Monitoring Plan for the Qwuloolt Restoration Project

DRAFT

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SUMMARY

The Qwuloolt restoration site is a former estuarine wetland in the Snohomish River system that will have tidal inundation returned via levee breach in late 2012. The broad, long-term goal of the project is to transform the site into a self-sustaining, vegetated estuarine wetland that 1) maximizes the modern, natural ecological potential of the site; 2) minimizes adverse effects on, and adds socioeconomic value for, the surrounding community; and 3) advances the science and practice of restoration. Monitoring is critical in evaluating the performance of the project.

For monitoring for the Qwuloolt site and adjacent reference sites we recommend monitoring of controlling abiotic attributes (topography and sediment dynamics, hydrology, and chemical contamination), and biota (vegetation, fishes, macroinvertebrates, and birds) with the ultimate priority on evaluation of biological response to the restoration. Comprehensive monitoring will require approximately $500,000 to $1,000,000 pre-breach ($300,000 already acquired), and post-breach an average of approximately $200,000 to $400,000 annually for the first 10 years, resulting in a total of approximately $5 million over the thirteen years covered by this plan.
A significant portion of the necessary resources can be assumed to be matching from NOAA Fisheries, Tulalip Tribes, and other participants in the monitoring, but we estimate that at least $3 million in funding will be required to implement the full plan.

Major pre-breach implementation recommendations and priorities are:

1. Complete the project design and revise monitoring plan accordingly
2. Continue pre-breach fish and hydrologic data collection in collaboration with NOAA Fisheries
3. Complete vegetation assemblage mapping and species inventory using field surveys, orthophotos, and LiDAR
4. Complete analysis of insect fallout and benthic core samples collected in 2009 and 2010, and NOAA Fisheries Chinook diet samples and catch data from the Snohomish estuary (2001-2009)
5. Install long-term elevation and sediment dynamics monitoring stations and evaluate soil conditions onsite at Qwuloolt and at reference sites
6. Collect and analyze soil samples at Qwuloolt and reference sites

7. Continue and expand bird surveys at Qwuloolt and reference sites

8. Collect and analyze anthropogenic chemical contaminants in soil, sediment, and fish

9. Analyze LiDAR and orthophoto data to develop marsh island and channel area relationships

10. Develop an adaptive management plan for the Qwuloolt project that anticipates potential trajectories for project performance and recommends responses to potential outcomes

11. Continue and expand outreach activities, especially with respect to academics and volunteers that could add research components and data collection capability beyond core efforts

12. Integrate monitoring plan approach and recommendations with monitoring efforts within the Snohomish Basin, Whidbey Basin, Puget Sound, and Pacific Northwest

13. Incorporate LiDAR; CTD; and water level, temperature, and salinity logger data into refined hydrodynamic model for the Snohomish estuary

INTRODUCTION

Project description.

The Qwuloolt restoration site (Figure 1) lies adjacent to Ebey Slough in the Snohomish River estuary of Puget Sound, Washington. Qwuloolt is approximately 142 hectares (360 acres) of former estuarine wetland (Collins and Montgomery 2001, Haas and Collins 2001) diked for agriculture a century ago. Restoration of the site is intended to be compensation to the public for injuries to natural resources as a result of the Tulalip Landfill, a Superfund site (Adolfson Associates 2006). Restoration actions will involve the return of tidal inundation to the Qwuloolt site in 2012 through levee breach and lowering on Ebey Slough, as well as channel excavation, ditch filling, installation of setback levees to protect adjacent properties (Figure 2), and some possible onsite manipulations of substrate and vegetation not yet defined.

Historically, the project area was tidal emergent marsh and forest scrub-shrub wetland, interlaced by tidal channels and streams (Haas and Collins 2001). In the early 1900s a levee was constructed on the north bank of Ebey Slough and tide gates were installed at the mouth of Allen and Jones Creeks to convert the land to agriculture (Figure 1). Levees and tide gates have prevented tidal processes from acting on the project area, transforming the site's ecological condition, and severely reducing its ability to support salmon and other estuarine biota. Today, the project area is fallow agricultural land that is covered by invasive reed canary grass, thistle, and blackberry (Cereghino 2006).

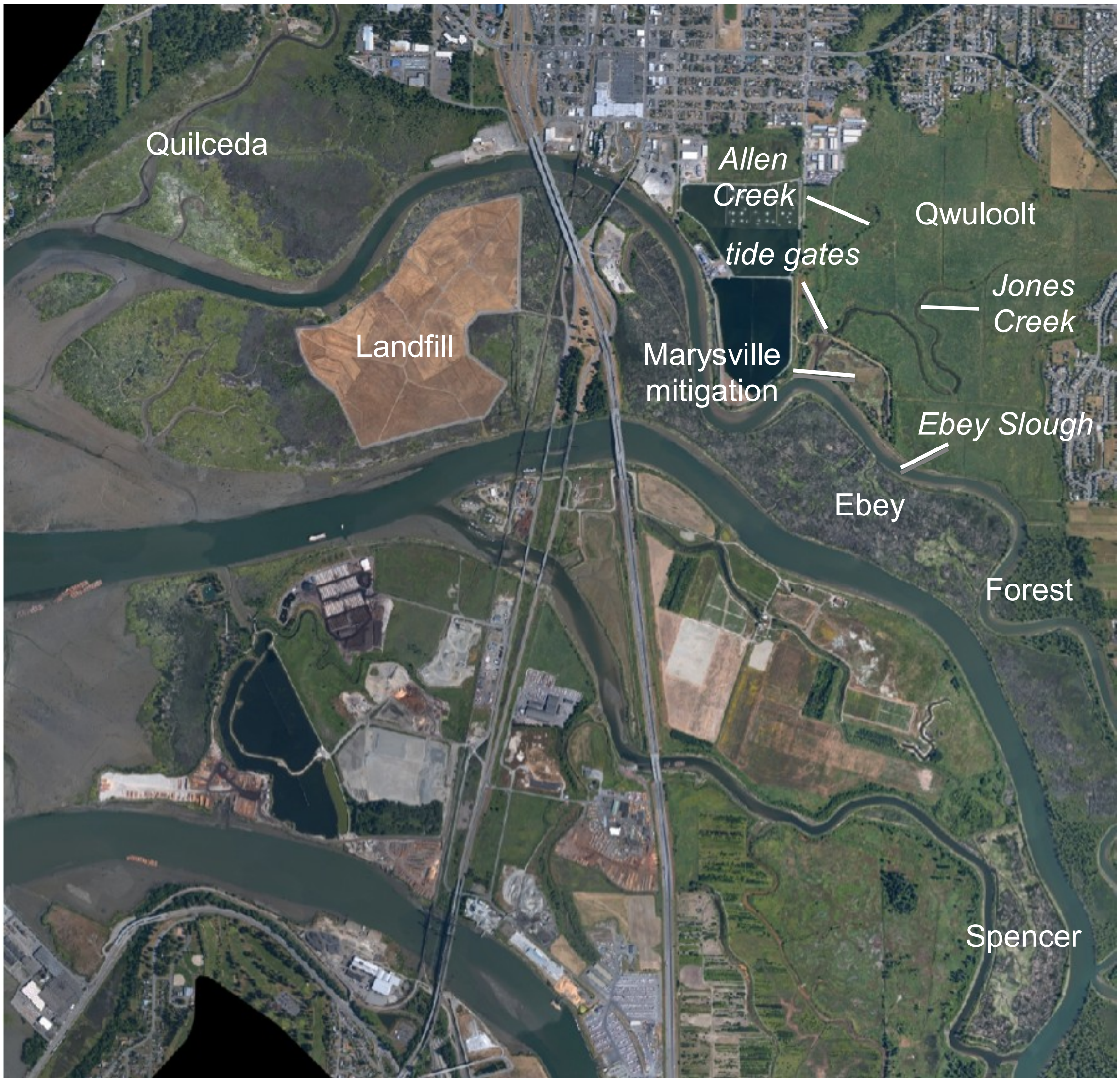

Figure 1. Qwuloolt and surrounding sites (July 2009).

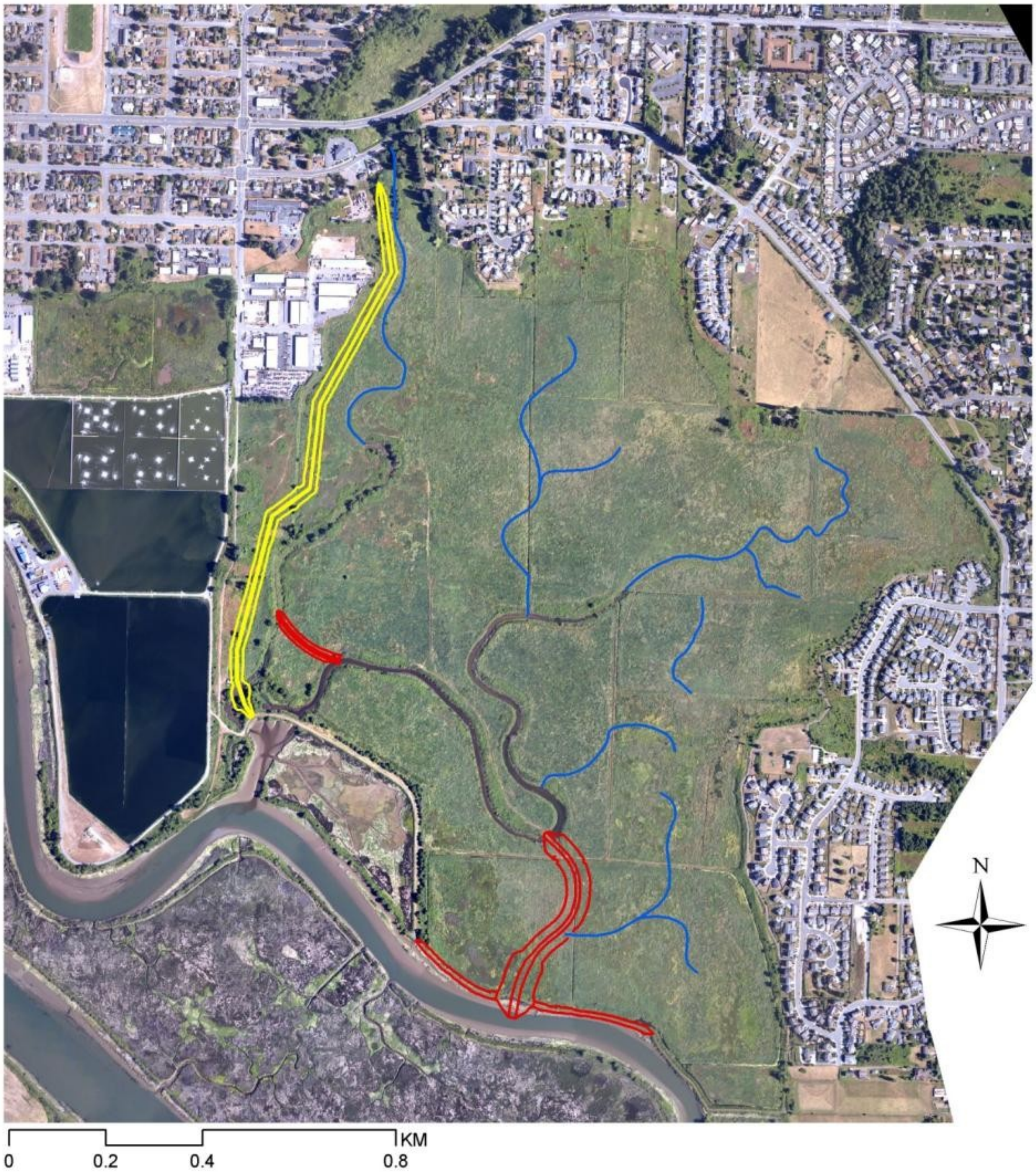

Figure 2. Future configuration of Qwuloolt site based on current (35%) design. Blue indicates minor excavation, red indicates major excavation, and yellow indicates new levee.

The Snohomish River estuary is the second largest in Puget Sound and is home to a rich biota, including federally listed Chinook salmon, bull trout, steelhead trout and five other salmonid species (Snohomish Basin Salmon Recovery Forum 2005). Like all Puget Sound river systems, the Snohomish estuary has been severely altered by human activity (Bortleson et al. 1980, Haas and Collins 2001, Collins and Sheikh 2005). Compared with historical conditions, only 17% of estuarine wetland area, and 25% of blind tidal sloughs remain (Figure 3). Because Chinook salmon use estuaries more extensively than any other salmon species (Healey 1982, Simenstad et al. 1982, Aitkin 1998), anthropogenic estuarine habitat changes may have reduced Chinook production capacity within the Snohomish considerably (Haas and Collins 1999). The 2005 Snohomish Basin Salmon Conservation Plan (Snohomish Basin Salmon Recovery Forum 2005) hypothesizes that the quality and quantity of rearing habitat in the nearshore, estuary, and mainstem rivers is *the primary factor limiting* Chinook and bull trout. The Qwuloolt project is expected to benefit these federally threatened species, as well as steelhead trout, other salmonids, and other fish and wildlife by increasing the areal extent and connectivity of estuarine wetlands in the Snohomish system. Monitoring ecological response of the Qwuloolt site is necessary to evaluate whether these expectations are being met.

Tulalip Tribes and project partners have pursued property acquisition of most lands within the floodplain of the project area and conducted feasibility and other site assessments to begin the restoration planning process. In 2002, the Army Corps of Engineers completed a restoration feasibility study that examined various breach options for the existing Ebey Slough levee. In 2005, building on this work, Tulalip and project partners initiated conceptual design, environmental compliance, and public review processes. In early 2006, project partners evaluated and presented four alternatives to the public and selected a preferred alternative for further refinement (Adolfson Associates 2006). Additional data collection and hydrodynamic modeling actions (Yang and Khangaonkar 2007) were also undertaken during this period. Finally, in 2008, through a formal cooperative agreement with the US Army Corps, Tulalip Tribes completed preliminary designs and initiated the permit and environmental review process. Final site preparation for the project is scheduled for 2011 and 2012, with dike breaching and the return of tidal inundation scheduled for 2012.

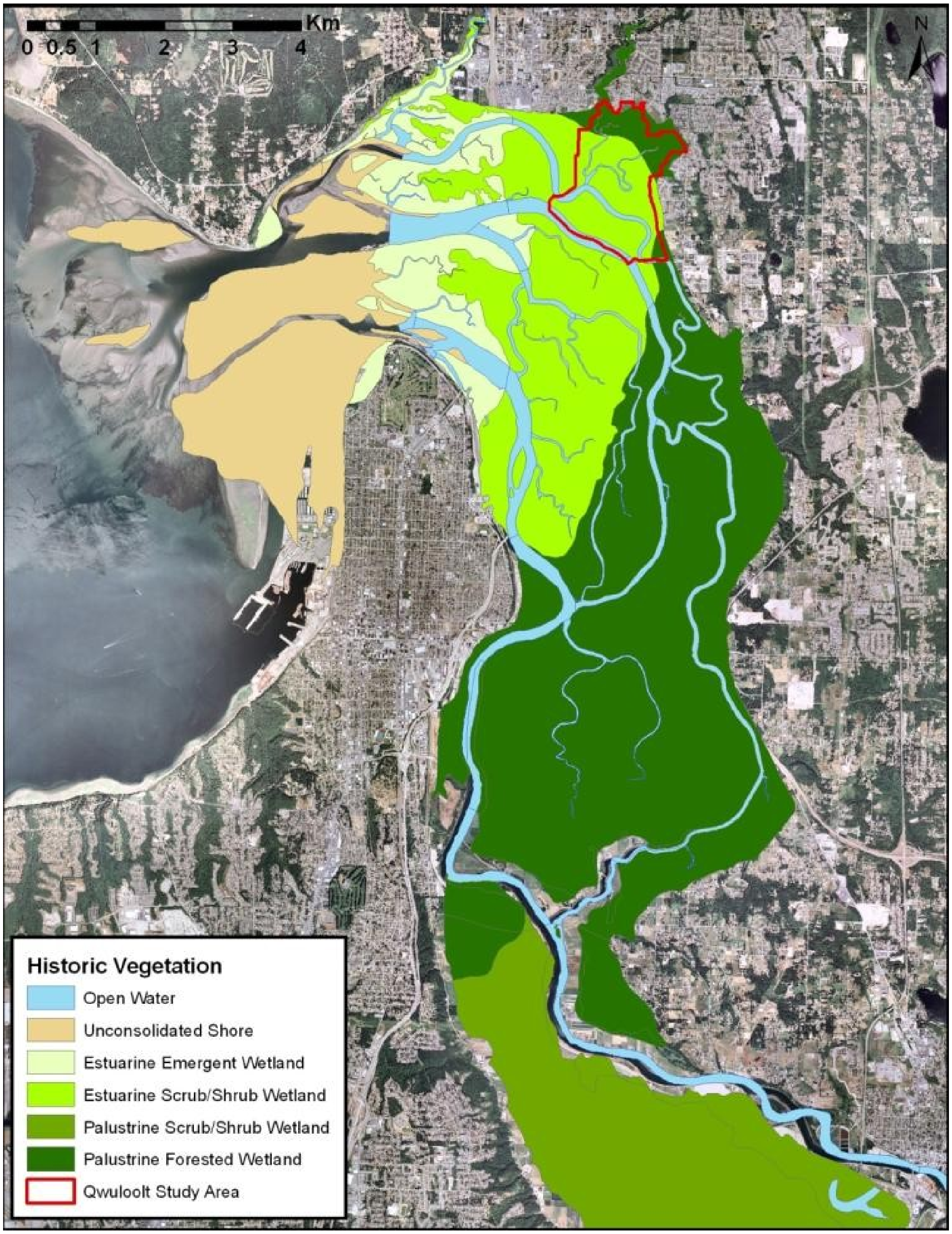

Figure 3. Historical vegetation zones in the Snohomish River estuary. Red line indicates boundary of Qwuloolt and adjacent reference sites. Data from Brian Collins, University of Washington.

