 4 watersheds is summarized in table 2 at right. Because the perennial streams have many more indicators and are of the most interest, it seems appropriate to allocate the majority of our sites to these streams. In addition, it seems like a good compromise to accept the lower precision of the intermittent stream sample given the level of effort it will require to sample these streams.

An optional smaller design that is patterned in the same way can be created by sampling 5 perennial and 3 intermittent sites for each panel in each watershed. This design has 128 total sites and 32 sites per panel (20 perennial and 12 intermittent). These initial design proposals can be changed through the number of panels, sites per panel, relative effort to perennial and intermittent streams, etc to tailor a program that balances cost, effort, and precision.

The site selection process will be completed by selecting the required number of sites from a master sample according the methods of Larsen et al<sup>10</sup>. A composite master sample will be created by combining the Oregon master sample and a new master sample for stream reaches not present in the Oregon master sample frame. This is necessary because the Oregon master sample is based on a 1:100,000 NHD layer that is missing many stream reaches present on the City’s more detailed stream layers.

year	panel			
	1	2	3	4
1	40			
2		40		
3			40	
4				40
5	40			
6		40		
7			40	
8				40
9	40			
10		40		
11			40	
12				40
13	40			
14		40		
15			40	
16				40
17	40			
18		40		
19			40	
20				40

Table 1: Number of sites sampled each year by panel for a 20 year 4 rotating panel design.

panel	perennial	intermittent
1	6	4
2	6	4
3	6	4
4	6	4

Table 2: Number of sites in each panel by stream type for the recommended design in a single watershed.

<sup>10</sup> D. Larsen, A. Olsen, and D. Stevens Jr. Using a Master Sample to Integrate Stream Monitoring Programs. *Journal of Agricultural, Biological, and Environmental Statistics*, 13(3):243–254, 2008

## Survey Analysis

Although the data analyzed using a sample survey may be analyzed using a variety of methods, traditional survey analysis is done using an analysis which is based on the randomization of the sites, rather than a statistical model like a normal distribution. For the GRTS sample design employed here, we will use our benchmarks to classify sample sites as being *impaired* or *not impaired*. Then we can calculate the estimated proportion of the stream length (also known as *extent*) in the city that is impaired versus not impaired for each indicator. This analysis is relatively straightforward and because the results are percentages of stream in several categories they are readily understandable to a broad audience including the general public. A good example of the relative ease with which this data can be communicated is *The Oregonian's*<sup>11</sup> story on Oregon DEQ's *Willamette Basin Rivers and Streams Assessment*<sup>12</sup>. The article cites several of the proportions calculated in the study in an easy to understand way:

The study spotlights the damage to stream life by urban development and farms. City streams account for about a 10th of the stream miles in the valley – and a fifth of the most biologically damaged streams, the study authors estimate.

In addition, we can calculate the risk that *stressors* pose to macroinvertebrates and fish. Stressors can then be ranked according to the severity of their effect and their extent. This direct analysis of which stressor poses the most risk to biological life, moves us toward focusing on the most important stressors rather than focusing only on those stressors that exceed regulatory criteria like toxics, nutrients, and temperature.

The fairly simple analysis above does not preclude the City from attempting more complex analysis based on models or integrating the data collected through this project with other data. For example, the data could be used to calibrate water quality models developed by Systems Analysis or to develop statistical models of water quality parameters at unmeasured sites. These methods could be used to create maps of stressor values or maps of the extent of species. With the proliferation of large scale probability surveys, new methods are being developed to analyze this data and model it. See Hancock (2007)<sup>13</sup> for one example of a new analysis method applied to stream probability survey data.

## Measurement Protocols

The Watershed Assessment Survey will use standardized protocols for measurements wherever possible. The majority of the habitat,

<sup>11</sup> S. Learn. Willamette basin's stream health in jeopardy. *The Oregonian*, October 19 2009. URL [http://www.oregonlive.com/environment/index.ssf/2009/10/rivers\\_that\\_define\\_willamette.html](http://www.oregonlive.com/environment/index.ssf/2009/10/rivers_that_define_willamette.html)

<sup>12</sup> M. Mulvey, R. Leferink, and A. Borisenko. Willamette basin rivers and streams assessment. Technical report, Oregon Department of Environmental Quality, Hillsboro, Oregon, June 2009. Draft

A *stressor* is an indicator which has the potential to affect biological populations in a negative way. Fine sediment, phosphorus, and low canopy cover are all examples of stressors.

<sup>13</sup> M. Hancock. Model-based combination of spatial information for stream networks. *Environmental and Ecological Statistics*, 14(3):267–284, 2007. DOI: 10.1007/s10651-007-0015-2

fish, and macroinvertebrate methods will be adapted from the *National Rivers and Streams Assessment Field Operations Manual*<sup>14</sup>. All protocols will be supported by written documentation. When written protocols do not exist, city staff will develop manuals describing the measurement methodology. Details of measurement methods are still being worked out. Currently, the plan is to perform a habitat survey and macroinvertebrate sampling once per year. Water quality sampling and fish sampling would be performed on a quarterly basis with three samples taken during dry weather conditions and one sample taken during a storm event. One of the water quality samples would be taken on the same day that physical habitat, macroinvertebrate sampling and fish sampling were completed. Relevant GIS measurements such as canopy cover and land use will be completed for the watershed upstream of each sample points, and updated on the same schedule as the sample data, so that landscape characteristics can be investigated along with site specific measurements.

<sup>14</sup> USEPA. National rivers and streams assessment: Field operations manual. Technical Report EPA-841-B-07-009, U.S. Environmental Protection Agency, Washington, D.C., April 2009