Monitoring background

Monitoring can be defined as “The systematic collection and analysis of data that provides information useful for measuring project performance,…determining when modification of efforts is necessary, and building long-term public support for habitat protection and restoration” (Thayer 2003). Elements of a monitoring program implicit in this definition are clear project goals, robust sampling designs and analytical methods, adaptive management of the project (including the monitoring itself), and outreach activities. In this plan we address all of these elements.

Ideally, monitoring is a long-term, interdisciplinary and inter-institutional effort that assists in the management of a given project, but also complements other concurrent efforts, and contributes to improved design and management of future restoration actions (Thom et al. 2007). Development of a monitoring plan is a series of steps that should begin early in the project planning process (Figure 3; Rice et al. 2005, Roni 2005) and is directly related to the specific goals of the project.

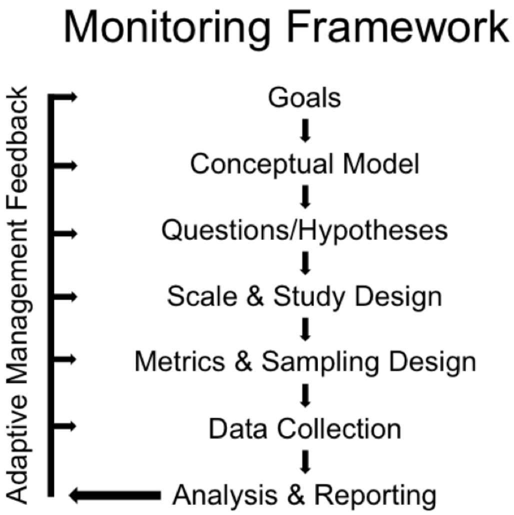

Figure 4. Basic steps, progression, and feedback in the development and application of a monitoring program (Modified from Roni et. al 2005).

Specific terminology varies for the several types of monitoring required for a comprehensive restoration monitoring program (National Research Council 1992, Roni 2005, Thom et al. 2007) but monitoring generally fall into three broad categories:

1) Implementation (also known as compliance or “as-built”)
   Does initial implementation meet design specifications?
2) Status and trend
   What is it like and how is it changing?
3) Effectiveness
   Did it have the expected effect?

All types of monitoring should be designed to have diagnostic capability; that is, the ability to explain the observed patterns in the data and reduce uncertainty about possible future trajectories at the site, improve restoration techniques, and update monitoring methods.

Since the biota—anadromous salmon in particular—is the overwhelming motivation for this and other restoration projects in the Snohomish, a key component of the monitoring should be to assess the biological response of the Qwuloolt restoration site. This approach requires, and places the highest priority on, direct measure of biological condition (Karr 2006), as well as the abiotic attributes (e.g., physical environment) that determine the biological condition. Guidance for developing and implementing restoration monitoring plans is available from a number of sources (e.g., Thom and Wellman 1996, Calloway et al. 2001, Elzinga et al. 2001, Neckles et al. 2002, Roni et al. 2005, Hood 2009, Roegner et al. 2009). We draw on many sources but do not follow any of them exactly.

This monitoring plan focuses on the Qwuloolt site itself but also briefly considers the broader context of multiple restoration sites and the Snohomish River estuary system. Consideration of this broader context is important because the Qwuloolt site is embedded in the larger Snohomish River estuary and is one of several historical and future restoration projects (Figure 5) that will influence each other (e.g., Yang 2009) and potentially contribute to cumulative effects at the system level. In addition, some of the primary biological response variables (e.g., attributes of juvenile salmon populations) are best assessed at spatial scales larger than the site (Simenstad et al. 2000b, Beamer et al. 2005, Simenstad et al. 2006b, Rice 2007, Greene and Beamer 2009). Finally, efficiency can be increased through collaboration across projects, for example, by pooling resources for system-wide data collection efforts. An expanded treatment of multi-site, Snohomish estuary, Whidbey Basin, and Puget Sound contexts is presented in the Snohomish River estuary restoration monitoring framework document (Rice et al. in prep).

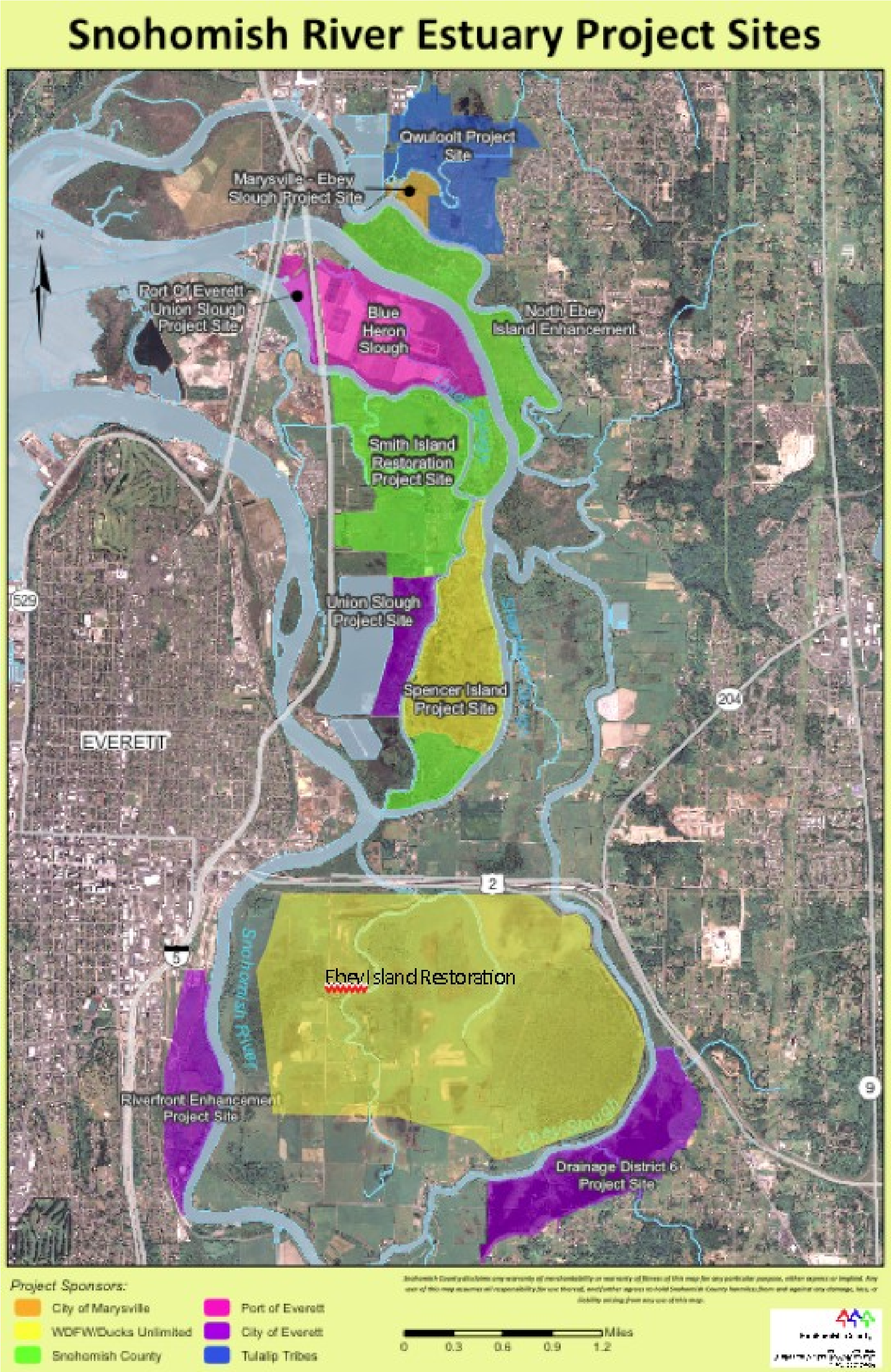

Figure 5. Map of completed, planned, and potential restoration projects in the Snohomish River estuary. Map courtesy of Snohomish County.

Interpretation of monitoring data from the Qwuloolt site requires some bases for comparison with conditions before and after the restoration occurs. Sources of such reference information include: 1) the specific conditions that the final design is intended to create onsite; 2) historical and current biotic and abiotic attributes of the Qwuloolt site itself; 3) historical and current biotic and abiotic attributes of reference sites within the Snohomish River estuary and elsewhere in Puget Sound, including other restoration projects that differ from Qwuloolt in both their natural ecological context as well as restoration goals and techniques; and 4) predictions from hydrodynamic (e.g., Yang 2009), vegetation (e.g., Hood 2007), and fish habitat connectivity models (e.g., Beamer et al. 2005, Beamer and Greene in prep) for both onsite and offsite effects of the restoration actions. The level at which these comparisons are pursued will depend on the degree to which the project management requires certain conditions onsite, the level of integration across restoration and other research and monitoring projects, and the amount of resources available for monitoring. Presently, the approach to post-breach management of Qwuloolt is passive with respect to ecological development of the site. It will rely on the return of tidal inundation to the site through dike breach (in a way that does not threaten private property and public infrastructure) and natural biological colonization. Consequently, the monitoring is focused on documenting and explaining observed changes over time—regardless of the trajectory—and describing those changes in the context of reference information.

The specific intent of this monitoring plan is to provide a detailed plan to evaluate the ecological development of the Qwuloolt site itself, a basic framework for how the Qwuloolt monitoring efforts can integrate with monitoring across the Snohomish River estuary, and implementation recommendations to assist in fully realizing monitoring plan elements. If implemented, the Qwuloolt and Snohomish River estuary monitoring efforts described here and elsewhere (Rice et al. in prep) will provide a science based capacity to evaluate the restoration of Qwuloolt and other restoration sites in the system, contribute to improved science and practice of estuarine restoration in the region, and also provide public information on restoration activities.

Project goals

The original project goal for the Qwuloolt project is to "Restore historic tidal circulation and processes and functions," and objectives were identified by project managers in support of attaining this goal (Adolfson Associates 2006). In addition to the original project goal and objectives we recommend an overarching project goal, and goals and objectives for major components of the system, including society. Because improved biology is the overwhelming motivation for Qwuloolt (and most other restoration actions) we recommend that the overarching project goal should be to move the site as much as possible toward biological integrity, originally defined as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981). Implicit in biological integrity are other attributes (e.g., biodiversity and resilience) often proposed as goals for ecosystem management and must be appropriate for a given place (Angermeier and Karr 1994). The integrity, or reference condition, is simply the biological character of the place before disturbance by modern humans, and can be characterized by measuring diverse attributes (e.g., taxonomic and trophic composition, size structure, individual condition) of the biota in undisturbed or minimally disturbed places with similar physical conditions.

Because it is not possible to return Qwuloolt to a pristine state, the project goal should be to return the site to historical conditions *within modern constraints* (Wilbur et al. 2000, Simenstad et al. 2006b). These constraints include human modifications to watersheds (Simenstad et al. 1992), estuarine wetlands (Haas and Collins 2001), and fish populations (Pess et al. 2003). In addition, the design of the project will impose constraints due to the practical realities of protecting public infrastructure and controlling project costs. In the Qwuloolt design, breach versus removal of dikes, mounding and side-casting during excavation, and armoring of shorelines will all constrain natural processes to some extent. Finally, the long-term influence of sea level rise must be considered in interpreting monitoring results. Goals by the various ecosystem components to be monitored are summarized in Table 1.

Table 1. Goals for major ecosystem components. These goals form the basis of monitoring questions.

Ecosystem component	Goals
Topography, soil, and sediment	Allow maximum tidal inundation; maintain and develop elevation, soil conditions, and hydrologic connectivity favorable to native biota historically present
Hydrology	Allow maximum tidal inundation; temperature, salinity, flow, and dissolved oxygen favorable to native biota historically present
Chemistry	Maintain anthropogenic nutrients and toxic chemicals below levels that cause adverse effects on native biota historically present
Biota	Over time, return character of the biota onsite to a condition similar to that historically present
Society	Minimize adverse effects on property and infrastructure; maximize positive contribution to natural and cultural heritage of the community in terms of conservation, education, and recreation; positive contribution to restoration science and practice

Conceptual model

A conceptual model of the system being restored is critical in the design as well as the monitoring of a restoration project (Thom and Wellman 1996, Simenstad et al. 2006a). The narrative conceptual models (e.g., Cereghino 2006) for the Qwuloolt project can be represented by a simple figure showing dieback of existing vegetation, change in average elevation over time as a result of the returning tidal processes, and consequent development of natural estuarine wetlands (Figure 6). The likely timeframes for these stages range from years for the initial dieback of the reed canary grass on the lower elevations of the site, to more than a century for the development of Sitka spruce forested wetlands historically present on part of the Qwuloolt site. Considerable uncertainty exists regarding the actual course of the project, and the nature and rate of change of various attributes of Qwuloolt could take many forms (Figure 7). Monitoring to document and diagnose change of the site over time will be critical in assessing whether the project develops in a direction that meets management goals.

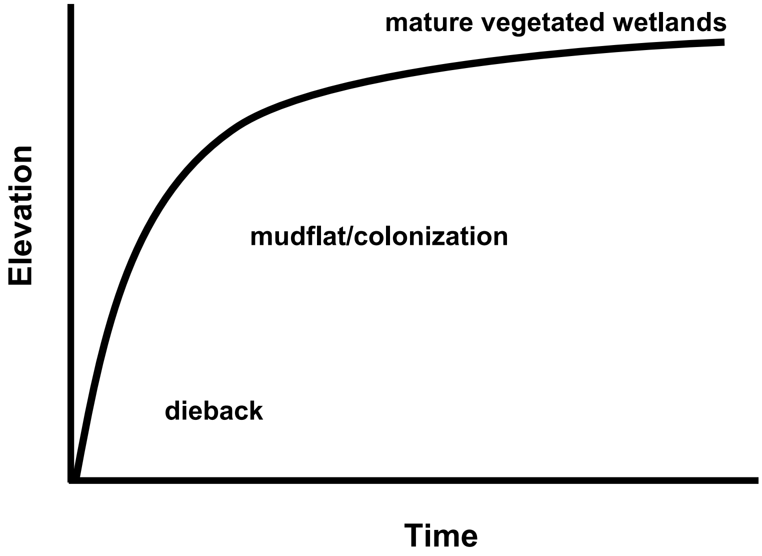

Figure 6. Simple conceptual model of ideal trajectory for Qwuloolt. Based on Williams and Orr (2002).

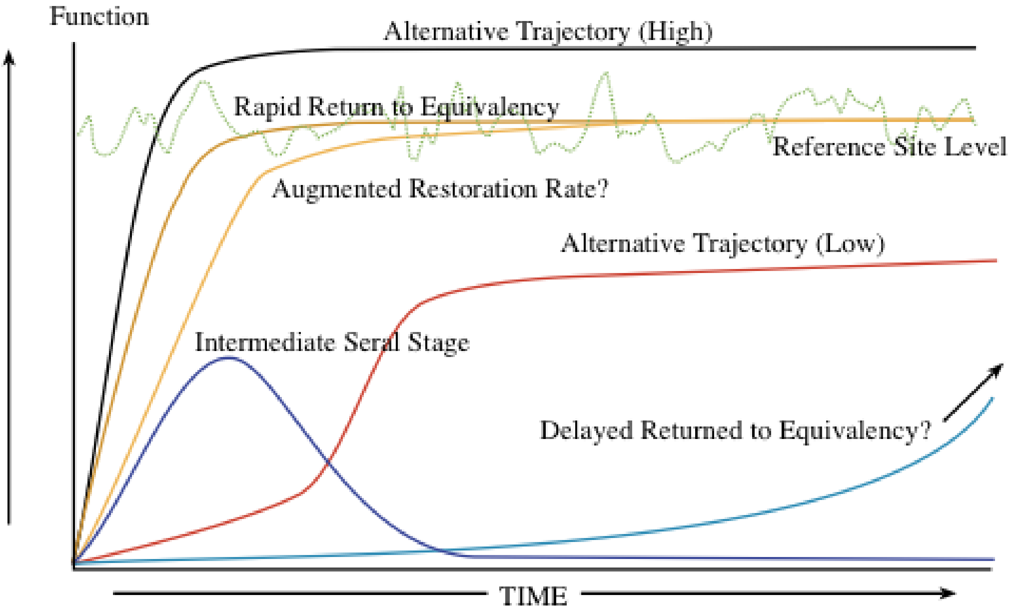

Figure 7. Conceptual model of multiple possible trajectories for restoration. A primary role of monitoring is to help managers identify which trajectory a site is taking. From Simenstad et al. (2000a).

In addition to conceptual models of potential site trajectories, we provide a simple chain-framework conceptual model (Figure 8) to help guide monitoring. This chain framework and the monitoring process in Figure 4 provide a comprehensive and coherent structure that identifies the main system components, relationships, priorities, and feedbacks of the restoration project in a way that can help organize monitoring planning and translate project goals into specific monitoring activities. For example, monitoring elements for the project can be organized in a table that connects them with basic components of system structure as represented in the ecosystem and site conceptual model, and translates monitoring questions into monitoring metrics and analytic methods (see monitoring questions, methods, and costs section below). Data will come from a variety of sources in the chain but information from the different components is not equivalent—*improved biology* is the major goal in restoration, and so should be the ultimate type of response variable. Assuming that “structure equals function,” and only measuring abiotic attributes and inferring biology, risks missing a true assessment of project performance.

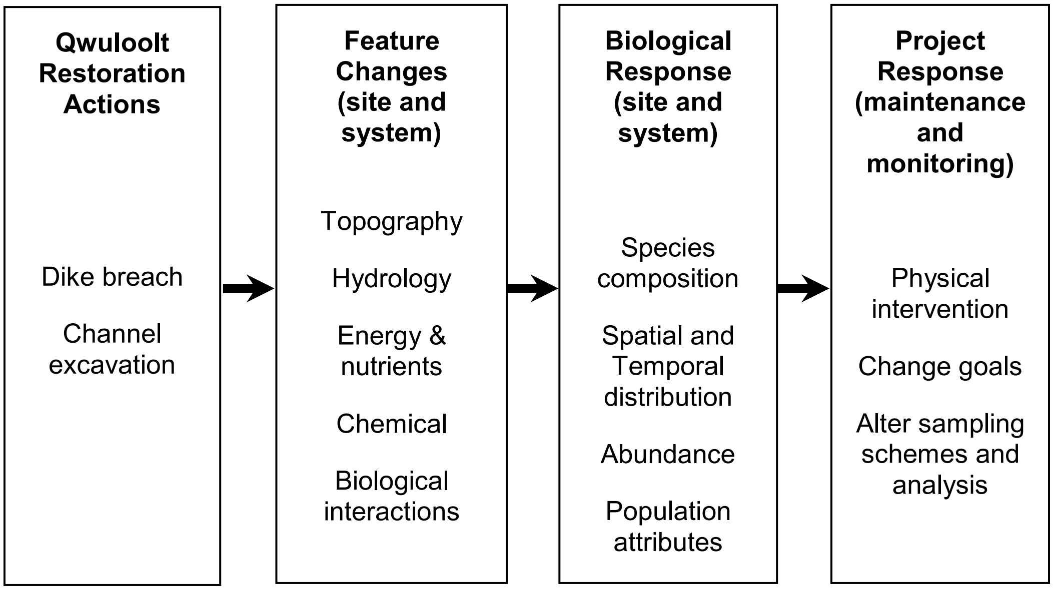

Figure 8. Simple conceptual model of Qwuloolt restoration project.

Basic study design

Study design typically refers to the experimental design used to compare treatment sites with untreated or differently treated sites, predictive models, or historical information (Schmitt and Osenberg 1996, Kingsford and Battershill 1998, Elzinga et al. 2001, Downes et al. 2002, Roni 2005). These include comparisons of the site before and after treatment, as well as with controls (sites that remain in the pre-treatment condition), and references, which are typically sites that are pristine or the desired condition of the site, but can also be sites that are in various stages of recovery in a post treatment space-for-time (Roni and Quinn 2001, Gray et al. 2002) designs, or even other restoration treatments.

Few relatively undisturbed places remain in the Snohomish estuary in the same position along the dominant environmental gradients (e.g., salinity, elevation, hydrologic connectivity) as Qwuloolt. The forested area adjoining the southern border of Qwuloolt is probably closest to any historical conditions on the site (Figures 1 and 3). Nearby Ebey and Spencer Islands, which are both in various stages of recovery from diking as a result of dike failures, and the Marysville mitigation site, which had tidal inundation restored in 1994 and monitoring in years 1-5, 8, and 10 after restoration actions (Jones and Stokes Associates Inc. 1999, Jones and Stokes Associates Inc. 2003) (Figure 1) are probably the best reference conditions for the emergent marsh that was also present on Qwuloolt. We recommend Ebey Island, the forested wetland, and Marysville mitigation sites as the best core reference areas for Qwuloolt. In addition, while farther downstream in the more saline region of the estuary, Quilceda marsh (Figure 1) provides a valuable reference as the most undisturbed marsh for reference information on channel morphology and vegetation relationships with elevation and salinity. The rest of the Quilceda system provides the closest analog of Allen and Jones Creeks that historically ran through Qwuloolt. Spawner counts in Quilceda and Allen Creek watersheds, for example, will be an important attribute to track after the Qwuloolt restoration (see fish section in questions, methods, and costs section below).

Our primary study design is a modified BACI (Before-After Control-Impact) design. No extensive portion of the site will remain as a control, but the several sites described above in the immediate vicinity of Qwuloolt will be used as the basis for comparison to evaluate recovery at Qwuloolt. Our design, then, is more appropriately called BARI (Before-After Reference-Impact). In addition, relationships currently being developed between channel and marsh island area, and between vegetation and elevation and substrate conditions across the whole estuary will provide useful context for conditions at Qwuloolt.

In addition to main study design, we also recommend event-triggered sampling that should be initiated when unpredictable events such as floods or seismic activity occur that can have a dramatic effect on the restoration.

MONITORING QUESTIONS, METHODS, AND COSTS

A suite of questions needs to be answered to adequately evaluate the changes at Qwuloolt as a result of restoration actions. Here we provide concise summary of the monitoring for Qwuloolt separated into essential, or core components, as the recommended minimum, and supplemental components that would add considerable value to the core monitoring (Neckles et al. 2002). We categorize these components into several major feature classes (e.g., topography, hydrology, biota) that encompass the whole system. A detailed budget spreadsheet and schedule (Appendix A) provides cost estimates based on monitoring components and priorities, and shows the practitioners and funding status for each individual element.

Before discussing the questions and methods it is important to point out that the sampling design for the Qwuloolt site is structured to facilitate data collection across all major environmental gradients in way that combines sampling efforts when possible and avoids conflicts (e.g., disturbance of sediment accretion data because of vegetation or fish surveys) among elements. The dominant environmental gradients are elevation, tidal regime, freshwater input, sediment supply, connectivity, and wave energy. We recommend a predominantly systematic sampling design with a 200 x 200 meter grid over the site that orients transects diagonal to the pattern of historical trenches and fence lines on the site to reduce potential effects of regular spatial patterns across the site (Figure 8). Using this design, transects for elevation and rapid vegetation surveys can crisscross the site, and cells between the gridlines provide systematic sampling locations for sedimentation and fish. In addition to this grid, we recommend transects across channels for intensive vegetation assessment and cross-sectional area measurement (Figure 9), as well as intensive, stratified random sampling of vegetation within dominant vegetation assemblages, and areas of excavation and berm and levee construction.

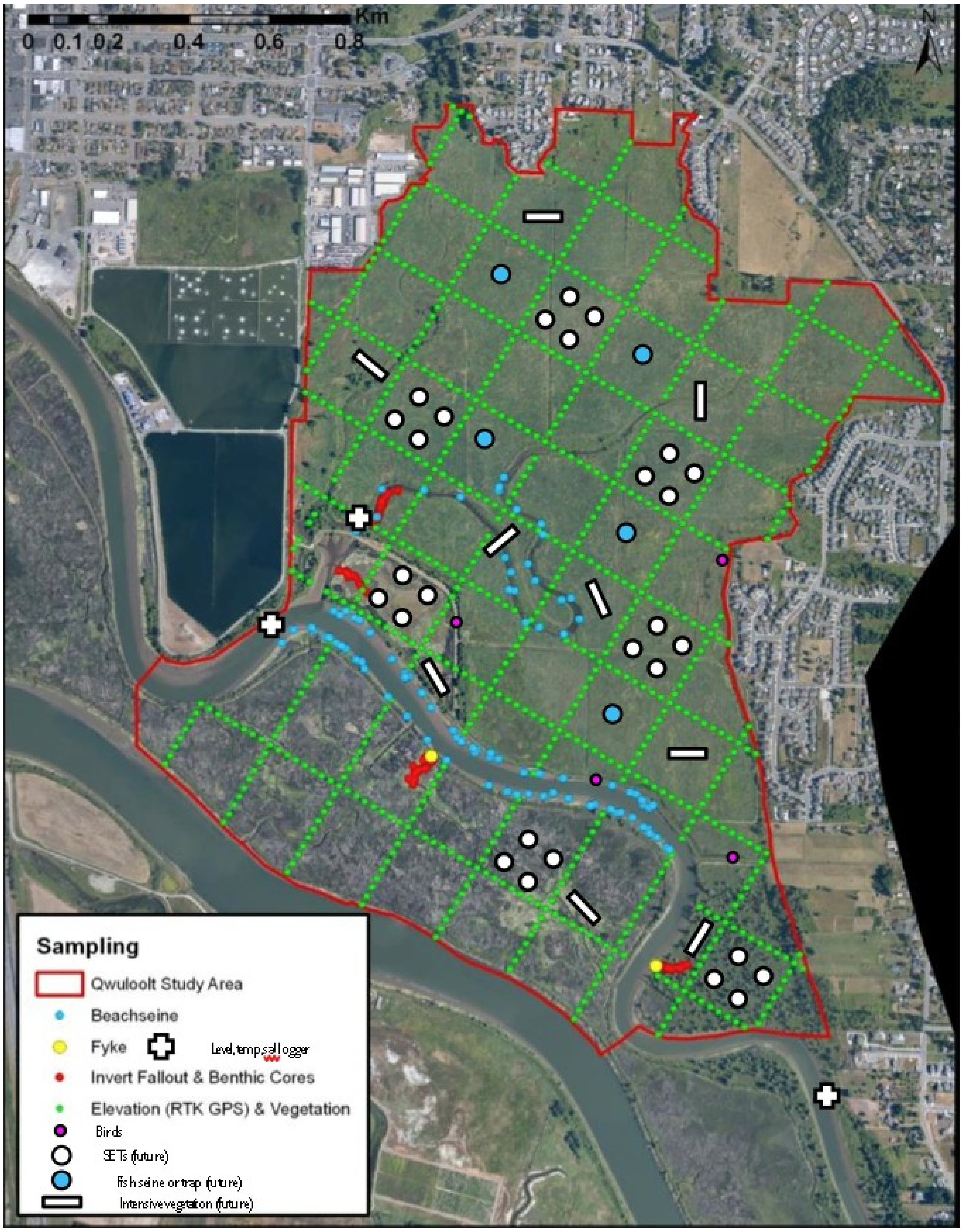

Figure 8. Qwuloolt and core reference sites showing subset of established (e.g., small blue dots at beach seine sites) and future sites (e.g., large blue dots for potential fishing sites) for monitoring of various attributes. Actual layout will change based on final design and construction of the overall project.

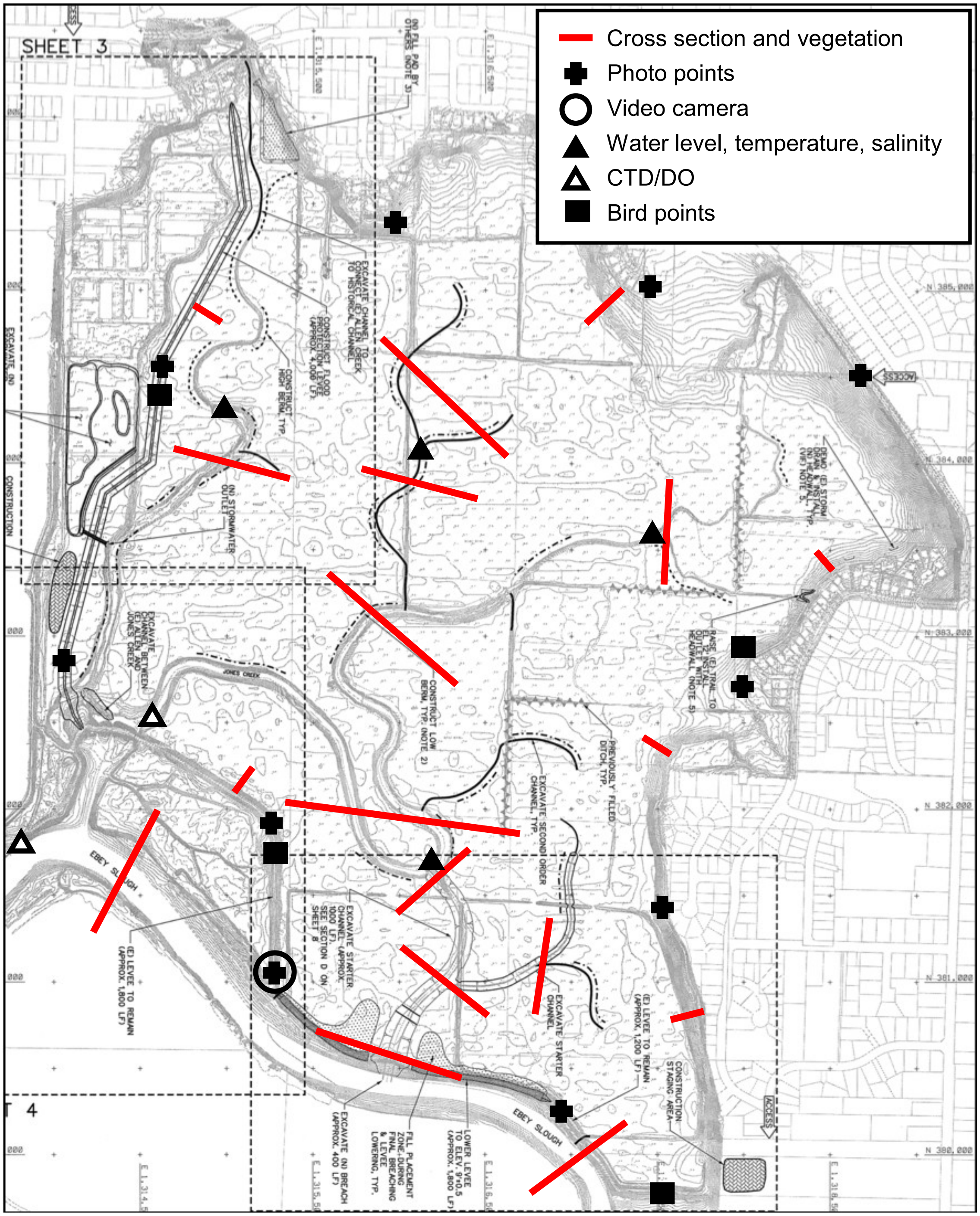

Figure 9. Preliminary locations for intensive elevation and vegetation transects (red lines; these should target places where overall transect grid does not intersect channel outlets and bifurcations); point locations for photo points (crosses), bird surveys (squares), continuous video recording (circles); and water level, temperature, salinity, and DO loggers (triangles); for the Qwuloolt site.

Qualitative Monitoring

Qualitative monitoring by still photography and continuous video provide a visual record of overall project condition useful for project management, monitoring, and scientific and public outreach, and should be core monitoring components at Qwuloolt. We recommend a minimum of semiannual, high and low tide panoramic photographs at seven stations around the Qwuloolt site, and continuous video stations with live internet feeds at one to three of those stations, with the site between the Marysville mitigation and Qwuloolt as the highest priority (Figure 9).

Table 2. Cost summary for qualitative photography and video monitoring.

Component	Cost
Pre-breach	
Core monitoring	
Panoramic photographs	$ 1,000
Supplemental monitoring	
Video cameras	$ 7,400
Post-breach	
Core monitoring	
Panoramic photographs	$ 5,000
Supplemental monitoring	
Video cameras	$ 24,000
Component Total	**$ 37,400**

Topography, sediment, and soils

Initial excavations will allow tidal inundation of the site, and development of the topography and sediment and soil composition over time will be key determinants of the ecology of Qwuloolt. Because the site is large, we recommend combining large scale and finer scale measurements of various attributes as described below.

Questions

Implementation

1) Did site manipulations produce topography specified in the final design?

Status and trend

2) How is the gross morphology of the site changing with respect to elevation, channel development, sediment accretion, and large wood recruitment?
3) How are sediment/soil grain size, organic and mineral content, nutrients, and salinity changing over time across the site?
4) Are built features (e.g., flood and wave control structures) maintaining their integrity?

Effectiveness

5) How does the channel morphology compare with natural and formerly diked wetlands in the Snohomish, Skagit, and other Puget Sound estuaries?
6) How do pre-breach sediment and soil attributes compare with reference sites?
7) Are built features performing as intended?

Diagnostic example

8) Are changes in elevation the result of surface or subsurface processes?

Methods

For gross topography a combination of remote sensing (preferably both LiDAR and orthophotos collected simultaneously) onsite, quarterly, high resolution panoramic photographs, and continuous web cams should be used. Pre-breach, low tide LiDAR and natural light orthophotos of the Snohomish River estuary were collected in summer 2009, and with historical aerial photos should be used to develop marsh island and channel area relationships, digital elevation maps, and connectivity characterization for Qwuloolt and reference sites. For detailed onsite measurements, survey grade (e.g., real time kinematic (RTK)) GPS measurements should be made at regular spatial intervals (at as high a resolution as is practicable) and channel edges along transects; and at designated cross-sectional area measurement points onsite, at reference sites, and in Ebey Slough (Figure 9). Several fixed elevation benchmarks should be established onsite (three of these were tentatively established in fall, 2010) prior to final construction to ensure accurate elevation measurements. In addition, photopoints should be established at several locations around the site to provide a visual record of overall change through time (Figure 9).

During the first two years following restoration of tidal inundation to the project site channel changes are likely to be rapid (Hood 2003, 2006), so RTK-GPS surveys of channel profiles and cross-sections should be relatively frequent. Our recommended surveying schedule would be time 0 (as-built survey), 3 months, 6 months, and years 1, 2, 3, 5, 7, 10, and every three to five years thereafter, concurrent with vegetation sampling. Periodic documentation of site conditions by orthophotos (at least every 2 to 3 years) should be paired with simultaneous RTK-GPS surveys of channel depths (longitudinal profiles and cross-sections at the channel outlets, midpoints, quarterpoints, and ¾-points) to document long-term channel dynamics. Orthophotos should be analyzed with GIS to quantify planform changes in channel geometry. In addition, the sonar survey conducted in Ebey Slough in 2006 (Global Remote Sensing 2007) could be repeated, if funds are available, at the same frequency as LiDAR for a continuous digital elevation model of Qwuloolt and adjacent reference sites.

Considering the number of projects likely to be done in the next five to ten years (Figure 4), the increasing use of LiDAR in planning by local governments, and the relatively low cost of current methods, paired LiDAR and orthophotos of the entire estuary every one to five years should be considered and costs shared across restoration projects and ongoing, system-level efforts such as the Snohomish County Critical Areas monitoring (Haas et al. 2009). Small boat based systems combining RTK GPS and echosounders (e. g., Takekawa et al. 2010) show some promise for characterizing elevations at high tide and are currently under consideration by project managers.

Finer, site-scale measurement of elevation and accretion should be measured by a combination of sedimentation-erosion tables (SETs) and artificial sediment horizon markers (Cahoon et al. 2002a, Cahoon et al. 2002b). These two techniques combined at stations across the site allow the assessment of changes in elevation due to both shallow and deep subsurface (e.g., soil compaction and subsidence), as well as surface (e.g., sedimentation) processes (Figure 10). We recommend 12-16 SET stations on Qwuloolt itself, and four each on Ebey Island, the forested wetland, and Marysville mitigation reference sites. Site visits with SET experts in Winter 2010 refined the recommended design but installation will depend on final site design, as well as pre-breach site preparation activities. Data collection and maintenance will follow standard guidelines; e.g., those developed by the Coastwide Reference Monitoring System (CRMS, Folse and West 2004).

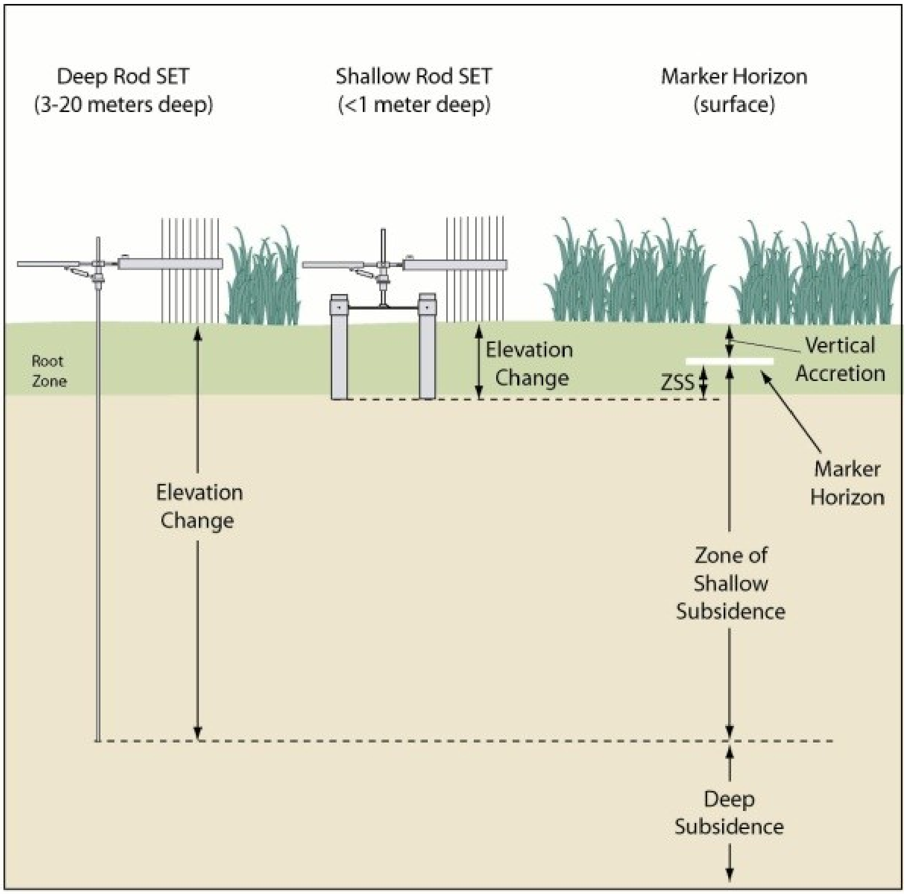

Figure 10. Diagram showing the portions of the soil profile measured by deep and shallow rod sedimentation-erosion table (SET) and marker horizon techniques.

The primary soil and sediment attributes of texture (grain size), organic matter content, salinity and pH are a top priority for substrate sampling as they are defining characteristics of the site and provide a basis for comparison over time and among sites (Zedler 2001). These basics are necessary for interpretation of plant response and contribute to understanding primary productivity, energy and sediment dynamics, and carbon and nutrient flux. Analysis of seasonal nutrient levels and bulk density provide additional diagnostic ability and are highly relevant in an urbanized watershed. Core samples should be collected at Qwuloolt and reference sites pre-breach, and in years, 1, 3, 5, and every 5 years post-breach, and measured using standard methods (e.g., Folk 1968, Plumb 1981). Costs for individual elements of topography and sediment dynamics are listed in Table 3.

Table 3. Cost summary for topography and soil and sediment monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
LiDAR and orthophotos	$ 88,000
Ground surveys (for cross sections; elevation included with vegetation)	$ 10,630
Total	$ 98,630
Supplemental monitoring	
Installation of SETs and horizon markers	$ 40,000
Sediment and soils analysis	$ 11,622
Total	$ 51,622

Post-breach

Core monitoring	
Orthophotos	$ 370,000
Ground surveys (for cross sections; elevation included with vegetation)	$ 21,500
Total	$ 391,500
Supplemental monitoring	
LiDAR	$ 141,000
SETs and horizon markers	$ 120,000
Sediment and soils analysis	$ 46,768
Total	$ 359.390
Component Total	**$ 849,520**

Hydrology

The return of tidal influence to the Qwuloolt site is the single most important driver of ecosystem change onsite, and should also have offsite effects (Yang 2009). Consequently, we recommend a combination of onsite and system level data collection, and hydrodynamic modeling to refine existing models (Yang and Khangaonkar 2007) with new environmental data and the final project design. Extent and timing of inundation by tidal and riverine processes are essential measurements. Temperature, salinity, and dissolved oxygen are often considered “water quality” variables but we include them here as basic hydrologic attributes. In addition to changes in surface water characteristics, changes in groundwater elevations, recharge rate, and retention time are potentially critical drivers of ecosystem change onsite. By characterizing groundwater elevations onsite and offsite, we will be able to evaluate groundwater recharge and discharge rates in relation to tidal, precipitation, transpiration, and riverine flow events. Finally, water velocity measurements can provide information on multiple attributes of the site response to restoration, including material flux, sedimentation and erosion, and fish use.

Questions

Implementation

1) Is full tidal exchange occurring immediately after breach?

Status and trend

2) How do surface and ground water levels, temperature, and salinity change over tidal periods, seasons, and years across the site?
3) Have surface water levels, temperature, salinity, and DO changed at offsite stations in Ebey Slough?

Effectiveness

4) Are surface water levels, temperature, salinity, and velocity as predicted in the hydrodynamic model?
5) Are the surface water levels, temperature, salinity, and DO similar to reference sites?
6) Are the groundwater water levels similar to reference sites?
7) Are surface water temperatures, salinity, and DO within favorable ranges for desired biota?
8) Are groundwater levels within favorable ranges for desired biota?

Diagnostic example

9) If temperatures onsite are not within desirable ranges, what factors are the cause?

Methods

Monitoring hydrologic attributes of surface water and groundwater requires moderate effort once the equipment is installed (although if velocity is added it will increase equipment and maintenance costs considerably). Equipment includes electronic data loggers, staff gauges, core groundwater monitoring wells (with loggers installed), and auxiliary groundwater monitoring wells (manually monitored) in sufficient numbers to cover Qwuloolt and reference sites and also provide some redundancy in case of equipment loss or damage. Installation and operation should generally follow guidelines developed by the Coastwide Reference Monitoring System (CRMS, Folse and West 2004). Instruments should be placed at various points across the site (Figure 9 for surface water, Figure 11 for groundwater), and georeferenced with established local vertical datum. Data should be retrieved from the electronic loggers quarterly. Water levels on staff gauges and within auxiliary groundwater monitoring wells should be recorded during other sampling efforts (e.g., fishing) when practicable. In addition to fixed data loggers and staff gauges, temperature, salinity, and DO should be measured at surface and depth with every fish sample; and vertical CTD profiles of temperature, salinity, and DO should be collected quarterly at high tide in Ebey Slough and along main channels in the Qwuloolt site. Due to the high cost and maintenance requirements of electronic equipment to measure water velocity, we recommend targeted measurement of velocity across a range of flow and tidal conditions. Costs for hydrologic monitoring are summarized in Table 4.

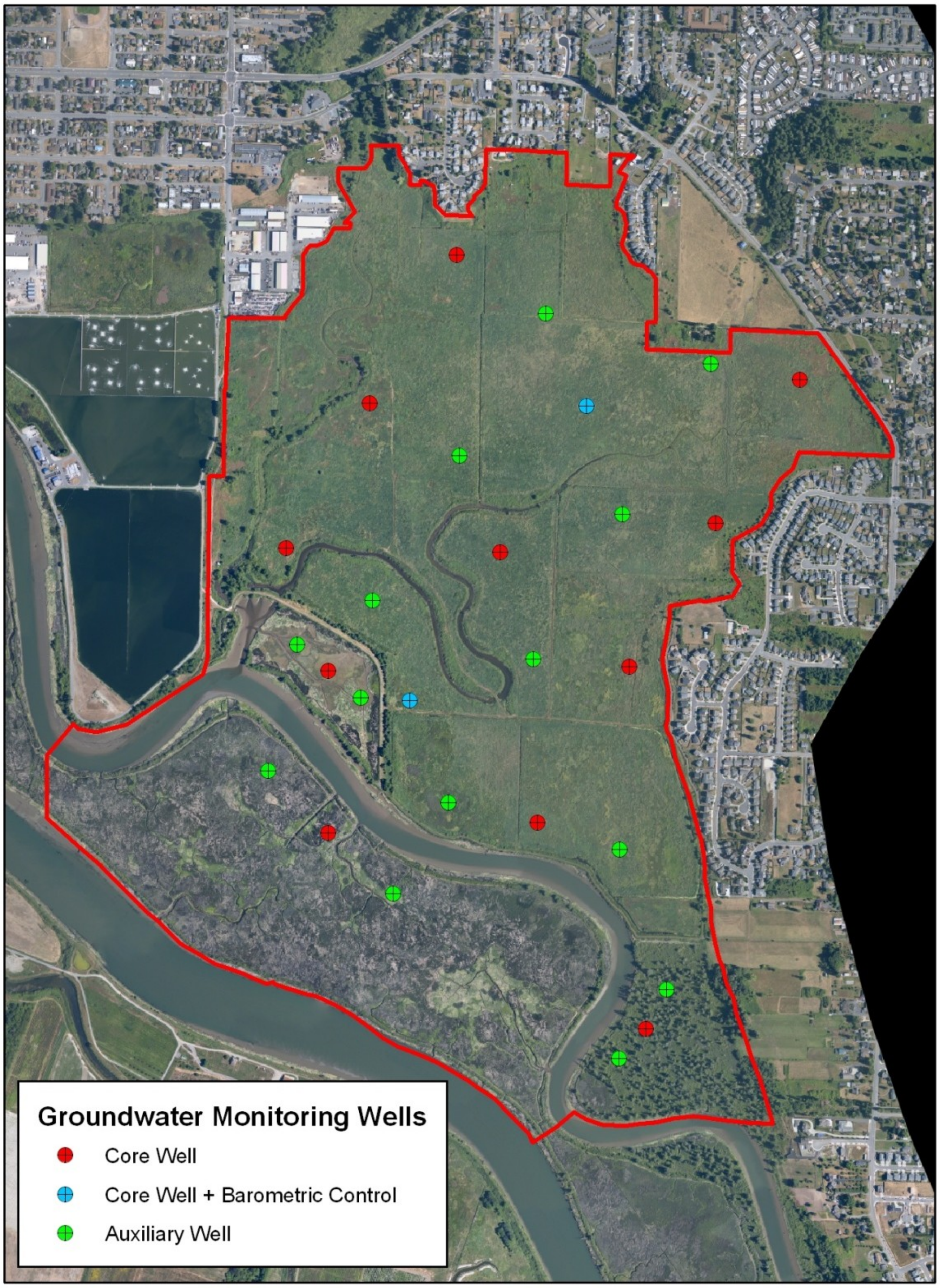

Figure 11. Map showing potential locations of core groundwater monitoring wells (monitoring well with loggers and barometric controls) and auxiliary groundwater wells (monitoring well without logger) relative to the study area (red outline). Core wells will capture water table levels at 15 minute intervals while auxiliary wells will be measured during other sampling events. The relationship between core and auxiliary wells can be used to interpolate water levels at auxiliary wells in between sampling events to provide a continuous record without requiring additional loggers.

Table 4. Cost summary for hydrology monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
Water level, temperature, and salinity	$ 49,217
Supplemental monitoring	
CTD data collection from across estuary	$13,000
Recalibrate and rerun PNNL hydrodynamic model to incorporate new LiDAR and CTD data	$ 85,000
Groundwater level loggers; groundwater monitoring wells	$10,000
Velocity	$5,000
Total	$ 113,000
Post-breach	
Core monitoring	
Water level, temperature, and salinity	$ 42,170
Supplemental monitoring	
Groundwater level loggers; groundwater monitoring wells	$10,000
Velocity	$15,000
CTD data collection from across estuary	$65,000
Total	$ 90,000
Component Total	**$ 294,387**

Sediment and water quality

Chemical contaminants

The Qwuloolt restoration site located in an urbanizing area where there is a potential risk of contaminant exposure and associated injury of the biota, as the former Tulalip landfill, and the City of Marysville wastewater treatment plant are nearby. The site may also be affected by stormwater and agricultural runoff from the city of Marysville and Allen and Jones Creek watersheds. Consequently, it is advisable to include toxics assessments as part of the restoration monitoring for the site. This is especially true as it appears that current and future monitoring in the area by other agencies is somewhat limited. For example, Snohomish County is monitoring concentrations of copper, lead, and zinc in Allen Creek (online water quality data at http://198.238.192.103/spw_swhydro/wq-search.asp) but there are few data on other contaminants of concern; as part of the Puget Sound Assessment and Monitoring Program (PSAMP) the Washington State Department of Ecology conducts sediment monitoring at a station in Ebey Slough (Long et al. 1999; Dutch et al. 2009), but does not collect detailed information on sediments at the Qwuloolt site.

We propose that in conjunction with monitoring of physical and biological attributes at the site, chemical contaminant concentrations should be measured in water, sediments, fish prey (i.e., in stomach contents), and in tissues of representative fish species. These would include the primary salmonid species present at the sites (e.g., Chinook, coho, chum, and pink), as well as a resident fish species such as starry flounder and staghorn sculpin.

Analytes to be measured would include: 1) polychlorinated biphenyls (PCBs), name (DDTs),) polybrominated diphenyl ethers (PBDEs), organochlorine (OC) pesticides, and polycyclic aromatic hydrocarbons (PAHs) in sediments and fish stomach contents (Sloan et al. 2005); 2) PCBs, DDTs, PBDEs, OC pesticides, and PAHs in fish bodies (Sloan et al. 2005); 3) Metabolites of PAHs and selected estrogenic compounds in fish bile (Krahn et al. 1984, Da Silva et al. 2009); 4) vitellogenin in fish blood as an indicator of exposure to estrogenic compounds (Peck et al in review); 5) metals, current use pesticides, and wastewater compounds in the water column. Samples would be collected in years 1, 5, and 10, unless results suggest more intensive study is necessary.

Nutrient loading

In addition to chemical contaminants, freshwater inputs from the Snohomish River and the Allen and Jones Creek watersheds also have the potential to deliver anthropogenic nutrients to Qwuloolt that may influence ecology of the site, especially the vegetation. Previous monitoring by Snohomish County has documented elevated phosphate and nitrate levels in these watersheds, as well as high fecal coliform concentrations (SCPW 2002). Snohomish County is currently conducting monthly water quality monitoring for nutrients at several locations in Allen Creek. We recommend annual and event based sampling for nutrients in the water column at selected sites within the study area as needed, to supplement these data. See topography and sediments section for information on sediment and soil nutrients. Nutrient flux is considered in the vegetation section.

Questions

Status and trends

1) What are the concentrations and spatial distribution of nutrients and contaminants of potential concern at the site?
2) Do concentrations of contaminants of potential concern at the site reach or exceed levels associated with injury to salmon and other biota?
3) How are contaminant and nutrient concentrations changing over time?

Effectiveness

4) How do contaminant and nutrient concentrations at the Qwuloolt site compare with those at reference sites?
5) How are levels of contaminants and nutrients changing over time following restoration?

Diagnostic example

6) If contaminant or nutrient concentrations are not within desirable ranges, what factors are the causes?

Cost estimates for chemistry sampling are summarized in Table 5.

Table 5. Cost summary for chemistry and nutrient monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
Water, sediment, and soil contaminant concentrations at Qwuloolt and at reference sites	$ 4,120
Tissue concentrations in juvenile Chinook at reference sites	$ 7,120
Tissue concentrations in other (more resident) fish species at Qwuloolt and reference sites	$13,120
Nutrient concentrations in water	$ 2,000
Total	$ 26,360
Post-breach	
Core monitoring	
Water and sediment contaminant concentrations at Qwuloolt and at reference sites	$ 12,360
Tissue concentrations in juvenile Chinook	$ 21,360
Tissue concentrations in other fish species at Qwuloolt and reference sites	$ 39,360
Nutrient concentrations in water	$ 20,000
Total	$ 93,080
Component Total	**$ 119,440**

Biota.

Ideally, biological response variables should be integrative measures of overall assemblage or community condition (Karr and Chu 1999). High priority candidates are ecologically diverse major taxa that are responsive to restoration, relevant to goals, and measureable. Thus, we recommend at least vegetation, fishes, invertebrates, and birds, and emphasize composition of whole assemblages and spatial arrangement or use of the site as primary response variables. Because vegetation is so central to the ecology of healthy estuarine wetlands it is the highest priority. Because recovery of Chinook and other salmon and trout are primary drivers of Qwuloolt restoration activities and a major local, regional, and national concern (Snohomish Basin Salmon Recovery Forum 2005) we place measurement of salmon and trout as the second major biological priority. Whole fish assemblages also provide a rich source of information about biological condition (Simon 1999) and so are our third priority. As potential prey for juvenile salmonids and another taxonomically rich and ecologically diverse group, invertebrates are fourth. Finally, birds provide a rich and efficient set of responses, and are of high public interest.

Vegetation

As a dominant biological component in its own right but also a major influence on other taxa, including juvenile salmonids, vegetation should be thoroughly characterized both before and after breaching using a combination of remote sensing and ground surveys. Current elevations at the Qwuloolt site show that the site has subsided and much of it is too low for native vascular plants to establish. This problem is common in agricultural fields returned to tidal influence (Zedler 2001). Literature values and Snohomish field surveys in the Snohomoish estuary indicate that vegetation in brackish marshes generally grows from about 2m above mean lower low water (MLLW) to approximately 3m MLLW in the Pacific Northwest, though lower salinities may result in plants growing at lower elevations (Ewing 1986). Except for berms created during the excavation of starter channels, most of the Qwuloolt site is at elevations below 2m. Considerable uncertainty exists regarding post-breach sediment accretion rates onsite but they are not likely to be more than 2-5 cm per year (Thom 1992, Cornu and Sadro 2002). Depending on dieback of existing vegetation and the changes in elevation onsite as a result of surface and subsurface processes, it could take decades for the majority of the site to become vegetated. Consequently, pre-breach and immediately post-breach monitoring should focus on spatial distribution and species composition at Qwuloolt and at reference sites, and immediate post-breach will track the dieback process, colonization by vascular plants at elevations likely to support them, and algae.

Questions

Status and trend

7) What is the spatial distribution of major plant assemblages on the site?
8) What is the taxonomic composition of the major plant assemblages on the Qwuloolt site?
9) What is the condition of the dominant species within the major plant assemblages across the site over time?
10) How are these attributes changing over time?

Effectiveness

11) How do vegetation attributes on the Qwuloolt site compare with those at reference sites?

Diagnostic

12) What biotic and abiotic factors are driving the observed plant attributes on the Qwuloolt site?

Methods

For large-scale vegetation monitoring we recommend GIS analysis of orthophotos combined with ground-truthing, both before and after breach at Qwuloolt and reference sites. The same large-scale methods that are used to measure gross topography will also provide large-scale data about vegetation assemblages.

Natural light orthophotos were collected in summer, 2009, and these or 4-band orthophotos should be collected annually for the first ten years post-breach then every three to five years thereafter. If this is not possible, Snohomish County plans on collecting biennial satellite imagery (Haas et al. 2009) that would provide some land cover data, but at a much lower resolution (2-4 m versus 0.15 m cells).

Ground surveys of vegetation should be done pre-breach and in years 1, 2, 3, 5, 7, 10, and every three to five year thereafter. To avoid the practical problems raised by installing permanent physical transect markers onsite, survey grade GPS should be used to navigate along permanent transects (Figure 8) across the entire site to mark changes in dominant vegetation transitions, channel edges, large wood, presence of invasive species, or any other significant biological or physical feature.

Because considerable uncertainty about vegetation response exists across the site, and optimal designs for sampling will depend on the monitoring question, we recommend a mixed sampling design that combines rapid, systematic sampling over the entire study area with stratified random sampling within dominant plant assemblages and across channels (Figures 8 and 9). Methods should allow simultaneous characterization of emergent, shrub, and tree components of each assemblage by considering vertical structure and plant size, and adjusting data collection accordingly.

For the extensive sampling component we recommend a rapid field survey that records elevation; the dominant species and subdominants present (up to 5 spp.) with relative abundance of each (dense, 90-100% cover; medium, 40-90%; low 10-40%; and rare <10%); and height, and qualitative condition (robust, medium, stressed, senescing, dead) of the dominant plant species within a 1m^2 area at 25m intervals (Figure 8) across the study area. These surveys were started in summer and fall of 2010.

For the intensive surveys dominant vegetation assemblages should be mapped using orthophotos, LiDAR, and ground surveys, and sampled at a minimum of three locations randomly selected within each assemlage. For initial surveys we recommend three sites within each stratum to test the feasibility of the methods and obtain data to refine the sampling scheme. At each sampling location, vegetation in each 1 m^2 cell of a 5-by-5 m grid will be recorded by noting presence of all species (the 25 cells in aggregate will provide a measure of relative abundance of all species), which species are ≤ 5% cover, and the categorical condition of each species (robust, medium, stressed, senescing, dead). When trees are present, each species will be recorded if its drip line falls within the 5-by-5 m grid. For each such species, the nearest tree of that species will be designated as the first tree-sampling point and the distance to the 4 trees of the same species closest to the first sampling point measured. An average of these distances will be used to calculate a density of these trees in the vegetation zone.

Because greatest change is likely to happen adjacent to channels and along strong elevation gradients, intensive vegetation transects should be established perpendicular to channels, for example, at the same locations as cross-sectional area measurements are taken (Figure 9). For each transect, $1m^2$ quadrats should be established at the toe of the channel, the channel bank, and 5m landward from the channel bank, on both sides of the channel. We recommend at least three of these transects for each channel order and elevation stratum.

A possible adjustment to both the extensive and intensive components of the overall design is to further stratify the site based on elevation bins, for example, increasing transect and especially quadrat density in areas of steeper slopes or higher topographic heterogeneity that will likely occur around the perimeter of the site and around channels. This option is being evaluated based on analysis of elevation and vegetation distribution data collected in spring and summer 2009, and summer 2010, and from other studies in the Snohomish system (e.g., Tulalip Tribes of Washington 2007, ICF Jones & Stokes 2009). Pre-breach vegetation surveys should also be done at the three primary reference sites and were initiated in summer, 2010. An additional consideration is the effects of disturbances related to site preparation. At a minimum, these areas should be mapped pre-breach for use in interpreting future vegetation patterns on the site. Evaluation of pilot data from vegetation and elevation surveys, along with consideration of final design will refine the sampling design. Costs for vegetation monitoring are summarized in Table 6.

Primary production and material flux

The generation, retention, import, and export of organic matter, nutrients, and sediment at Qwuloolt will influence ecological conditions both on- and off-site. Measuring these attributes could be very useful in evaluating project performance, but does add considerable difficulty and cost to the monitoring.

Productivity

Measuring plant biomass within a marsh is one way to quantify net aboveground primary productivity (NAPP) and provides a common measure of net productivity within a site. Changes in NAPP will be most useful for tracking the initial die back of vegetation post breach as well as indicating the functional trajectory of the restored marsh (Simenstad and Thom 1996). The Qwuloolt site is currently dominated by *Phalaris arundinacea*, an aggressive perennial that often out-competes native wetland species. While *P. arundinacea* is fairly tolerant of saturated soils the species is intolerant to long periods of inundation (Rice and Pinkerton 1993). Preliminary hydrodynamic models of the site post-breach indicate significant inundation will occur throughout study area. In addition to stem density, plant height, and visual condition, monitoring APP in *P. arundinacea* pre-and post breach, and any colonizing vegetation post-breach, could be useful for evaluating vegetation changes at Qwuloolt.

Various methods are used to estimate APP (Hsieh 1997). Under- or over-estimation of APP depending on when measurements take place (peak-season, several times per year) and what is being measured (new growth, total growth, dead material, etc.). Several studies have used multiple methods at a single location by establishing treatments within individual plots to determine the best method for a particular site/species (Shew et al. 1981, Kawadji 1990, Edward and Mills 2005). We recommend positioning sampling locations systematically across the site, making sure to include elevation gradients, and establishing permanent plots. Specific sampling locations are to be determined but protocols will follow Edward and Mills (2007). At each location, 1m^2 quadrats (100m apart, will be divided into four 30 cm^2 plots each being measured by a different method. Each event will consist of an initial harvest followed by a secondary harvest four weeks later. Differences in biomass within each event will determine the NAPP for each plot.

Flux

The outwelling hypothesis states that marshes are net contributors to estuary productivity in terms of carbon and nutrient inputs (Teal 1962, Odum 1968, Nixon 1980). Local urbanization and water quality issues, as well as global climate change, press the question of whether marshes are sinks or sources for carbon and nutrients (Boorman 1999). Most of the science on the topic has been done outside of the Pacific Northwest and indicates that overall, marsh flux studies do not show universal support for the outwelling hypothesis (Nixon 1980, Childers et al. 2000). Some marshes have been found to be net importers of carbon and/or nutrients while others have been found to be exporters. The degree to which marshes import or export can often be explained by geomorphology, tidal range, and/or successional stage of the marsh (Childers et al. 2000). Younger marshes tend to export less than older marshes, probably due to lower overall primary productivity. The tendency of marshes to contribute energy-rich materials to surrounding systems is still generally assumed by researchers (Valiela, 2000).

Methods to evaluate material flux include marsh flume studies that directly sample the water column as it exits and enters the site, and concentrations of nutrients, organic matter and stable isotopes measured. Subsurface flow and transport by organisms are not accounted for in water column samples. Further, the nature of nutrient cycling itself makes sampling, handling and analysis complex. A recent effort in the St. Lawrence estuary provides an example of a water column flux study (Poulin et al. 2009) where water samples were collected weekly for one year. Qwuloolt may be a good candidate for this type of study due to its relatively simple inflow/outflow design. The proximity of a wastewater treatment plant and residential development add interest to questions of nutrient processes and interactions at the site. However, we consider the value of material flux studies at Qwuloolt to be a relatively low priority for monitoring and are evaluating the research potential for the topic at Qwuloolt and other sites. Cost estimates for flux studies are not included in this plan.

Table 6. Cost summary for vegetation monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
Mapping from orthophotos, LiDAR, and ground-truthing, includes elevation; extensive and intensive ground surveys for species composition and plant condition	$ 42,500
Supplemental monitoring	
Productivity	$1,200
Post-breach	
Core monitoring	
Mapping from orthophotos, LiDAR, and ground-truthing, includes elevation; extensive and intensive ground surveys for species composition and plant condition	$ 143,500
Supplemental monitoring	
Productivity	$ 6,000
Grand Total	**$ 193,200**

Fish

Positive effects on fish—juvenile salmon in particular—are the single most cited potential benefits of the Qwuloolt project, and should be a major emphasis of the monitoring. The areas of interest with respect to fish response to restoration actions are onsite, in the Allen and Jones Creek watersheds, immediately offsite, and estuary-wide. Here we emphasize all but the estuary-wide monitoring which is discussed in the Snohomish estuary restoration monitoring framework (Rice et al. in prep).

Questions

Status and trend

1) What is the taxonomic composition and species size distributions of fish assemblages onsite and immediately offsite in Ebey Slough?
2) What are the seasonal distributions and cumulative mean densities of juvenile salmon onsite, immediately offsite in Ebey Slough, and at reference sites?
3) What is the abundance of returning adult coho in the Allen Creek watershed?
4) How are these attributes changing over time?

Effectiveness

5) Are fish assemblage and population attributes on the Qwuloolt site similar to those at reference sites?
6) Are the seasonal distributions and cumulative mean densities of juvenile salmon species onsite similar to those at reference sites?
7) Has adult coho abundance after breach increased relative to Quilceda Creek?

Diagnostic

8) What biotic and abiotic factors are influencing the observed fish attributes on the Qwuloolt site?

Methods

Responses of fish populations and assemblages will vary depending on the attribute in question. Occupation of the site should be immediate, but the nature of the use will change as the habitat develops. Effects of restoration on juvenile population attributes such as “fish days” (cumulative mean density (Skalski 2005, Greene and Beamer 2009)), seasonal distribution (Bottom et al. 2005), residence time, and relative abundance of life history types within the estuary should be apparent beginning in the first few years. It may, however, take many years to detect significant change in populations of returning adults. Annual sampling is critical because unpredictable factors such as ocean conditions and flooding events can have dramatic impacts on outmigrant population sizes, and estuarine habitat use can be strongly influenced by density dependant processes (Beamer et al. 2005, Beamer and Greene in prep).

The two major classes of monitoring metric are overall assemblage composition, and population and individual attributes of selected species, especially salmon. The simplest and most common metrics are presence/absence and abundance at single or few time points over the year. These metrics are limited in terms of assessing the influence of the habitat on taxonomic diversity and trophic status of the whole assemblage, and, in the case of salmon, effects on population attributes (Simenstad and Cordell 2000). Putting site level data into the larger context of the system is critical in interpreting monitoring data. For example, if density dependent processes are limiting juvenile salmon rearing in the estuary (Beamer et al. 2005, Beamer and Greene in prep), declining *local* densities may be a positive response to a given restoration action.

Beneficial effects of estuarine restoration on juvenile salmon populations have never been conclusively demonstrated. Collecting information that might reflect such positive changes in realized function of restored habitats (Simenstad and Cordell 2000) requires extensive and intensive sampling in space and time, and, ideally, the collection of data on diet, residence time, growth, life history diversity, and disease (see Appendices G, H, I, and J in Snohomish estuary restoration monitoring framework (Rice et al. in prep)). Fish/habitat relationships cannot be characterized effectively without intensive sampling in space and time because of strong seasonal heterogeneity of fish use of estuarine habitat, protracted—even multimodal—distributions of wild juvenile Chinook in estuarine habitats (Beamer et al. 2005, Rice 2007), and influences in one habitat may not be evident until “downstream” later in the life cycle. Consequently, we recommend sampling every two weeks at least from late winter into early fall (and preferably year-round), every year, across the full range of estuarine habitats to develop as full a picture of fish use as possible. At Qwuloolt this means sampling biweekly onsite and at reference sites from February through August using a variety of sampling methods, preferably integrated into an estuary-wide fish sampling effort (Rice et al. in prep). Detailed sampling protocols for the Qwuloolt site will be influenced by the final site configuration at the time of dike breaching, and will also likely evolve over time as the site changes. Depending on the final design, this should require a combination of fyke trapping in blind tidal channels (Figure 12), and beach seines on more open shorelines or mudflats onsite and at reference sites. For beach seining in Ebey Slough immediately offsite, we recommend six random sites selected (with replacement) for each biweekly sampling. Preliminary power analysis from NOAA Fisheries Snohomish estuary fish catch data (Rowse et al. unpublished) suggests three to six samples per stratum as a minimum. This mix of index and random sites will preserve and enhance the NOAA time series, while also providing data for a less biased estimate of fish densities, and more representative assessment of fish assemblages in the slough before and after restoration.

Because of the low elevation of much of the Qwuloolt site, and uncertainty about how it will change over time, preparations should be made for high tide sampling by small beach seines or lampara nets, for example, if site conditions preclude effective fyke trapping. Sites for this sampling should be chosen by assigning six cells (randomly, with replacement) from the 200 x 200 m grid not designated as sediment monitoring locations (Figure 8).

Fish sampling should use gear consistent with NOAA Fisheries ongoing sampling (Rowse and Fresh 2003). Attributes to be measured for every fish sampling are total counts by species, individual lengths on all salmonids, up to 25 individual lengths per species for non-salmonids, check for coded wire tags (CWT), and dependent on funding and permitting, lethal sampling of up to five each of marked and unmarked Chinook salmon per site per sampling period for analysis of diet, otoliths, genetics, chemical contaminants, and disease.

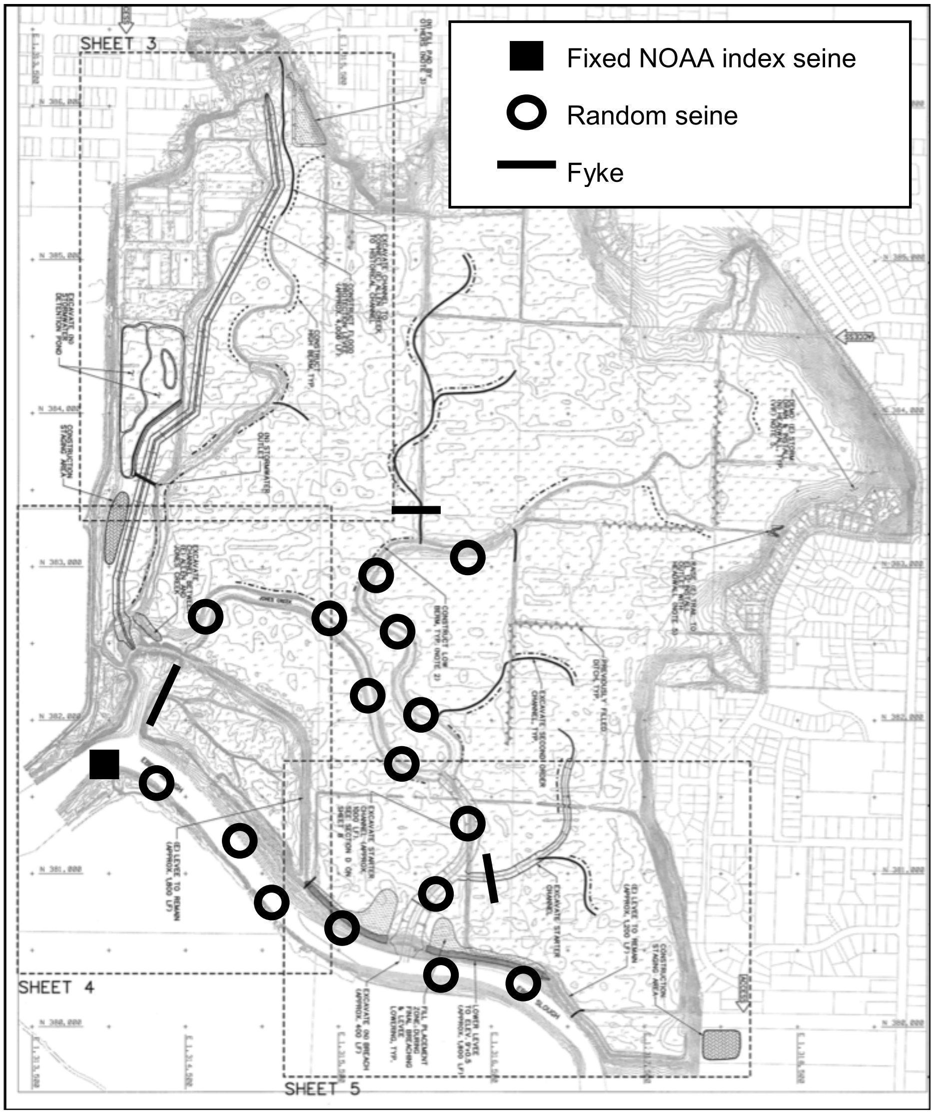

Figure 12. Examples of potential fyke trap and beach seine locations for Qwuloolt and adjacent Marysville mitigation site. Grid cells in areas away from channels (see Figure 9) may be sampled with small seines or lampara nets.

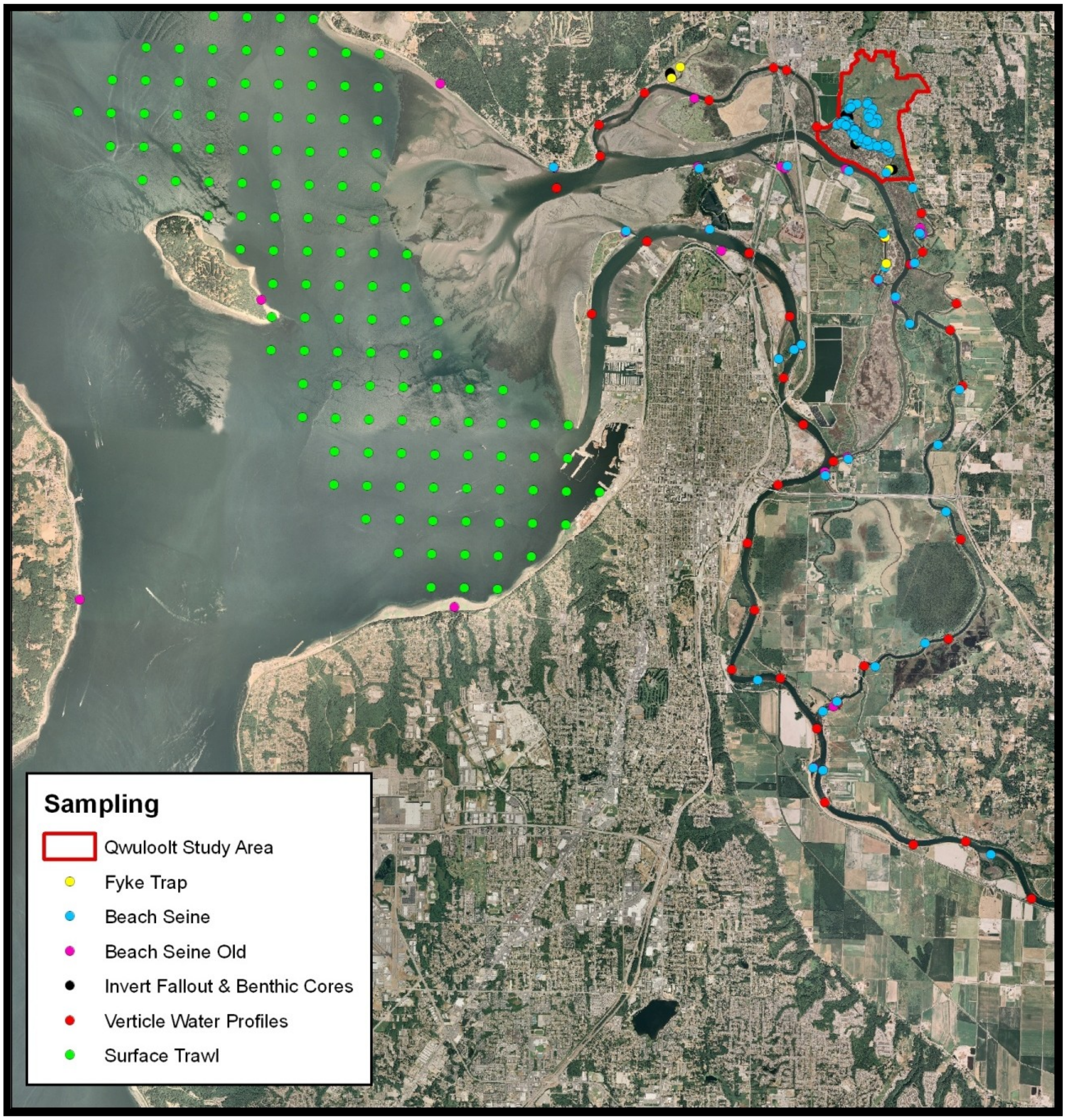

Figure 13. Sampling sites related to Qwuloolt and ongoing NOAA juvenile Chinook salmon ecology study in the Snohomish River estuary. Green surface trawl dots represent pool of sites from which 6 actual sites were randomly drawn each month.

Allen and Jones Creeks

Allen Creek and the much smaller Jones Creek are the two streams that flow across the Qwuloolt site (Figure 1) and currently support spawning coho and chum salmon and cutthroat and occasionally steelhead trout (Carroll 1999). Coho salmon spawner surveys have been conducted in upstream sections of Allen and nearby Quilceda Creek by the Washington Department of Fish and Wildlife since at least 1977. The majority of chum salmon are thought to be strays from the Tulalip hatchery. Both Quilceda and Allen creeks have been impacted by residential and urban development and several problems limit productivity of Allen Creek upstream of Qwuloolt including water quality, lack of LWD, high levels of fine sediment, and others (see Carroll 1999, Snohomish County Public Works 2002).

More than 1000 meters of Allen Creek flow through the Qwuloolt site and the outlet is currently controlled by tide gates, which are thought to restrict salmon migration at some flows. The restoration of the Qwuloolt site will lead to improved fish habitat conditions in both sections of Allen and Jones Creeks flowing across the site and improved fish passage. Three main monitoring questions that could be asked about Allen Creek in relation to Qwuloolt restoration are whether the project is 1) affecting fish assemblage composition in Allen and Jones Creeks within the Qwuloolt site, 2) altering production of salmon parr and smolts in Allen Creek, and 3) affecting adult coho salmon spawning.

All three questions would require a before and after study design. The first of these questions will be addressed by fish monitoring proposed for the Qwuloolt site itself, which will include fyke netting and seining of channels, and perhaps seining or lampara netting of tidally inundated vegetated areas or mudflats within the project itself. Seine sampling in Jones Creek was initiated in 2010 (Figure 8). The second question is problematic for a number of reasons. First, all salmon spawning occurs upstream of Qwuloolt and fish will largely migrate into Qwuloolt to rear. Second, fish from elsewhere in the Snohomish may migrate into Allen Creek to rear. Third, there has been no preproject monitoring of parr or smolts and several years of preproject data would be needed to establish a baseline (Liermann and Roni 2008). In addition, monitoring of smolts would require installation of a smolt trap every spring during outmigration.

Summer parr surveys would require a stratified random or systematic sampling of stream reaches throughout the watershed. Finally, parr and smolt production above the Qwuloolt site is largely driven by instream habitat conditions upstream and previous reports have documented numerous impacts from urbanization (Carroll 1999, Snohomish County Public Works 2002). Given these limitations for monitoring parr and smolts production in the Allen Creek watershed, we do not recommend monitoring of parr and smolts in Allen Creek.

The question regarding adult response is feasible and cost effective because there is ongoing monitoring and considerable preproject data. WDFW has surveyed spawners in three index reaches of Allen Creek since at least 1977. In addition, WDFW has surveyed coho spawner abundance in three reaches of Quilceda Creek over the same period (Figure 13). The trends in abundance between the two streams are very similar and thus Quilceda Creek could serve as an adequate reference site; helping to account for any variation in spawner abundance that is not related to Qwuloolt restoration (i.e., continued impacts from urbanization). Moreover, if WDFW continues to do these spawner surveys the monitoring costs to the Qwuloolt project would be negligible.

Changes in fish assemblage composition in the Allen and Jones Creek watersheds upstream of Qwuloolt could result from the project. This would require snorkel and/or electrofishing surveys. The feasibility and design of this component are presently under consideration, and preliminary cost estimates are included in the budget.

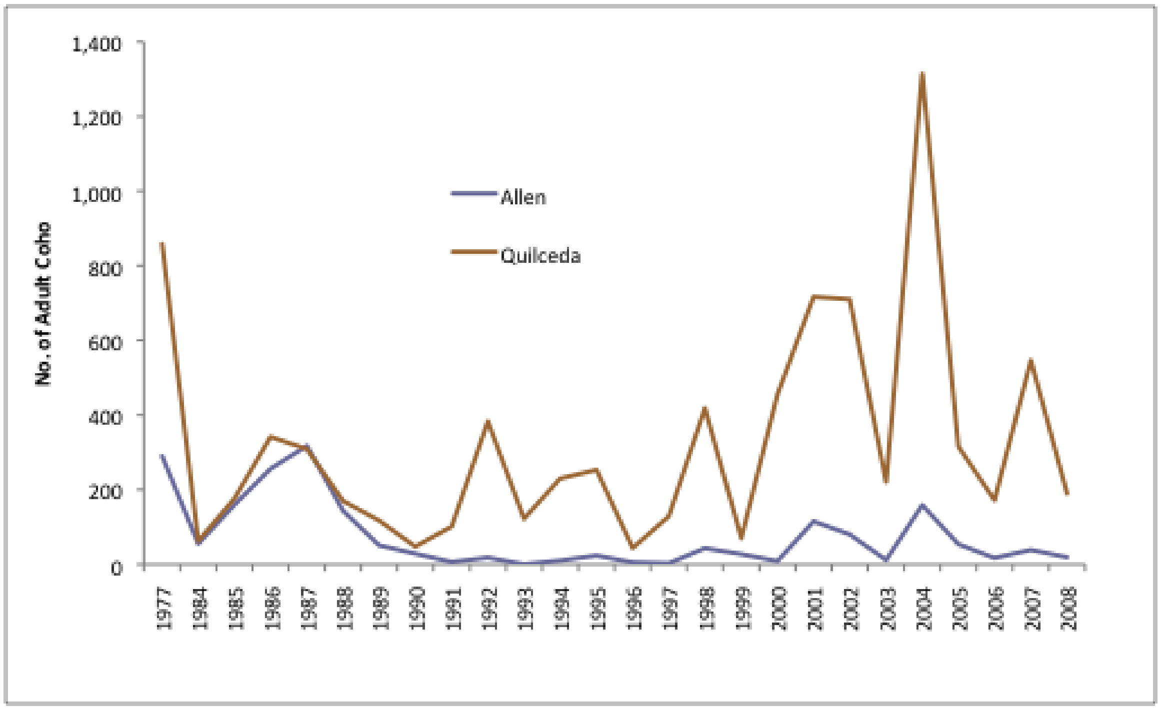

Figure 13. Coho adult salmon production based on area under the curve estimates for Allen and Quilceda creeks. Data courtesy of Peter Verhey Washington Department of Fish and Wildlife.

Table 7. Cost summary for fish monitoring. Data collection, analysis, and reporting included. Additional potential components are discussed in the Snohomish estuary restoration response framework document (Rice et al. in prep).

Component	**Cost**
Pre-breach	
Core monitoring	
Fyke trapping and beach seining in Ebey Slough and reference sites	$ 233,734
Spawner surveys	$ 27,360
Total	$ 261,094
Supplemental monitoring	
Diet analysis of juvenile Chinook onsite and at reference sites	$32,120
Otolith analysis of juvenile Chinook onsite and at reference sites	$20,240
Smolt, parr, and assemblage monitoring in Allen Creek watershed	$ 154,480
Total	$ 206,840

Table 7 (continued). Cost summary for fish monitoring. Data collection, analysis, and reporting included. Additional potential components are discussed in the Snohomish estuary restoration response framework document (Rice et al. in prep).

Post-breach

Core monitoring

Fyke trapping and beach seining onsite, and in Ebey Slough and reference sites	$ 703,580
Spawner surveys	$ 91,200
Total	$ 794,780

Supplemental monitoring

Diet analysis of juvenile Chinook onsite and at reference sites	$225,600
Otolith analysis of juvenile Chinook onsite and at reference sites	$122,400
Smolt, parr, and assemblage monitoring in Allen Creek watershed	$ 772,400
Total	$ 1,120,400
Grand Total	**$ 2,383,114**

Macroinvertebrates

Invertebrates should be sampled to evaluate potential prey availability for juvenile salmonids and to provide further information on taxonomic composition and overall biological condition at the site.

Questions

Status and trend

1) What is the taxonomic composition and abundance of macroinvertebrates in and adjacent to channels at Qwuloolt and reference sites before and after breach?
2) How are these attributes changing over time?

Effectiveness

3) Are macroinvertebrate assemblage composition and abundance on the Qwuloolt site similar to those at reference sites?
4) Are macroinvertebrate assemblages characteristic of those associated with suitable juvenile salmonid rearing habitats?

Diagnostic

5) What biotic and abiotic factors are influencing the observed macroinvertebrate attributes on the Qwuloolt site?

Methods

Because of the emphasis on juvenile salmon prey resources, invertebrate sampling should be conducted concurrently with fish sampling at the same sites. While fish sampling should be conducted biweekly, we recommend sampling for macroinvertebrates monthly or once every other month from early spring to lat summer due to the high cost of sample processing. Macroinvertebrate sampling should occur in years 1, 2, 3, 5, 7, 10, and every three to five years thereafter. We recommend a combination of benthic core, fallout trap, and neuston net sampling using established methods developed and applied widely in Puget Sound and elsewhere (Simenstad et al. 1991, Cordell et al. 2001, Stamatiou et al. 2009). Neuston could be added as a supplemental component. Five replicate samples per site and sample type provide both a good level of statistical power, and also some redundancy for loss or damage to samples in the field. Benthic core and fallout samples were collected during September, 2009, and in May and July of 2010, at Qwuloolt, Ebey Island, the forested wetland, and Quilceda marsh (tidal conditions precluded core sampling at Quilceda in 2009). In addition to these sites, we recommend expanded sampling post-breach on Qwuloolt at several channels that will hopefully be amenable to fyke trapping (Figure 11) to provide replication onsite and more complete characterization of the whole site once tidal inundation returns. Cost estimates for invertebrate monitoring are in Table 8.

Table 8. Cost summary for macroinvertebrate monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
Taxonomic analysis of benthic core, fallout trap, and neuston	$ 86,832
Post-breach	
Core monitoring	
Taxonomic analysis of benthic core, fallout trap, and neuston	$ 386,256
Grand Total	**$ 473,088**

Birds

Birds are a major taxon that provides information on overall biological condition, has high public appeal (Furness and Greenwood 1993), and is also relatively efficient to sample.

Questions

Status and trend

1) What is the taxonomic composition and abundance of bird assemblages at Qwuloolt and reference sites before and after breach?
2) How are these attributes changing over time?

Effectiveness

3) Are bird assemblage composition and abundance on the Qwuloolt site similar to those at reference sites?

Diagnostic

4) What biotic and abiotic factors are influencing the observed bird attributes on the Qwuloolt site?

Methods

Because bird assemblages are heavily influenced by seasonal and tidal conditions, as well as offsite influences, we recommend a combination of point and line transect surveys (Bibby et al. 2000) every year monthly at high, low, and intermediate tidal stages. Some pre-breach and post-breach (low tide) bird surveys could be done concurrent with elevation and vegetation sampling. At a minimum, we recommend quarterly surveys from the six perimeter points (Figure 9), including the Marysville mitigation site, were all bird species and counts are noted within the immediate area. Additional point and line transect surveys should be done onsite and at nearby reference sites. Cost estimates for bird component are in Table 9.

Table 9. Cost summary for bird monitoring. Data collection, analysis, and reporting included.

Component	Cost
Pre-breach	
Core monitoring	
Whole assemblage point surveys quarterly from perimeter	$ 25,600
Total	$25,600
Supplemental monitoring	
Line transect surveys of whole assemblages at Qwuloolt and reference sites	$ 15,800
Total	$ 15,800
Post-breach	
Core monitoring	
Whole assemblage point surveys quarterly from perimeter	$ 88,000
Total	$ 88,000
Supplemental monitoring	
Line transect surveys of whole assemblages at Qwuloolt and reference sites	$ 158,000
Total	$ 246,000

Monitoring activities and priorities will be different depending on what time point pre- and post-breach, but the overall core monitoring program is listed below in way that moves through the planning process from questions to metrics and analysis (Table 10).

Table 10. Summary of core monitoring elements for the Qwuloolt restoration.

Feature Class	Question(s)	Scale(s)	Study design	Reference Information	Response Variable(s)	Sampling Design	Analysis & reporting	Cost (13 years)
Controlling Abiotic Attributes								
Topography, sediment , and soils	Is the topography on the Qwuloolt site: 1) as intended in the final design, 2) as predicted by channel geometry relationships, and 3) similar to reference sites?	Site, partial estuary	Before/after; Treatment/ Reference; Space for time	Pre-restoration conditions, final design specifications, adjacent reference sites, Skagit model and data	Elevation, Sediment accretion, channel geometry	Annual remote sensing, and onsite surveys (including SET and horizon marker checks; ground photos) at least for first 10 years post-breach	Univariate statistics	$490,130
	Is large wood naturally recruiting to the site?				Wood recruitment; size and complexity of wood pieces; vegetation and wildlife taxonomic composition	Annual remote sensing and onsite surveys	Univariate and multivariate statistics	
	Is soil developing toward natural estuarine wetlands?				Grain size, bulk density, organic and mineral content, nutrients, salinity	Core samples pre-breach and in years 1,2,3,5,7, and 10	Univariate and multivariate statistics	
Hydrology	Are hydrologic conditions on the Qwuloolt site: 1) as intended in the final design; 2) as predicted by the hydrodynamic model, and 3) similar to reference sites?	Site, partial estuary	Before/after; Treatment/ Reference; Space for time	Pre-restoration conditions, final design specs, hydrodynamic model, adjacent reference sites	Water level (surface and ground), tidal prism, temperature, salinity, velocity	Continuous data loggers, monthly and event-triggered onsite observations	Univariate and multivariate statistics	$91,387

Feature Class	Question(s)	Scale(s)	Study design	Reference Information	Response Variable(s)	Sampling Design	Analysis & reporting	Cost (13 years)
Anthropogenic chemical contaminants and nutrients	What anthropogenic chemicals are present on the site and adjacent reference sites, and are levels below those likely to cause adverse biological effects? Are nutrient levels onsite within desirable ranges?	Site, partial estuary	Before/after; Treatment/ Reference; Space for time	Literature, adjacent reference sites	Chemical concentrations in water, sediment, and biota; nutrient concentrations in water and sediment	Pre-breach and in years 1, 3, 5, and 10, and event-triggered surveys	Univariate and multivariate statistics	$119,440
Biota								
Vegetation	What is the spatial extent and distribution of major plant assemblages on the site? Is the overall character of the vegetation moving toward desired condition (e.g., pre-disturbance, less disturbed reference sites)?	Site, estuary, Puget Sound	Before/after; Treatment/ Reference; Space for time	New data from adjacent reference sites (Ebey, Forested wetland, Marysville, Quilceda), other restoration sites (Union and Blue Heron Sloughs), literature, NOAA fish monitoring, elevation and salinity surveys (veg), Skagit River estuary, PSAMP and Audubon bird surveys	Taxonomic composition, abundance, area and percent cover (veg)	Annual remote sensing; onsite point and line transect, ground photos	Univariate and multivariate statistics	$186,000

Feature Class	Question(s)	Scale(s)	Study design	Reference Information	Response Variable(s)	Sampling Design	Analysis & reporting	Cost (13 years)
Fish	What is the taxonomic composition and species size distributions of fish assemblages onsite and at reference sites over time? What are the seasonal distributions and cumulative mean densities of juvenile salmon onsite, immediately offsite in Ebey Slough, and at reference sites? Has adult coho abundance after breach increased relative to Quilceda Creek?		Before/after; Treatment/ Reference; Space for time	New data from adjacent reference sites (Ebey, forested wetland, Marysville, Quilceda), other restoration sites (Union and Blue Heron Sloughs), literature, NOAA fish monitoring, Skagit River estuary	Taxonomic composition, abundance, length	twice monthly fyke trap, beach seine sampling from winter to fall in all years	Multivariate & univariate statistics	$1.055,874
Macroinvertebrates	Are macroinvertebrate assemblage composition and abundance on the Qwuloolt site similar to those at reference sites? Are macroinvertebrate	Site, partial estuary	Before/after; Treatment/ Reference; Space for time	Same as above	Taxonomic composition, abundance	Every other month in spring and summer, concurrent with fish sampling	Multivariate and univariate statistics	$473,088

Feature Class	Question(s)	Scale(s)	Study design	Reference Information	Response Variable(s)	Sampling Design	Analysis & reporting	Cost (13 years)
	assemblages characteristic of those associated with suitable juvenile salmonid rearing habitats?							
Birds	What is the taxonomic composition and abundance of bird assemblages at Qwuloolt and reference sites before and after breach? Are bird assemblage composition and abundance on the Qwuloolt site similar to those at reference sites?	Site, partial estuary	Before/after; Treatment/ Reference; Space for time	New data from adjacent reference sites (Ebey, forested wetland, Spencer, Quilceda), other restoration sites (Union and Blue Heron Sloughs), literature, PSAMP and Audubon bird surveys	Taxonomic composition, abundance	Monthly ground surveys	Multivariate and univariate statistics	$113,600

PRE-BREACH PRIORITIES, CURRENT STATUS, AND IMPLEMENTATION

Pre-breach priorities include the collection and analysis of pre-breach data; completing site design, construction, and adaptive management plans; completing final protocols for the monitoring; and identifying entities to support and conduct as many of the monitoring elements as possible. The trustees are completing site design and construction plans. In collaboration with Tulalip Tribes, NOAA Fisheries has initiated sampling at Qwuloolt and adjacent reference sites, and is continuing and expanding ongoing fish monitoring in the Snohomish estuary. Installation of hydrologic monitoring equipment and collection of data began in winter 2010, coincident with fish sampling. NOAA Fisheries has completed a contract through the Puget Sound LiDAR Consortium for the collection of LiDAR and orthophoto data for the Snohomish estuary and is presently analyzing those data, and has contracted with the University of Washington Wetland Ecosystem Team for the analysis of invertebrate samples collected in 2009 and 2010, as well as a subset of juvenile Chinook diet samples archived between 2001 and 2009, and samples newly collected in 2010. Analysis of these samples is partially complete and ongoing. Design of SET installation began with a site visit in spring, 2010, with expert collaborators from USGS. NOAA Fisheries has also initiated conversations among scientists conducting monitoring at multiple projects in Puget Sound, including the Skagit River System Cooperative, The City of Everett, Wildlands, Nisqually National Wildlife Refuge, The Nature Conservancy, the Washington Department of Fish and Wildlife, and the members of the Institute for Applied Ecology’s Estuary Technical Group in Oregon.

Some funding has been secured and other sources are being identified. In addition to providing considerable matching resources, NOAA Fisheries has received an initial $300K but future funding is uncertain. The Trustees have reserved $100K for monitoring but have not yet assigned it to any monitoring tasks. Additional funding sources include EPA and WDFW grants, and we are currently evaluating their potential to fund Qwuloolt and Snohomish estuary monitoring and research activities.

CUMULATIVE RESTORATION EFFECTS AND SYSTEM-LEVEL MONITORING IN THE SNOHOMISH RIVER ESTUARY

Assessing cumulative effects of multiple aquatic restoration projects has rarely been done and little cumulative effects monitoring guidance exists (Johnson et al. 2008). While the topic has received some interest in freshwater, the concept is largely missing in studies of estuary restoration. Many large estuarine restoration programs such as the Everglades, Chesapeake Bay have developed monitoring programs, but have not addressed cumulative effects of these projects. A few recent efforts in the Pacific Northwest have attempted link together multiple estuarine restoration projects. For example, Johnson et al. (2008) developed a monitoring program for the Columbia River Estuary that is designed to examine both additive effects of individual projects and synergistic cumulative effects at broader scales. Similarly, a monitoring plan designed to examine the cumulative effects of multiple estuarine restoration projects in the Skagit River Delta on juvenile salmon abundance and life history diversity is ongoing (Greene and Beamer 2009). Within the Snohomish, Haas and Collins (2001) have attempted to determine the cumulative effect of habitat loss across the historical estuary footprint upon salmon populations. Like all other analyses, this study did not take into account the influence of variation in connectivity (Beamer et al. 2005), and like Bartz et al. (2006), likely used existing density estimates, which are probably biased low compared to historical numbers.

While considerable progress is being made with respect to data collection and analytical tools, it is important to note that no population level effect of estuarine restoration has ever been demonstrated in Pacific salmon. However, evaluation of the cumulative effects of multiple restoration sites on some attributes across the Snohomish estuary with the potential to affect salmon populations should be possible, but will require considerable data collection and analysis. For example, system-wide patterns of tidal inundation, temperature, and salinity regimes; taxonomic composition and spatial distribution of plant, bird, and fish assemblages; and relative abundance of juvenile salmonid life history types, can all be reliably quantified at the scale of the Snohomish estuary, but only by sampling at sufficient temporal and spatial extent and resolution.

These aspects are thoroughly reviewed in the Snohomish River estuary monitoring framework report (Rice et al. in prep).

Basic requirements for system-level monitoring are a stratification of the system into major ecological gradients, meaningful response variables, common methods, and coordination and collaboration. We recommend structuring the overall effort around historical vegetation zones and out into the nearshore, as well as across the various sloughs, including the major bifurcations, thus covering the upstream-downstream, cross-system, and connectivity dimensions of the system (Rice et al. in prep). Temporally, biweekly sampling from winter into fall for most strata every year is critical for juvenile salmon, whereas most other attributes do not require such intensive sampling.

ANALYSIS AND REPORTING

The processing of raw data should include error checking, summarizing the data in tables and figures of descriptive statistics, and archiving the data in multiple, secure locations. The Trustees should develop guidance for the archiving and distribution of data but we recommend that all monitoring data be made publicly available as soon as is practicable. Presently, NOAA Fisheries and the Tulalip Tribes are each maintaining copies of all data.

Analysis of the data should emphasize full reporting and synthesis of results into coherent narrative and graphical presentations in annual reports that are organized consistently with the conceptual project framework (Figure 7). In addition to simple tabular, graphical, and conventional statistical analysis (Zar 1996, Elzinga et al. 2001), we encourage the use of multivariate (Clarke and Warwick 2001, McCune and Grace 2002) and information-theoretic approaches (Burnham and Anderson 2002) to the analysis of monitoring data. Where possible, results should be published in the peer reviewed scientific literature. Presently, NOAA Fisheries is ultimately responsible for analysis and reporting of results.

ADAPTIVE MANAGEMENT

Adaptive management plans are not currently available for the Qwuloolt project but should be developed. The monitoring program should provide information to project managers, and also to scientists conducting the monitoring so that both can adjust their efforts accordingly (Thom et al. 2007). Entities include the Trustees managing the project; agencies, academics, and volunteers doing the monitoring; and State and local governments potentially affected by the performance of the project. Adaptive management actions include physical intervention on and off site, changing goals and expectations for project performance, and adjustments to monitoring activities. Presently, the most likely trigger for action is significant change to onsite and offsite structural attributes that may threaten adjacent and property and infrastructure. Project managers should identify and prioritize these structural attributes and incorporate them into monitoring activities. In addition, the monitoring itself could change considerably as the site changes over time, and as the informational value of the data is evaluated. An annual review of the monitoring program should be conducted as part of the annual report, and adjustments made to the sampling plan each winter where necessary.

OUTREACH

General outreach guidance is being developed for the Snohomish estuary restoration monitoring framework (Rice et al. in prep). Essential elements for outreach in support of Qwuloolt are the formulation of goals, audiences, messages, and the methods and media to achieve the outreach goals. Outreach can help maximize the value of the Qwuloolt project by increasing monitoring data and integrating it with other efforts, and by engaging and informing the public. Presently, outreach activities are concentrated on communicating with other scientists, and evaluating onsite public information materials.

REFERENCES

Adolfson Associates. 2006. Qwuloolt Restoration Project Alternatives Assessment. Seattle, Washington.

Aitkin, J. K. 1998. The importance of estuarine habitats to anadromous salmonids of the Pacific Northwest: a literature review. U.S. Fish and Wildlife Service, Lacey, WA.

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. Bioscience **44**:690-697.

Beamer, E., and C. M. Greene. in prep. Biotic and abiotic factors controlling wild juvenile Chinook abundance in the Skagit River tidal delta.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005. Delta and Nearshore Restoration for the Recovery of Wild Skagit River Chinook Salmon: Linking Estuary Restoration to Wild Chinook Salmon Populations. Appendix D of the Skagit Chinook Recovery Plan, Skagit River System Cooperative, LaConner, Washington.

Beamer, E., C. A. Rice, R. Henderson, and D. P. Lomax. in preparation. Juvenile Chinook salmon in the Skagit River estuary—abundance and size across tidal delta, shoreline, and neritic habitats.

Bibby, C. J., N. D. Burgess, D. A. Hill, and S. Mustoe. 2000. Bird Census Techniques. Academic Press, London.

Boorman, L. A. 1999. Salt marshes–present function and future change. Mangroves and Salt Marshes **3**:227-241.

Bortleson, G. C., M. J. Chrzastowski, and A. K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound region, Washington. U.S. Geological Survey hydrological investigations atlas HA-617.

Bottom, D. L., K. K. Jones, T. J. Cornwell, A. Gray, and C. A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine and Coastal Shelf Science **64**:79-93.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach. 2nd Edition. Springer-Verlag, New York.

Calloway, J. C., Sullivan, G., Desmond, J. S., Williams, G. D., and Zedler, J. B. Assessment and monitoring. 2001. Pages 271-335 in Zedler, J. B. (Editor), *Handbook for Restoring Tidal Wetlands.* CRC Press, Boca Raton.

Cahoon, D. R., J. C. Lynch, P. Hensel, R. Boumans, B. C. Perez, B. Segura, and J. Day, J.W. . 2002a. High-precision measurements of wetland sediment elevation: I. Recent improvements to the sedimentation-erosion table. Journal of Sedimentary Research **72**:730-733.

Cahoon, D. R., J. C. Lynch, B. C. Perez, B. Segura, R. Holland, C. Stelly, G. Stephenson, and P. Hensel. 2002b. High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. Journal of Sedimentary Research **72**:734-739.

Carroll, J. 1999. Quilceda/Allen fish management plan. Snohomish County Public Works, Everett, Washington.

Cereghino, P. 2006. Wetland Assessment for Restoration at Qwuloolt Marsh, Marysville, WA (Revised draft, December 6, 2006). NOAA Restoration Center, Seattle, Washington.

Childers, D. L., J. W. J. Day, and H. N. J. McKellar. 2000. Twenty more years of marsh and estuarine flux studies: revisiting Nixon (1980). Pages 391-423 *in* M. P. Weinstein and D. A. Kreeger, editors. Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, Boston.

Clarke, K. R., and R. M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E, Plymouth, UK.

Collins, B. D., and D. R. Montgomery. 2001. Importance of Archival and Process Studies to Characterizing Pre-Settlement Riverine Geomorphic Processes and Habitat in the Puget Lowland.*in* J. M. Dorava, D. R. Mongomery, B. B. Palcsak, and F. A. Fitzpatrick, editor. Geomorphic Processes and Riverine Habitat. American Geophysical Union, Washington, D.C.

Collins, B. D., and A. J. Sheikh. 2005. Historical reconstruction, classification, and change analysis of Puget Sound tidal marshes. Project completion report to Washington Department of Natural Resources, Aquatic Resources Division. Olympia, WA.

Cordell, J. R., L. M. Tear, and K. Jensen. 2001. Biological Monitoring at Duwamish River Coastal America Restoration and Reference Sites: A Seven-Year Retrospective. SAFS-UW-0108, University of Washington School of Aquatic & Fishery Sciences, Seattle.

Cornu, C. E., and S. Sadro. 2002. Physical and functional responses to experimental marsh surface elevation manipula- tion in Coos Bay's south slough. Restoration Ecology 10:474– 486.

Da Silva, D., J. Buzitis, W. Reichert, G. Ylitalo, M. S. Myers, L. L. Johnson, S. M. O'Neill, J. West, O. P. Olson, M. Willis, B. Anulacion, G. Yanagida, D. Lomax, and M. Krahn. 2009. Endocrine disruptors in bile of English sole (Parophrys vetulus) from Puget Sound, WA: a simple and fast method of analysis. Proceedings of Oceans and Human Health Principal Investigators Meeting, Oct. 6-8, 2009, Seattle, WA.

Downes, B. J., L. A. Barmuta, P. G. Fairweather, D. P. Faith, M. J. Keough, P. S. Lake, B. D. Mapstone, and G. P. Quinn. 2002. Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters. Cambridge University Press, Cambridge, UK.

Elzinga, C., D. Salzer, J. G. Willoughby, and J. Gibbs. 2001. Monitoring Plant and Animal Populations. Blackwell Publishing.

Folk, R. L. 1968. Petrology of Sedimentary Rocks. Hemphills, Austin, TX.

Folse, T. M., and J. L. West. 2004. A Standard Operating Procedures Manual for the Louisiana Department of Natural Resource's Coastal Restoration Division: Methods for Data Collection, Quality Assurance / Quality Control, Storage, and Products., Louisiana Department of Natural Resources, Baton Rouge, LA.

Furness, R. W., and J. J. D. Greenwood. 1993. Birds as Monitors of Environmental Change. Chapman and Hall, London.

Global Remote Sensing. 2007. Bathymetric Survey Report Snohomish River and Estuary, Everett, Washington, October - December 2006. Seattle, WA.

Gray, A., C. A. Simenstad, D. L. Bottom, and T. J. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River Estuary, Oregon, U.S.A. Restoration Ecology **10**:514-526.

Greene, C. M., and E. M. Beamer. 2009. Monitoring of population responses by Skagit River Chinook salmon to estuary restoration. Intensively Monitored Watershed Program Annual Report.

Haas, A., G. Ahn, M. Rustay, and B. Dittbrenner. 2009. Critical Areas Monitoring 2008 Status Report. Snohomish County Public Works Surface Water Management, Everett, Washington.

Haas, A., and B. D. Collins. 2001. A Historical Analysis of Habitat Alteration in the Snohomish River Valley, Washington since the mid-19th Century: Implications for Chinook and Coho Salmon. Report for Snohomish County.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pages 315-341 *in* V. S. Kennedy, editor. Estuarine Comparisons. Academic Press, New York.

Hood, G. W. 2007. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation. Water Resources Research **43**:1-15.

Hood, W. G. 2009. Habitat Monitoring Strategy for the Tidal Skagit Delta. Skagit River System Cooperative, LaConner, WA.

ICF Jones & Stokes. 2009. As-Built and Year 1 Monitoring Report Smith Island/Union Slough Restoration Project. Finalized April 2009. (ICF J&S 00993.07.) Seattle, WA. Prepared for City of Everett Public Works Department.

Johnson, G. E., H. L. Diefenderfer, A. B. Borde, E. M. Dawley, B. D. Ebberts, D. A. Putman, G. C. Roegner, M. Russell, J. R. Skalski, R. M. Thom, and J. Vavrinec III. 2008. Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2007. PNNL-17437. Pacific Northwest National Laboratory, Richland, WA.

Jones and Stokes Associates Inc. 1999. Wetland Mitigation Monitoring—Year 5. City of Marysville Public Works Department Sewage Treatment Facilities Improvement Project. Prepared for City of Marysville Public Works Department, Bellevue, WA.

Jones and Stokes Associates Inc. 2003. Wetland Mitigation Monitoring—Year 10. City of Marysville Public Works Department Sewage Treatment Facilities Improvement Project. Prepared for City of Marysville Public Works Department, Bellevue, WA.

Karr, J. R. 2006. Seven foundations of biological monitoring and assessment. Biologia Amientale **20**:7-18.

Karr, J. R., and E. W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington, D.C.

Kingsford, M. J., and C. N. Battershill. 1998. Studying Temperate Marine Environments. A Handbook for Ecologists. Canterbury University Press, Christchurch, New Zealand.

Krahn, M. M., M. S. Myers, D. G. Burrows, and D. C. Malins. 1984. Determination of metabolites of xenobiotics in the bile of fish from polluted waterways. Xenobiotica **14**:633-646.

Liermann, M. C., and P. Roni. 2008. More sites or more years? Optimal study design for monitoring fish response to watershed restoration. North American Journal of fisheries Management **28**:935-943.

McCune, B., and J. B. Grace. 2002. Analysis of Ecological Communities. MJM Software Design, Gleneden Beach, OR.

National Research Council. 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, D.C.

Neckles, H. A., M. Dionne, D. M. Burdick, C. T. Roman, R. Buchsbaum, and E. Hutchins. 2002. A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales. Restoration Ecology **10**:556-563.

Nixon, S. W. 1980. Between coastal marshes and coastal waters, a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. Pages 437-525 *in* P. Hamilton and K. B. Macdonald, editors. Estuarine and Wetland Processes. Plenum Press, New York.

Odum, E. 1968. Outwelling ref.

Pess, G. R., D. R. Montgomery, T. J. Beechie, and L. Holsinger. 2003. Anthropogenic alterations to the biogeography of Puget Sound salmon. Pages 129-154 *in* D. R. Montgomery, S. Bolton, D. B. Booth, and L. Wall, editors. Restoration of Puget Sound rivers. University of Washington Press, Seatte, WA.

Plumb, R. H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Tech. Rpt. EPA/CE-81-1, US Army Corps of Engineers, Vicksburg, MS.

Rice, C., P. Roni, G. Hood, C. Greene, K. Fresh, A. Thomas, and A. Haas. in prep. Restoration monitoring in the Snohomish River estuary—site, system, and regional contexts.

Rice, C. A. 2007. Evaluating the biological condition of Puget Sound. PhD dissertation. University of Washington, Seattle, WA.

Rice, C. A., W. G. Hood, L. M. Tear, C. A. Simenstad, G. D. Williams, L. L. Johnson, B. E. Feist, and P. Roni. 2005. Monitoring Rehabilitation in Temperate North American Estuaries.*in* P. Roni, editor. Monitoring Stream and Watershed Restoration. American Fisheries Society, Bethesda, MD.

Rice, C. A., J. R. Karr, T. J. Beechie, and G. R. Pess. in preparation. The forsaken fjord: science, society, and biological decline in Puget Sound.

Rice, J. S., and B. W. Pinkerton. 1993. Reed canary grass survival under cyclic inundation. Journal of Soil and Water Conservation **48**:132-135.

Roegner, G. C., H. L. Diefenderfer, A. B. Borde, R. M. Thom, E. M. Dawley, A. H. Whiting, S. A. Zimmerman, and G. E. Johnson. 2009. Protocols for monitoring habitat restoration projects in the lower Columbia River and estuary. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-97.

Roni, P., editor. 2005. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, MD.

Roni, P., M. C. Liermann, C. Jordan, and E. A. Steel. 2005. Steps for designing a monitoring and evaluation program for aquatic restoration.*in* P. Roni, editor. Monitoring Stream and Watershed Restoration. American Fisheries Society, Bethesda, MD.

Roni, P., and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences **58**:282-292.

Rowse, M., and K. L. Fresh. 2003. Juvenile salmonid utilization of the Snohomish River estuary, Puget Sound.*in* T. W. Droscher and D. A. Fraser, editors. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference (2003).

Schmitt, R. J., and C. W. Osenberg, editors. 1996. Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Academic Press, San Diego, CA.

Simenstad, C., M. Logsdon, K. Fresh, H. Shipman, M. Dethier, and J. Newton. 2006a. Conceptual Model for Assessing Restoration of Puget Sound Nearshore Ecosystems. Puget Sound Nearshore Partnership Report No. 2006-03. Seattle, Washington.

Simenstad, C., D. Reed, and M. Ford. 2006b. When is restoration not? incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecological Engineering **26**:27-39.

Simenstad, C., J. Toft, H. Higgins, J. Cordell, M. Orr, P. Williams, L. Grimaldo, Z. Hymanson, and D. Reed. 2000a. Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH) preliminary report. Wetland Ecosystem Team, University of Washington School of Fisheries, Seattle, Washington.

Simenstad, C. A., and J. R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering **15**:283-302.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Pages 343-364 *in* V. S. Kennedy, editor. Esuarine Comparisons. Academic Publishers, New York.

Simenstad, C. A., W. G. Hood, R. M. Thom, D. A. Levy, and D. L. Bottom. 2000b. Landscape Structure and Scale Constraints on Restoring Estuarine Wetlands for Pacific Coast Juvenile Fishes.*in* M. P. Weinstein and D. A. Kreeger, editors. Concepts and Controversies in Tidal Marsh Ecology. Klewer Academic Publishing, Dordrecht, The Netherlands.

Simenstad, C. A., D. A. Jay, and C. R. Sherwood. 1992. Impacts of watershed management on land-margin ecosystems: the Columbia River Estuary as a case study. Pages 266-306 *in* R. Naiman, editor. Watershed management : balancing sustainability and environmental change. Springer-Verlag, New York.

Simenstad, C. A., C. D. Tanner, R. M. Thom, and L. L. Conquest. 1991. Estuarine Habitat Assessment Protocol. Report to the U.S. Environmental Protection Agency, Region 10. EPA 910/9-91-037, Fisheries Research Institute, University of Washington, Seattle,WA.

Simenstad, C. A., and R. M. Thom. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecological Applications **6**:38-56.

Simon, T. P., editor. 1999. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC, Boca Raton, FL.

Skalski, J. R. 2005. Monitoring the Skagit River estuary by estimating cumulative fish-days of usage. Draft report prepared for the Watershed Program of the Northwest Fisheries Science Center, NOAA. University of Washington, Seattle, Washingtn.

Sloan, C. A., D. W. Brown, R. W. Pearce, R. H. Boyer, J. L. Bolton, D. G. Burrows, D. P. Herman, and M. M. Krahn. 2005. Determining aromatic hydrocarbons and chlorinated hydrocarbons in sediments and tissues using accelerated solvent extraction and gas chromatography/mass spectrometry.*in* G. K. Ostrander, editor. Techniques in Aquatic Toxicology Volume 2. CRC Press, Boca Raton, FL.

Snohomish Basin Salmon Recovery Forum. 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division, Everett, WA.

Snohomish County Public Works. 2002. Allen Creek Drainage Needs Report DNR#8. Snohomish County Public Works, Surface Water Management Division, Everett, Washington.

Stamatiou, L., J. Toft, J. Cordell, and C. Simenstad. 2009. Wetland Ecosystem Team Diet and Prey Resource Sampling Gear and Methods. Draft protocol. University of Washinton, Seattle, WA.

Takekawa, J., I. Woo, N. D. Athearn, S. Demers, R. Gardiner, W. Perry, N. Ganju, G. Shellenbarger, and D. Schoellhamer. 2010. Measuring sediment accretion in early tidal marsh restoration. Wetlands Ecology and Management 18: 297-305.

Teal. 1962. Outwelling ref.

Thayer, G. 2003. NOAA monitoring document.

Thom, R. M., N. K. Sather, M. G. Anderson, and A. B. Borde. 2007. Monitoring and Adaptive Management Guidelines for Nearshore Restoration Proposals and Projects PNWD-3861. Battelle Marine Sciences Laboratory, Sequim, WA.

Thom, R. M., and K. F. Wellman. 1996. Planning Aquatic Ecosystem Restoration Monitoring Programs. IWR Report 96-R-23, Institute of Water Resources, and Waterways Experimental Station, U.S. Army Corps of Engineers, Alexandria, VA, and Vicksburg, MS.

Thom, R. M. 1992. Accretion rates of low intertidal salt marshes in the Pacific Northwest. *Wetlands* 12: 147-156.

Tulalip Tribes of Washington. 2007. Quality Assurance Plan: Tulalip Reservation Quilceda Estuary Vegetation Characterization & Monitoring Project. Tulalip Tribes of Washington Department of the Environment, Tulalip, Washington.

Wilbur, P., G. W. Thayer, M. Croom, and G. Mayer. 2000. Goal setting and success criteria for coastal habitat restoration. Ecological Engineering **15**:165-395.

Williams, P. B., and M. K. Orr. 2002. Physical Evolution of Restored Breached Levee Salt Marshes in the San Francisco Bay Estuary. Restoration Ecology **10**:527-542.

Yang, Z., and T. Khangaonkar. 2007. Hydrodynamic Modeling Study of the Snohomish River Estuary: Snohomish River Estuary Restoration Feasibility Study. PNWD-3864. Battelle, Richland, Washington.

Yang, Z., T. Khangaonkar, M. Calvi, and K. Nelson. 2009. Simulation of cumulative effects of nearshore restoration projects on estuarine hydrodynamics. Ecological Modeling **in press**.

Zar, J. H. 1996. Biostatistical analysis. 3rd edition. Prentice-Hall, Englewood Cliffs, NJ.

Zedler, J. B., editor. 2001. Handbook for restoring tidal wetlands. CRC Press, Boca Raton